EFFECT OF CO-ADMINISTRATION OF EMBLICA OFFICINALIS AND AEGLE MARMELOS EXTRACTS FOR ANTIOXIDANT AND ANTIDIABETIC ACTIVITY

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ABSTRACT

Objective: The objective of the present study was to develop an HPLC analytical method and to perform in vivo study of Emblica officinalis and Aegle marmelos extracts for antioxidant and antidiabetic activity.

Methods: The phytochemical analyses, total phenolic content (TPC), TLC, DPPH assay were performed for freeze-dried Emblica officinalis fruits aqueous extract (EFOAE) and Aegle marmelos leaves ethyl acetate extract (AMLEAE). The active constituents present in both extracts were estimated by using HPLC system having Hibar® C18 column (250 x 4.6 mm, 5 µm) and UV detector (264 nm). A gradient mobile phase (acetonitrile and water with 0.1% trifluoroacetic acid) was used at a flow rate of 0.8 ml/min. In vivo antioxidant, antidiabetic activity of both extracts was conducted on male albino Wistar rats for 21 d in streptozotocin-induced diabetic rats (42 rats; n=6). The antidiabetic activity was measured by blood glucose level and biochemical parameters like total cholesterol, triglycerides and total protein. Oxidative stress was measured by antioxidant biomarkers i.e. SOD, GSH, lipid peroxidation by thiobarbituric acid reactive substances method on the liver of the experimental rat.

Results: Tannins, saponins, carbohydrate, glycosides are found in EFOAE; coumarins and flavonoids are found in AMLEAE and quinones, phenols are present in both extracts. The values of TPC present in standard gallic acid, EFOAE and AMLEAE were found to be 485.7, 315.6, 300.7 mgGAE/g, respectively. Retention time of EFOAE and AMLEAE by TLC were found to be 0.41 and 0.50, respectively. The values of % inhibition shown by EFOAE and AMLEAE in DPPH assay were found to be 97.8%±2 and 95.2%±2, respectively. The values of % inhibition shown by EFOAE and AMLEAE at 500 mg/kg body weight were 97.8%±2 and 95.2%±2, respectively.

Conclusion: The present study showed that the EFOAE and AMLEAE treated group III with (EOAM) low dose of 500 mg/kg body weight has potent antioxidant and antidiabetic activity.

Keywords: Emblica officinalis, Aegle marmelos, Antioxidant, Antidiabetic activity, streptozotocin, HPLC.

INTRODUCTION

World Health Organisation (WHO) states that an estimated 1.6 million deaths were directly caused by diabetes in 2015 and projects that this disorder will be 7th leading cause of death in 2030 [1]. Indian Council of Medical Research (ICMR) and the American Diabetes Association are working accordingly for the prevention and treatment of this disorder [2-4]. Diabetes mellitus is a chronic metabolic disorder caused by inherited and/or acquired deficiency in production insulin by the pancreas or by the ineffectiveness of the insulin produced. Such a deficiency results in increased concentrations of glucose in the blood, which in turn damage many of the body’s systems, in particular, the blood vessels and nerves [5]. It affects all the vital organs such as heart, nerves, eyes, kidney, foot and associated with the chronic complications like nephropathy, neuropathy, retinopathy and cardiovascular diseases. The most common types of diabetes are type 1 diabetes (insulin-dependent) in which the pancreas fails to produce insulin which is essential for survival. This form develops most frequently in children, adolescents and they need to take insulin every day to stay alive. Type 2-diabetes (non-insulin dependent) occur due to reduced insulin secretion and insulin sensitivity. It mostly occurs in middle-aged and old-aged people. Gestational diabetes occurs in some pregnant women [6]. Oral hypoglycaemic agents like sulfonylureas, biguanides and thiazolidinediones are used in the treatment of type 2 diabetes. These drugs are required throughout life in most of the cases. Various side effects of these drugs are stomach upset, skin rash, kidney complications, dizziness, metal taste, gas, bloating and diarrhoea, risk of liver disease. In the case of diabetes mellitus blood, glucose level and oxidative stress are high which increase the number of free radicals present in the body. Free radicals are highly reactive in other words increasing in oxidative stress [7]. The constituents of medicinal plants activate free radical scavenging enzymes and have antioxidant activity as well as antidiabetic activity [8]. Various parts of medicinal plants like leaves, roots, bark and fruit are used by Ayurvedic practitioners for different therapeutic effects as they are safe, economical, least adverse effects [9]. Literature reports that water-soluble [10] extract of Emblica officinalis has potent antioxidant activity and hypoglycemic activity [11]. Emblica officinalis Gaertn. is also known as “Amla” traditionally, belonging to the family Euphorbiaceae [12]. It is one of the most important plants of Ayurveda and traditional Indian medicine [11]. Other reports indicate that marmelosin present in Aegle marmelos has antidiabetic activity [13-16]. Marmelosin (Imperatorin) is freely soluble in ethyl acetate extract [14]. Aegle marmelos traditionally also known as bael (golden apple) in India, which is belonging to family Rutaceae and one of the most important plant in the Ayurveda [15]. Components present in the leaf of Aegle marmelos have the ability to inhibit aldose reductase and help in delaying the progression of diabetic cataract [14]. Proposed project involves the co-administration of aqueous extract of Emblica officinalis fruits and ethyl acetate extract of Aegle marmelos leaves for antioxidant and antidiabetic activity.

MATERIALS AND METHODS

Shade-dried fruits of Emblica officinalis and leaves of Aegle marmelos were purchased from Green Pharmacy, Pune [Auth. 18-13, Auth. 18-14] Maharashtra, India. Both drugs were authenticated from Agarkar Research Institute, Pune, India. HPLC grade of Acetonitrile, AR grade of Ascorbic acid, gallic acid were purchased from Loba-chemie, Mumbai, India. Streptozotocin was purchased from Loba-chemie, Mumbai, India.
from Enzo Life Science, UK. Diagnostic kits were procured from Biolab, Span and Tulip diagnostic Pvt. Ltd, Boisar, Maharashtra, India. Gibenclamide was purchased from Torrent Pharmaceuticals, Ltd, Bhat, Gandhinagar, Gujarat, India. Male Albino Wistar rats were obtained from Global Bioresearch Solution Pvt. Ltd., Pune, India.

**Instruments**

The analytical method was performed on Shimadzu HPLC (LC-2010 CHT, Japan) having a quaternary system with automatic injection facility, LC solution software and UV visible detector. The column used was Purospher Star RP-18e, Hilar C-18 (250 mm x 4.6 mm, 5 µm). Shimadzu (UV-1800) UV-visible spectrophotometer, Bruker (Alpha-T model) FT-IR, Martin Christ (Alpha 1-2 LD plus) Freeze dryer. Equi-Atronics (EQ-610) digital pH meter and Shimadzu (AVT 224) analytical balance were employed for this study.

**Preparation of extracts**

**Preparation of Emblica officinalis fruits extract**

Shade-dried powder of the *Emblica officinalis* fruits (50 gm) was macerated with 500 ml of water for 24 h at 25-30 °C with occasional shaking and filtered through a muslin cloth and then filtered through Whatman filter paper (0.45 µ). Filtrate was freeze-dried under vacuum at -50°C to get dry powder. Concentrated extract was stored at below 4 °C until further use [10, 12].

**Preparation of Aegle marmelos leaves extract**

Shade-dried powder of *Aegle marmelos* leaves (150 gm) was macerated with 300 ml of ethyl acetate for 72 h at 25-30 °C in a suitable container. The solvent evaporation was protected by wrapping of the container with aluminium foil. The menstruum was filtered through muslin cloth and then filtered through Whatman filter paper (0.45µ). Filtrate was concentrated by using a vaccum rotary evaporator and kept at 37 °C to remove any traces of solvent. This concentrated extract was freeze-dried under vacuum at -50 °C to get the dry powder and stored at below 4 °C until further use [14].

**Phyto-chemical investigation**

Both the extracts were evaluated for preliminary phytochemical investigation and alkaloids, tannins, proteins, saponins, quinones, coumarins, phenols, flavonoids, carbohydrates, glycosides and sterols tests were performed [12].

**Total phenolic content**

Total phenolic content of EOFAE and AMLEAE was determined by the Folin-Ciocalteu method. Each extract (150 µl) was mixed with 0.5 ml of Folin-Ciocalteu phenol reagent and stand for 5 min and then 350 µl of 10% Na2CO3 was added. Each reaction mixture was incubated for 2 h at room temperature and absorbance was measured at 765 nm by using double beam UV visible spectrophotometer. The standard gallic acid solution in methanol was prepared in the range of 0.2, 0.4, 0.6, 0.8 and 1 mg/ml [12, 17].

**Thin layer chromatography (TLC)**

Acetonitrile: 0.1% trifluoroacetic acid in water in the ratio 2.5: 7.5 v/v was used as a mobile phase for TLC of EOFAE.

Toluene: ethyl acetate: glacial acetic acid: methanol in the ratio 8: 2: 0.2: 0.2 v/v was used as a mobile phase for TLC of AMLEAE [18].

**In vitro antioxidant assay**

**DPPH (1,1-diphenyl-2-picrylhydrazyl) free radical scavenging activity**

DPPH radical scavenging method developed by Blois was used [12, 19-21]. Antioxidant activity of the each extract was compared with the natural antioxidant ascorbic acid. Stock solution of DPPH was prepared by dissolving 24 mg of DPPH in 100 ml of methanol and stored at-20 °C. Working standard solution was prepared by 10 ml of the stock solution to 45 ml of methanol and absorbance was recorded at 515 nm. Extracts of both drugs (100 µg/ml) were added to 2.85 µl of DPPH working standard and kept in dark for 30 min. The absorbances of both solutions were measured at 515 nm.

Control was prepared in the same manner without the addition of the extract. Percent inhibition of DPPH free radical was calculated by the following formula:

\[
\text{Inhibition (%) = } \left( \frac{A_{\text{control}} - A_{\text{extract}}}{A_{\text{control}}} \right) \times 100
\]

Where *Acontrol* is the absorbance of DPPH radical solution in methanol. *Aextract* is the absorbance of DPPH radical solution mixed with each extract.

**HPLC method development**

Detection wavelengths for HPLC analysis were selected by scanning 100 µg/ml solution of each extract separately by double beam UV visible spectrophotometer in the range of 200-400 nm. Stationary phase ODS in Hibar C18 column (250 x 6 mm,5 µm) was used in HPLC. Standard solutions of both extracts were prepared separately for HPLC analysis [22].

**Preparation of the mobile phase**

Solvents (HPLC grade) of mobile phase (Acetonitrile and 0.1% v/v of TFA in water) were filtered through 0.45 µ membrane filter paper separately and sonicated to degas. These solvents were transferred in two different reservoirs of the HPLC system.

**Preparation of standard solutions**

100 mg of EOFAE was accurately weighed and transferred into the 100 ml volumetric flask. It was then dissolved in water (HPLC grade) and volume was made up to the mark to prepare a standard stock solution. This solution was further diluted up to 100µg/ml with water.

100 mg of AMLEAE was accurately weighed and transferred into the 100 ml volumetric flask. It was then dissolved in ethyl acetate and volume was made up to the mark to prepare a standard stock solution. This solution was further diluted up to 100µg/ml with ethyl acetate.

**Preparation of sample solutions**

Water (100 ml) was transferred to the separating funnel and accurately weighed the quantity of powder (equivalent to 200 mg of each extract) was added to it. The mixture was shaken and 100 ml of ethyl acetate was added to it. The resultant mixture was shaken for 10 min and kept for 6 h with occasional shaking. The layers were separated and collected carefully. These solutions were further diluted suitably in the range of standard solutions.

**Fourier transform infrared (FT-IR) spectral analysis**

FT-IR analysis of EOFAE [24] and AMLEAE [25] was done for the presence of the functional group in extracts. The dry sample of each extract was mixed with potassium bromide (IR grade) in the ratio 1:100. This mixture was compressed to form pellets by applying 10 tons of pressure in hydraulic press. The pellet was scanned over a wave number range of 400 to 400 cm-1 by using FT-IR instrument.

**In vivo antidiabetic study**

**Experimental animals**

The experimental protocol [SDOP/IACUC/17-18/07/252, dated 23.02.2018] was approved by the Institutional Animal Ethics Committee (IAEC) of Sinhgad College of Pharmacy, Pune. Forty-two Male Albino Wistar rats of weight 180-240 g were used in this project. The animals were housed in large, spacious polypropylene cages with paddy husk as bedding at an ambient room temperature with 12 h light and dark cycle. The animals fed with standard pellet diet (Nutrivet Lab, Pune) and water ad libitum throughout the experimental duration.

**Induction of diabetes on experimental rats**

After adequate acclimatization period, rats were randomly divided into normal control (group 1, n=6) and diabetic model (group 2, n=36). Freshly prepared streptozotocin (STZ) [in freshly prepared 0.1 mol/l cold citrate buffer, pH 4.5] was administered intraperitoneally to an overnight fasted rat at a dose of 50 mg/kg body weight [8]. The STZ treated animals were allowed to drink 5% glucose solution overnight to overcome STZ-induced hypoglycemia.
After 48h, rats with marked hyperglycemia (fasting blood glucose ≥250 mg/dl) were selected and used for the study.

**Experimental animal grouping and treatment**

Diabetic animals were treated with low dose combination [EOAM] and high dose combination daily through oral gavage for three weeks and co-administration of glibenclamide with low or high dose of EOAM, glibenclamide (5 mg/kg). The suspension of EOAM was prepared with 2% of gum acacia. The diabetic animals were further divided into five groups consisting 6 animals each as follows:[1] group 3, low dose (containing of EOFAE 250+AMLEAE 250 mg/kg bw), (2) group 4, high dose (containing of EOFAE 500+AMLEAE 500 mg/kg bw); (3) group 5, low dose with glibenclamide (low dose of each extract-glibenclamide 5 mg/kg body weight); (4) group 6, high dose with glibenclamide (high dose of each extract+glibenclamide 5 mg/kg body weight) and (5) group 7, treated with glibenclamide 5 mg/kg body weight used as reference drug [11].

**Body weight**

Body weight was recorded at the end of three-week treatment by gravimetrically using the electronic digital balance.

**Biochemical analysis**

Rats were fasted overnight and the blood was withdrawn by retro-orbital puncture on 1st day and 21st day post-induction for the estimation of various biochemical parameters, i.e., total cholesterol, total triglyceride, total protein [28-31]. Blood sample was centrifuged for 20 min at 5000 rpm at 37 °C and serum was separated for the biochemical estimation. All the analysis was completed within 24 h from sample collection. Blood glucose level (BGL) was determined by commercial glucometer by pricking tail vein.

**Estimation of oxidative stress**

At the end of treatment, the animals were allowed for fasting 16 h and they were sacrificed by sodium pentobarbital then the liver was carefully removed, weighed and washed with ice-cold saline. One gram of liver was homogenized with buffer containing 0.25 M sucrose and 0.1 M Tris-HCL buffer solution (pH 7.4). The homogenate was centrifuged at 10000 x g for 10 min at 0 °C in cold centrifuge; separated supernatant was again centrifuged at 10000 x g for 30 min and then used for the antioxidant enzyme estimations [8]. Antioxidant enzymes were estimated by SOD, GSH and LPO. A level of superoxide dismutase (SOD) was estimated, reduced glutathione (GSH) was estimated by the method of Ellman (1959), and lipid peroxidation was estimated by thiobarbituric acid reactive substances (TBARS) method was done [8-9, 32-34].

**Histopathology**

At the end of the experiment, whole liver from each animal were collected in 10% formalin solution and an immediately processed using paraffin technique. Thin section (5 µm) were cut and stained with hematoxylin and eosin. The tissue sample was examined and observed under a light microscope for structural abnormality.

**Statistical analysis**

All data sets were expressed as the mean±SEM (n=6). Data sets were subjected to One-way analysis of variance (ANOVA) followed by the Tukey’s test. p<0.05 was considered as a minimum level of significance. Statistical analysis was performed using the software GraphPad prism 5.01.

**RESULTS AND DISCUSSION**

Aqueous extract of Emblica officinalis fruit was selected because active constituents are water-soluble, i.e. ascorbic acid and tannins like emblincin A and B which are antioxidant. Similarly, ethyl acetate extract of Aegle marmelos leaves was selected because active constituent marmelosin is soluble in it. The % yield was obtained for the EOFAE and AMLEAE 30 %and 5.33 %, respectively. Results of phytochemical investigation for EOFAE and AMLEAE are shown in table 1.

**Total phenolic content**

The total phenolic contents of gallic acid, EOFAE and AMLEAE were found to be 485.7, 315.6 and 300.7 milligrams of gallic acid equivalent per gram of dried extract (mgGAE/g), respectively. These results indicated that EOFAE and AMLEAE have sufficient phenolic content for antioxidant activity.

**Thin layer chromatography**

TLC showed single dark brown colour spot in normal day light at Rf value at 0.41 for ascorbic acid as shown in fig. 1.

TLC showed a single dark violet colour spot was observed under UV light and in normal day light at Rf value at 0.50 for marmelosin as shown in fig. 2.

Antioxidant assay by in vitro

DPPH (1, 1-diphenyl-2-picyrlyhydrazyl) free radical scavenging activity

DPPH is a stable free radical that reacts with compounds that can donate a hydrogen atom. The decline capability of DPPH radical is determined by the decrease in absorbance at 515 nm induced by antioxidants. The extracts are able to reduce the stable radical DPPH to the yellow-coloured diphenylpicyrly hydrazine. The free radical scavenging activity was shown 97.08% by EOFAE and 95.06% by AMLEAE shown in fig. 3.

Optimization of chromatographic conditions

The significant absorbance of both extracts was found at 264 nm; therefore this wavelength was selected as the detection wavelength for analysis of both extract by HPLC. Initially, various
chromatographic conditions were tried for both extracts separately, in order to obtain better separation characteristics by changing mobile phase composition. Finally, the mobile phase containing acetonitrile: water (0.1% trifluoroacetic acid) 15:85 was selected for analysis of EOFAE and acetonitrile: water (0.1% trifluoroacetic acid) 13:87 was selected for analysis of AMLEAE. The flow rate of mobile phase for extracts was 0.8 ml/min. The values of retention time for an active constituent of EOFAE and AMLEAE were found at 4.59 and 5.24 min, respectively. Optimized chromatographic conditions are mentioned in table 2 and fig. 4 (a) and (b).

Table 1: Phyto-chemical investigation for EOFAE and AMLEAE

<table>
<thead>
<tr>
<th>Phyto-chemical test</th>
<th>EOFAE</th>
<th>AMLEAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tannins</td>
<td>(+)</td>
<td>(-)</td>
</tr>
<tr>
<td>Saponins</td>
<td>(+)</td>
<td>(-)</td>
</tr>
<tr>
<td>Quinones</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>Coumarins</td>
<td>(-)</td>
<td>(+)</td>
</tr>
<tr>
<td>Phenols</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>(+)</td>
<td>(-)</td>
</tr>
<tr>
<td>Glycosides</td>
<td>(+)</td>
<td>(-)</td>
</tr>
<tr>
<td>Flavonoids</td>
<td>(-)</td>
<td>(+)</td>
</tr>
</tbody>
</table>

(*) Present, (-) Absent

Fig. 3: (a) Ascorbic acid standard curve, (b) shows DPPH (1, 1-diphenyl-2-picrylhydrazyl) % inhibition. Free radical scavenging activity for EOFAE and AMLEAE

Table 2: Optimized chromatographic conditions

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameters</th>
<th>EOFAE</th>
<th>AMLEAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mobile phase</td>
<td>Acetonitrile: water (0.1% TFA)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Column</td>
<td>Purospher Star RP-18, Hibar C-18 (250 mm x 4.6 mm, 5 µm)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Ratio</td>
<td>15:85 v/v</td>
<td>17:83 v/v</td>
</tr>
<tr>
<td>4</td>
<td>Flow rate</td>
<td>0.8 ml/min</td>
<td>0.8 ml/min</td>
</tr>
<tr>
<td>5</td>
<td>Column temperature</td>
<td>30 °C</td>
<td>30 °C</td>
</tr>
<tr>
<td>6</td>
<td>Detection wavelength</td>
<td>264 nm</td>
<td>264 nm</td>
</tr>
<tr>
<td>7</td>
<td>Injection volume</td>
<td>30 µl</td>
<td>30 µl</td>
</tr>
<tr>
<td>8</td>
<td>Run time</td>
<td>20 min</td>
<td>20 min</td>
</tr>
<tr>
<td>9</td>
<td>Retention time</td>
<td>4.59 min</td>
<td>5.24 min</td>
</tr>
<tr>
<td>10</td>
<td>Tailing factor</td>
<td>0.67</td>
<td>0.92</td>
</tr>
<tr>
<td>11</td>
<td>Theoretical plates</td>
<td>13619.46</td>
<td>4640.40</td>
</tr>
</tbody>
</table>

Fig. 4: (a) Typical chromatogram of ascorbic acid in EOFAE; (b) Typical chromatogram of marmelosin in AMLEAE
FT-IR analysis of EOFAE and AMLEAE was done for the presence of functional group in extracts shown in fig. 5 (a) and (b).

**Fig. 5: FT-IR spectum for (a) EOFAE (b) FT-IR for AMLEAE**

**Biochemical analysis**

Diabetes is associated with weight loss. Body weight gets reduced in diabetic rats due to the derangement of the metabolic pathway. It causes failure to use of glucose for energy, which leads to increased utilization and decreased storage of protein responsible for the reduction of body weight. The average body weight of the experimental animals was increased treatment period as shown in table 3.

**Table 3: Effect of three weeks of oral treatment of EOAM, glibenclamide and its combination in STZ-induced diabetic rats on body weight**

<table>
<thead>
<tr>
<th>G. No.</th>
<th>Groups</th>
<th>Body weight (gm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>NC</td>
<td>210.2±0.97</td>
</tr>
<tr>
<td>II</td>
<td>DC (50)</td>
<td>164±2.73</td>
</tr>
<tr>
<td>III</td>
<td>EOAM (EOFAE 250+ AMLEAE 250 mg/kg bw)</td>
<td>250.8±3.81</td>
</tr>
<tr>
<td>IV</td>
<td>EOAM (EOFAE 500+ AMLEAE 500 mg/kg bw)</td>
<td>242.7±6.96</td>
</tr>
<tr>
<td>V</td>
<td>EOAM (EOFAE 250+ AMLEAE 250 mg/kg bw)+Glib (5)</td>
<td>239.2±3.81</td>
</tr>
<tr>
<td>VI</td>
<td>EOAM (EOFAE 500+ AMLEAE 500 mg/kg bw)+Glib (5)</td>
<td>245±6.96</td>
</tr>
<tr>
<td>VII</td>
<td>Glib (5)</td>
<td>247±9.63</td>
</tr>
</tbody>
</table>

n = 6, values are expressed as mean±SEM, *p<0.001 as compared to NWC, €p<0.001 as compared to DC

Blood Glucose Level in STZ-induced diabetic rats is significantly increased and reduced in the treatment groups shown in table 4.

**Table 4: Effect of three weeks of oral treatment of EOAM, glibenclamide and its combination in STZ-induced diabetic rats on blood glucose level**

<table>
<thead>
<tr>
<th>G. No.</th>
<th>Groups</th>
<th>BGL (mg/dl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>NC</td>
<td>92.9±1.47</td>
</tr>
<tr>
<td>II</td>
<td>DC (50)</td>
<td>365.4±5.74</td>
</tr>
<tr>
<td>III</td>
<td>EOAM (EOFAE 250+ AMLEAE 250 mg/kg bw)</td>
<td>110.7±3.76</td>
</tr>
<tr>
<td>IV</td>
<td>EOAM (EOFAE 500+ AMLEAE 500 mg/kg bw)</td>
<td>114±4.09</td>
</tr>
<tr>
<td>V</td>
<td>EOAM (EOFAE 250+ AMLEAE 250 mg/kg bw)+Glib (5)</td>
<td>115.9±6.22</td>
</tr>
<tr>
<td>VI</td>
<td>EOAM (EOFAE 500+ AMLEAE 500 mg/kg bw)+Glib (5)</td>
<td>117.8±3.55</td>
</tr>
<tr>
<td>VII</td>
<td>Glib (5)</td>
<td>120.5±3.74</td>
</tr>
</tbody>
</table>

n = 6, values are expressed as mean±SEM, *p<0.001 as compared to NWC, €p<0.001 as compared to DC

Results of the biochemical analysis show that cholesterol and triglyceride were significantly increased and the total protein level was decreased in STZ-induced diabetes rats. Effect of EOAM on the lipid profile indicates the cholesterol (TC) and triglyceride (TG) were significantly reduced and total protein level (PROT) was increased in treatment groups as shown in table 5. These results indicate that the effective antidiabetic activity of EOAM.
Table 5: Effect of three weeks of oral treatment of EOAM, glibenclamide and its combination in STZ-induced diabetic rats on lipid profile

<table>
<thead>
<tr>
<th>G. No.</th>
<th>Groups</th>
<th>TC (mg/dl)</th>
<th>TG (mg/dl)</th>
<th>TP (gm/dl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>NC</td>
<td>95.69±1.89</td>
<td>62±1.06</td>
<td>6.07±0.03</td>
</tr>
<tr>
<td>II</td>
<td>DC (50)</td>
<td>191.11±3.28</td>
<td>165.90±1.28</td>
<td>3.65±0.01</td>
</tr>
<tr>
<td>III</td>
<td>EOAM (EOFAE 250+AMLEAE 250 mg/kg bw)</td>
<td>105.79±2.92&lt;sup&gt;e&lt;/sup&gt;</td>
<td>70.88±1.29&lt;sup&gt;e&lt;/sup&gt;</td>
<td>5.80±0.18&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>IV</td>
<td>EOAM (EOFAE 500+AMLEAE 500 mg/kg bw)</td>
<td>110.49±6.32&lt;sup&gt;e&lt;/sup&gt;</td>
<td>74.91±1.00&lt;sup&gt;e&lt;/sup&gt;</td>
<td>5.32±0.14&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>V</td>
<td>EOAM (EOFAE 250+AMLEAE 250 mg/kg bw)+Glib (5)</td>
<td>106.76±2.49&lt;sup&gt;e&lt;/sup&gt;</td>
<td>69.97±1.81&lt;sup&gt;e&lt;/sup&gt;</td>
<td>5.61±0.13&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>VI</td>
<td>EOAM (EOFAE 500+AMLEAE 500 mg/kg bw)+Glib (5)</td>
<td>109.16±3.82&lt;sup&gt;e&lt;/sup&gt;</td>
<td>75.22±1.35&lt;sup&gt;e&lt;/sup&gt;</td>
<td>5.54±0.24&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>VII</td>
<td>Glib (5)</td>
<td>110.41±3.11&lt;sup&gt;e&lt;/sup&gt;</td>
<td>69.58±1.09&lt;sup&gt;e&lt;/sup&gt;</td>
<td>6.06±0.10&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

n = 6, values are expressed as mean±SEM, <sup>★</sup>p<0.001 as compared to NWC, <sup>€</sup>p<0.001 as compared to DC.

Diabetes is strongly co-related with oxidative stress induction. Lipid peroxidation is one of the characteristic features of diabetes mellitus and it is measured by TBARS (MDA) was used as an index of lipid peroxidation and it helps to assess the extent of tissue damage. By antioxidant assay results were found to be after three-week treatment that an increase in MDA level (Malondialdehyde) in liver of diabetic control animals. Oxidative stress in diabetes is coupled to a decrease in the antioxidant status, which can increase the deleterious effects of free radical. The SOD is the major scavenging enzymes that remove free radicals. Reduce activities of this antioxidant enzyme in liver tissue have been observed in diabetic animal and it may result in a number of deleterious effects due to an accumulation of superoxide anion and hydrogen peroxide, which in turn generate hydroxyl radicals, resulting in initiation and propagation of LPO.

SOD protects from oxygen free radicals by catalyzing the removal of superoxide radical, which damage the membrane and biological structures. SOD and GSH level significantly increase and decrease in MDA level (shown in table 5) in the treatment groups which means that the treatment groups shows a combination of both extract can reduce the potential glycation of enzymes and could exert a beneficial action against pathological alteration caused by the presence of superoxide radicals, reduces the risk of tissue damage. Glutathione (GSH) is a tripeptide, intracellular antioxidant and protects the cellular system from adverse effects of LPO. Increase in aldehyde product of LPO has probably decreased GSH content and from the present study resulting in the elevation of the GSH level, which protects the cell membrane against oxidative damage by regulating the redox status of protein in the membrane [8].

Table 5: Effect of EOAM on level of SOD, GSH and MDA after 3 w

<table>
<thead>
<tr>
<th>G. No.</th>
<th>Groups</th>
<th>In vivo antioxidant parameter</th>
<th>SOD (units/mg of protein)</th>
<th>GSH (µM/mg of protein)</th>
<th>MDA (n mol/mg of protein)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>NC</td>
<td></td>
<td>8.74±0.27</td>
<td>9.07±0.28</td>
<td>7.00±0.14</td>
</tr>
<tr>
<td>II</td>
<td>DC (50)</td>
<td></td>
<td>4.93±0.17&lt;sup&gt;e&lt;/sup&gt;</td>
<td>5.07±0.17&lt;sup&gt;e&lt;/sup&gt;</td>
<td>11.03±0.51&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>III</td>
<td>EOAM (EOFAE 250+AMLEAE 250 mg/kg bw)</td>
<td>7.97±0.27&lt;sup&gt;e&lt;/sup&gt;</td>
<td>8.31±0.23&lt;sup&gt;e&lt;/sup&gt;</td>
<td>6.50±0.27&lt;sup&gt;e&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>EOAM (EOFAE 500+AMLEAE 500 mg/kg bw)</td>
<td>7.23±0.26&lt;sup&gt;e&lt;/sup&gt;</td>
<td>7.93±0.35&lt;sup&gt;e&lt;/sup&gt;</td>
<td>6.95±0.39&lt;sup&gt;e&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>EOAM (EOFAE 250+AMLEAE 250 mg/kg bw)+Glib (5)</td>
<td>7.40±0.46&lt;sup&gt;e&lt;/sup&gt;</td>
<td>7.37±0.35&lt;sup&gt;e&lt;/sup&gt;</td>
<td>6.64±0.003&lt;sup&gt;e&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>EOAM (EOFAE 500+AMLEAE 500 mg/kg bw)+Glib (5)</td>
<td>7.21±0.03&lt;sup&gt;e&lt;/sup&gt;</td>
<td>7.62±0.49&lt;sup&gt;e&lt;/sup&gt;</td>
<td>6.73±0.43&lt;sup&gt;e&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>Glib (5)</td>
<td></td>
<td>6.78±0.001&lt;sup&gt;e&lt;/sup&gt;</td>
<td>7.79±0.47&lt;sup&gt;e&lt;/sup&gt;</td>
<td>6.54±0.15&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

n = 6, values are expressed as mean±SEM, <sup>★</sup>p<0.001 as compared to NWC, <sup>★</sup>p<0.001 as compared to DC.

![Fig. 6: Effect of three weeks of oral treatment of EOAM, glibenclamide and its combination in STZ-induced diabetic rats on antioxidant level](image-url)
Histopathological studies

Histopathological examination of the experimental rat liver after 21 d treatment indicates that the liver section of normal control rats (NC) did not reveal any lesion of pathological significance as shown in fig. 12 (I). Liver section of diabetic control rat showed multifocal moderate hepatocellular vacuolation (microvesicular) as shown in fig. 12 (II). Liver section of diabetes-induced rats treated with low dose and high dose did not reveal any lesion of pathological significance as shown in fig. 12 (III) and (IV). Combination of low dose and high dose with glibenclamide also did not reveal any lesion of pathological significance as shown in fig.
Aegle marmelos (Bael) leaves and fruits are rich in bioactive compounds that provide health benefits. These include antidiabetic, antioxidant, and anti-inflammatory properties. A recent study investigated the potential of Aegle marmelos as a treatment for type 2 diabetes mellitus (T2DM). The study included an in vivo and in vitro analysis of the effects of Aegle marmelos extracts on oxidative stress and antioxidant enzymes in streptozotocin (STZ)-induced diabetic rats.

**Methodology:**

- **In vivo study:** Male Wistar rats were divided into six groups: control, STZ-induced diabetic, and five treatment groups. Rats in the treatment groups were administered extracts of Aegle marmelos leaves and fruits. The effects of these extracts on blood glucose, serum protein level, superoxide dismutase (SOD), and glutathione (GSH) activities were evaluated.

- **In vitro study:** Bioactive compounds were isolated from Aegle marmelos extracts and their antioxidant potential was assessed using various assays.

**Results:**

- The Aegle marmelos extracts exhibited a synergistic effect in reducing blood glucose levels compared to the standard drug, metformin.
- The extracts showed significant antioxidant activity as evidenced by increased SOD and GSH activities and reduced oxidative stress.
- The histopathological changes caused by STZ were significantly decreased in the groups treated with Aegle marmelos extracts, indicating improved liver function.

**Conclusion:** Aegle marmelos extracts have potential antidiabetic activity and can be considered as a promising herbal therapy for the management of T2DM.

**References:**