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Research Article

Antiobesity and Hypolipidemic Activity of *Moringa oleifera* Leaves against High Fat Diet-Induced Obesity in Rats

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In the present study, the methanolic extract of *Moringa oleifera* leaves (MEMOL) was evaluated for antiobesity activity in rats. The antiobesity potential of MEMOL was studied against high fat diet-induced obesity (HFD) in rats. In this study, chronic administration of HFD in rats produced hypercholesterolemia (116.2 ± 0.27 mg/dL), which led to an increase in the body weight (225 gr), total cholesterol, triglycerides (263.0 ± 4.69 mg/dL), and attenuation in the levels of HDL (34.51 ± 2.20 mg/dL) as well as changes in body temperature of animals. Treatment of obese rats with MEMOL for 49 days resulted in a significant ($P < 0.001$) change in body weight, total cholesterol, triglycerides, and LDL level along with a significant ($P < 0.001$) increase in body temperature as compared to the HFD-induced obesity. MEMOL treated rats also showed a significant decrease in the level of liver biomarkers, organ weight, and blood glucose level. Further, rats treated with MEMOL (200 mg and 400 mg/kg) show reduced atherogenic index (1.7 ± 0.6 and 0.87 ± 0.76). The results indicate that the rats treated with *Moringa oleifera* (MO) have significantly attenuated the body weight without any change in the feed intake and also elicited significant thermogenic effect and to act as hypolipidemic and thermogenic property in obesity related disorders.

1. Introduction

Nowadays Obesity has emerged as a major health problem and risk factor for various disorders worldwide [1]. Overweight and obesity are defined as abnormal or excessive fat accumulation triggered by disproportion in energy intake and expenditure [2–4]. In addition to this attenuation in adipogenesis and over expression of pancreatic lipase enzyme which plays a pivotal role in progression of obesity [5]. The literature review revealed that alteration in dietary habit and less physical exercises, too, increase the frequency of obesity and related disorders [6, 7]. Further, obesity has been found to be associated with various disorders such as osteoarthritis [8], ischemic heart diseases (IHD) [8], atherosclerosis, diabetes, and hypertension [9–11]. A streak of evidence indicates that serotonin, histamine, dopamine, and their associated receptor activities are closely associated with obesity regulation [5]. Most importantly, strong evidences are available that elicited the role of leptin, ghrelin, and neuropeptides in obesity [12–14]. Currently, no pharmacological treatment provides sustained weight loss with minimal adverse effects [15, 16]. Thus, attempts have been made to reduce body weight with such pharmacological intervention that possesses minimal side effects. Plants have been used as traditional natural medicines for healing many diseases. In particular, various oriental medicinal plants are reported to have biological activity [17]. Literature review has revealed that various herbal plants such as *Fucus vesiculosus, Citrus aurantium* [18], *Yacon syrup* [19], *Curcumin* [20], *Nigella Sativa, Camellia Synensis, Green Tea, and Black Chinese Tea* [21] are used in the management of obesity. *M. O.* (*M. oleifera*) Lam that belongs to Moringaceae family is commonly known as Drumstick tree that possesses various nutritional and medicinal values attributed to its roots, bark, leaves, flowers, fruits, and seeds [22–24]. Data revealed that most of the parts of the plant possess antimicrobial activity [25, 26], antidiabetic [27–29], hepatoprotective [30], and for cardiac stimulation [31]. Recently, hypocholesterolemic activity of crude extract of *M. oleifera*

crude extract was explored [32], but its thermogenic and antiobesity activity has not been investigated; hence, the study delineated with antiobesity property of methanolic extract *M. oleifera* leaves in experimentally induced obesity.

2. Materials and Methods

Age matched young wistar albino rats of either sex, weighing 120–150 gr, were housed in room temperature of 25 ± 1°C and 12 hrs light and dark cycles (9:00 AM). Animals of control group were feed on a standard chow diet (Ashirwad Industries, Ropar, India) and water *ad libitum*, whereas animals used for evaluation of obesity are feed on a HFD and water *ad libitum*. The experimental protocols were approved by the Institutional Animal Ethics Committee (IAEC) and conducted according to the guidelines of the Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA), New Delhi, India {CPCSEA Approval No.: RIP/IAEC/2012-2013/13}. The animals were distributed in five groups of 10 animals each and were fed a HFD. Rats receiving the MEMOL extract were dosed for 7 weeks in parallel as detailed in Table 2.

2.1. Drugs and Chemicals. Sibutramine was purchased from Lupin (Bhopal), Pyridine from S.D. Fine Chemicals Ltd., Mumbai. Solvents like methanol, chloroform, petroleum ether, acetone, di-ethyl ether were of analytical grade (AR). Serum Cholesterol kit, Serum Triglyceride kit, Serum HDL-Cholesterol kit, Serum LDL-Cholesterol kit, Serum VLDL-Cholesterol kit, Blood-Glucose kits were provided from Spruce Enterprises Ambala.

2.2. Collection and Preparation of Plant Extract. Leaves of *Moringa oleifera* (M. O.) were collected after proper identification and authentication by the chief scientist of NISCAIR, New Delhi, with voucher number (NISCAIR/RHMD/Consult/2013/2279/54) and kept in the herbarium. The fresh leaves were air-dried for a period of two weeks, crushed in a mortar, and later pulverized into fine powder using electric blender. The powder was sieved through a mesh (2 mm) and used for preparation of methanolic extract. The extract was prepared by adding 100 gm of the plant powder in 200 mL of petroleum ether to remove fatty materials in a conical flask. The mark obtained from petroleum ether extraction was again extracted with 200 mL of methanol. The solvent was completely removed under reduced pressure till the dried extract was obtained. A dark greenish semisolid residue was obtained with a yield of 7%. The extract was stored in desiccators and a weighed (1 gm) amount was suspended in distilled water using carboxyl methyl cellulose (CMC) (2%) as suspending agent prior to administration.

2.3. Dose Selection. In the present study, two doses of the *Moringa oleifera* leaf extract were selected as 200 mg and 400 mg/kg, p.o. These doses were selected on the basis of previous reports of the acute toxicity study performed using the single dose of orally administered 2 g/kg of methanolic extracts of *M. oleifera* (leaf) which shows no signs of toxicity in rats [33].

2.4. High-Fat Diet Formula. HFD that consists of 58% fat, 25% protein and 17% carbohydrate, lard (13%), cholesterol (1%), vitamin, and minerals (0.6%) as a percentage of total kcal *ad libitum*, respectively, was administered every day [34]. Food intake was calculated every day and body weight was measured once in every two days. The composition of normal pellet diet (NPD) and HFD diets is shown in Table 1.

2.5. Preliminary Phytochemical Screening. The preliminary phytochemical screening of MEMO was carried out according to the methods described by Khandelwal [35] and Kokate [36]. Phytochemical analysis of the extract was performed for the identification of phytochemicals such as carbohydrates, alkaloids, tannins, saponins, flavonoids, triterpenoids, and steroids.

2.6. Methodology. High-fat diet (HFD) induced obesity in rats is considered to be a reliable tool for the evaluation of antiobesity activity. The study comprises 5 groups with 10 animals in each group. Group 1 represented the normal control in which the animals were feed on a normal diet (NPD) and had free access to water. Group 2 represented a negative control in which the rats were feed on high-fat diet (HFD) for a period of 49 days. Group 3 represented standard control in which rats were treated with simvastatin (3 mg/kg, p.o). Group 4 represented test treatment in which rats were treated with the 1st dose of methanolic extract of *M. oleifera* (200 mg/kg) along with high-fat diet. Group 5 represented test treatment in which rats were treated with the 2nd dose of methanolic extract of *M. oleifera* (400 mg/kg) along with high-fat diet for 49 days (Table 2). Various parameters like cholesterol (TC), high density lipoproteins (HDL-C), triglycerides (TG), low density lipoproteins (LDL-C), very low density lipoproteins (VLDL-C), atherogenic index, percentage protection, serum glutamic oxaloacetic transaminase (SGOT), serum glutamic pyrubic transaminase (SGPT), and total bilirubin were also recorded weekly. At the end of the protocol, animals were sacrificed by cervical dislocation and liver and kidney were removed to measure the change in weight and for histopathological evaluation [34].

2.7. In Vivo Pharmacological Evaluation

2.7.1. Body Weight and Food Intake. The body weight (gm) was recorded on day one and then weekly consecutively for 49 days using a digital weighing balance. In addition to this, the daily food intake for each group was measured weekly for 49 days.

2.7.2. Body Temperature. The body temperature was noted using a rectal thermometer before and after drug administration at 0, 30, 60, 90, and 120 minutes with a contact time of 1 minute.

Table 1: Composition of the control and test diets.

	Control (%)*	HFD (%)**
Fat	58%	58%
Protein	12.4%	12.4%
Carbohydrate	17%	17%
Lard	12%	11%
Cholesterol	0	1%
Vitamin and mineral	0.6%	0.6%
Total (gm)		

*Lab chow diet (NPD). **High-fat diet (cholesterol: 1%).

Table 2: Treatment Groups.

Groups	Treatment (mg/kg body weight)
1	Control
2	High-fat diet (HFD)
3	Standard group (simvastatin-3 mg/kg, p.o)
4	HFD + MEMOL (200 mg/kg, p.o)
5	HFD + MEMOL (400 mg/kg, p.o)

2.8. Biochemical Estimations. On the 49th day of the experiment all the animals were sacrificed by cervical dislocation, and blood samples were collected by carotid bleeding separately into sterilized dry centrifugation tubes and allowed to stand for 30 minutes at 20–25°C. The clear serum was separated at 2500 rpm for 10 min using a centrifuge. The levels of serum glucose, total TC, HDL-C, TG, LDL-C, VLDL-C, atherogenic index, percentage protection, SGOT, SGPT, and total bilirubin were determined to analyze using auto-analyzer (semi-autoanalyzer star 21 plus), with commercial kits (autospan diagnostics Pvt. Ltd.). The Friedewald formula [37] was used to calculate serum low-density lipoprotein cholesterol (LDL-C) values and atherogenic index as follows: LDL-C = TC-(HDL-C +TG/5) and atherogenic index = (TC-HDL-C)/HDL-C.

2.9. Statistics. Data were analysed with one-way ANOVAs followed by Tukey's post hoc tests, with significance set to $P < 0.001$. Food consumption was analysed using two-way ANOVA repeated measures tests followed by Tukey's post hoc tests, with significance set to $P < 0.001$. All analyses were performed using Sigma Stat (10.0).

3. Results

3.1. Preliminary Phytochemical Analysis. The results of the preliminary phytochemical screening of methanolic extract of *M. oleifera leaves* (MEMOL) showed the presence of alkaloids, tannins, flavonoids and terpenoids, and steroids.

3.2. Effects of High-Fat Diet and MEMOL on Food Intake and Body Weight. There was no momentous difference in all of the treatment groups at the commencement of the study. However, animals feed with high-fat diet showed significant increase in body weight compared to those feed with normal pellet diet (NPD) ($P < 0.001$). Similarly, the average daily feed intake of all the groups was the same at the start of the study; however, 21-day treatment with HFD resulted in a slight increase in food intake (Figure 1).

Following 2 week treatment with MEMOL supplementation, low food intake was observed in the MEMOL 200 mg/kg and MEMOL 400 mg/kg groups ($P < 0.001$) when compared to the HFD group. Subsequently, the body weight gain (at days 0, 7, 14, 21, 28, 35, 42, and 49) in these groups was significantly lower than the rats feed with HFD (Figure 2).

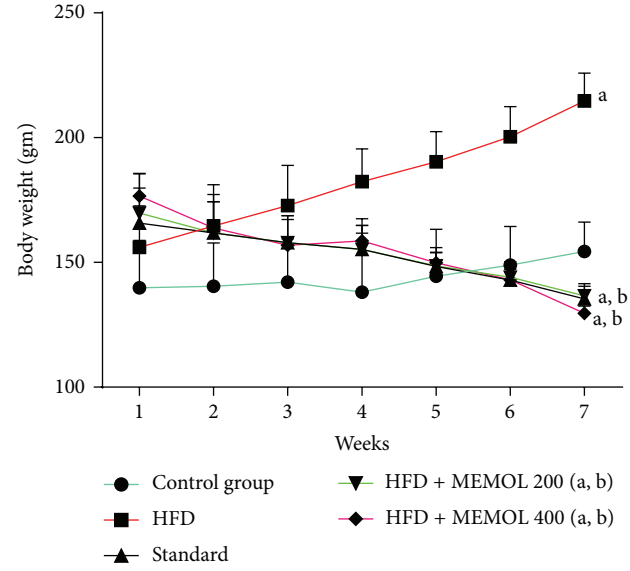


Figure 1: Body weight of rats fed a high-fat diet and treated with MEMOL extracts for 7 weeks; all values are expressed as Mean ± SEM, ($n = 10$). (a) Significant difference compared to control; (b) significant difference compared to HFD, $P < 0.001$ (one-way ANOVA, Tukey's post hoc test, $n = 10$ per group).

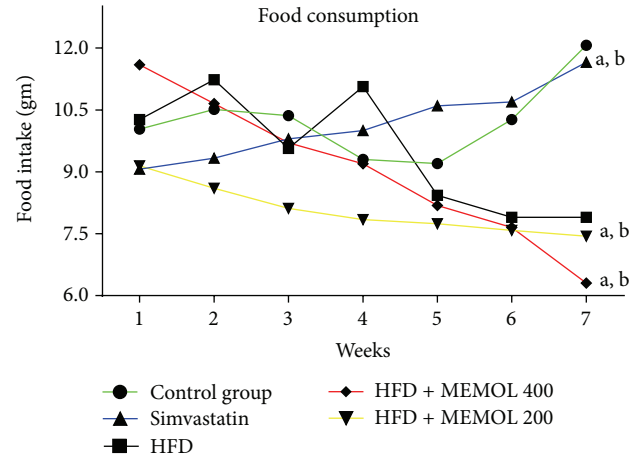


Figure 2: Food consumption (kcal) in rats fed a high-fat diet and treated with MEMOL for 7 weeks; all values are expressed as Mean ± SEM, ($n = 10$) (a) significant difference compared to control; (b) significant difference compared to HFF, $P < 0.001$ (one-way ANOVA, Tukey's post hoc test).

Table 3: Effect of MEMOL on liver parameters and blood glucose in obese rats.

Parameter	Normal Control	HFD	Standard (3 mg/kg)	MEMOL 200 mg/kg	MEMOL 400 mg/kg
Total cholesterol	75.180 ± 0.847	116.2 ± 0.271$^{\#\#\#}$	85.86 ± 0.461^{a***}	98.16 ± 0.52^{a**}	87.620 ± 0.543^{a***b*}
Triglycerides	217.68 ± 2.4	263.0 ± 4.69$^{\#\#\#}$	238.58 ± 2.64^{a***}	246.5 ± 8.65^{a***}	242.92 ± 6.58$^{a***b\,ns}$
HDL (mg/dL)	69.6 ± 2.9	34.51 ± 2.20$^{\#\#\#}$	45.18 ± 0.41^{a***}	35.76 ± 1.31^{a***}	46.71 ± 2.381^{a***}
LDL (mg/dL)	46.71 ± 2.381	61.68 ± 2.94$^{\#\#\#}$	44.5 ± 4.8^{a***}	48.4 ± 5.5^{a***}	45.25 ± 5.2^{a***}
VLDL (mg/dL)	15.03 ± 0.169	38.22 ± 4.6$^{\#\#\#}$	17.172 ± 0.092^{a***}	23.5 ± 6.6^{a**}	19.6 ± 0.105^{a**}
SGOT (U/L)	31.4 ± 0.50	67.2 ± 1.9$^{\#\#\#}$	47.8 ± 2.9^{a***}	57.2 ± 2.25^{a***}	36.1 ± 4.6^{a***}
SGPT (U/L)	37.7 ± 0.6	76.2 ± 2.02$^{\#\#\#}$	45.6 ± 1.5^{a**}	54.3 ± 3.7^{a**}	42.8 ± 5.4^{a***}
Total bilirubin (mg/dL)	0.5 ± 0.04	1.9 ± 0.08$^{\#\#\#}$	1.17 ± 0.9^{a***}	0.99±0.12$^{a***b\,ns}$	0.73 ± 0.19^{a***b**}
Blood glucose (mg/dL)	78.9 ± 3.4	94.1 ± 4.9$^{\#\#\#}$	86.0 ± 6.0^{a*}	81.3 ± 3.3^{a**}	73.2 ± 5.2^{a***b**}

All values are expressed as Mean ± SEM, ($n = 10$), $^{\#\#\#}P < 0.001$ when compared with the normal control group, $^{*}P < 0.05$; $^{***}P < 0.001$; $^{**}P < 0.01$; $^{ns}P > 0.05$. ^{a}versus high fat diet-induced obesity; ^{b}versus standard control (one-way ANOVA, Tukey's post hoc test, $n = 10$ per group).

3.3. Effect of MEMOL on High Fat Diet-Induced Obesity. As mentioned in Table 3, it has been observed that rats feed on high-fat diet consecutively for 21 days resulted in a marked increase in the level of lipids, characterized by elevated levels of total cholesterol, triglycerides, LDL ($P < 0.001$), VLDL, and reduced levels of HDL ($P < 0.001$) when compared to normal control, that is, rats receiving the normal feed. An increased level of LDL indicates hypercholesterolemia (Table 3). No significant increase was found on the 7th and 14th days. However, treatment with MEMOL for 3 weeks reversed the hyperlipedimic effect produced by high-fat diet significantly ($P < 0.001$). Similar results were obtained with the standard drug. Further, there was a significant increase in the atherogenic index in rats feed on HFD. Treatment with MEMOL (200 mg/kg and 400 mg/kg) significantly reduced the atherogenic index (Table 4).

3.4. Effect of MEMOL Extract on Rectal Body Temperature and Blood Glucose. It has been observed that rats receiving high-fat diet show a remarkable increase in blood glucose level and reduction in rectal body temperature evaluated on the 49th day at 0, 30, 60, 90, and 120 minutes. Treatment with extract 200 mg/kg and 400 mg/kg dose dependently decreased the blood glucose level (Table 3) and increased the body temperature (Table 5).

3.5. Effect of MEMOL Extract on Liver Enzymes. As shown in Table 3, treatment with MEMOL extracts exhibits a hepatoprotective effect, indicated by decreased levels of SGOT, SGPT, and total bilirubin. Further, histopathological studies indicated that rats feed with high-fat diet alone developed a high degree of steatosis, apoptosis with hepatocyte swellings (Figure 3), whereas no histological abnormalities were observed in normal control. The effect of increased liver enzyme levels and the formation of hepatic steatosis (Fatty Liver) in the high fat diet-feed group is allied with a significant increase of liver weight (Table 1). The administration of the extract resulted in the prevention of hepatic fatty deposition in hepatocytes.

Table 4: Effect of MEMOL supplementation on atherogenic index and percentage protection.

Groups	Atherogenic index	Percentage protection
Normal control	0.08 ± 0.53	—
HFD	2.3 ± 0.8^{a***}	—
Standard (3 mg/kg)	0.9 ± 0.12^{b**}	60.8
MEMOL (200 mg/kg)	1.7 ± 0.6^{b*}	26.0
MEMOL (400 mg/kg)	0.87 ± 0.76^{b**}	62.1

All values are expressed as Mean ± SEM. ^{a}versus normal Control; ^{b}versus HFD-induced obesity. $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$, (one-way ANOVA, Tukey's post hoc test, $n = 10$ per group).

3.6. Effect of MEMOL Extract on Organ Weight. The untreated obese group showed significantly higher organ weight (liver) in comparison to the HFD group ($P < 0.05$). Conversely, groups treated with MEMOL extract at 200 mg/kg and 400 mg/kg showed a significantly lower organ/body weight (Table 6). However, no significant increase was predicted with high-fat diet on kidney.

3.7. Histopathology of Liver in HFD Treated Rats. A liver section of normal rat liver showed no cellular degeneration and necrosis Figure 3(b). Liver section of HFD treated rats showed marked vascular congestion fatty deposition and foamy degeneration of hepatocytes Figure 3(c), Liver section of the standard (simvastatin, 3 mg/kg) drug treated rats showed normal hepatocytes and central vein but some degree of swelling Figure 3(d). Liver section of MEMOL ext. (200 mg/kg) treated rats showed recovered normal hepatocytes Figure 3(e). Liver section of MEMOL ext. (400 mg/kg) treated rats showed recovered normal hepatocytes Figure 3. (CD: cellular degeneration, VCD: vascular congestion fatty deposition, FDH: foamy degeneration of hepatocytes, CV: central vein, and N: necrosis).

Table 5: Effect of MEMOL on Body temperature.

S. No	Groups	Body temperature °C				
		0 min	30 min	60 min	90 min	120 min
I	Control	39.3 ± 1.117	37.2 ± 1.219	39.7 ± 0.653	38.3 ± 2.240	38.5 ± 1.364
II	High-fat diet	32.9 ± 2.295^{ns}	$27.3 \pm 2.508^{a*}$	$25.0 \pm 2.87^{a**}$	$25.1 \pm 2.84^{a**}$	$23.3 \pm 1.83^{a***}$
III	Standard (3 mg/kg)	36.1 ± 1.411^{ns}	$39.9 \pm 1.161^{b**}$	$35.4 \pm 1.161^{b*}$	$35.6 \pm 1.340^{b*}$	$34.6 \pm 2.228^{b*}$
IV	MEMOL (200 mg/kg)	39.5 ± 0.81^{ns}	$38.4 \pm 0.934^{b**}$	$35.4 \pm 1.391^{b***}$	$38.9 \pm 0.817^{b**c ns}$	$36.1 \pm 1.554^{b*c ns}$
V	MEMOL (400 mg/kg)	36.2 ± 1.53^{ns}	$34.0 \pm 1.455^{b*}$	$39.1 \pm 2.026^{b**}$	$41.3 \pm 0.497^{b***c*}$	$40.6 \pm 0.702^{b***c*}$

All values are expressed as Mean ± SEM ($n = 10$). Statistical significance testing for the comparisons was made by ANOVA, followed by Tukey's post hoc test. $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$, $^{ns}P > 0.001$. [a]versus Normal Control; [b]versus HFD-induced obesity; [c]versus standard control (one-way ANOVA, Tukey's post hoc test, $n = 10$ per group).

Table 6: Effect of MEMOL supplementation on organ weight.

Organ weight (g)	Normal control	HFD	Standard (3 mg/kg)	MEMOL 200 mg/kg	MEMOL 400 mg/kg
Liver	5.737 ± 0.088	$8.845 \pm 0.982^{a***}$	$6.158 \pm 0.892^{b***}$	$7.573 \pm 0.779^{b*}$	$6.947 \pm 1.754^{b**}$
Right Kidney	0.765 ± 0.012	$1.76 \pm 0.095^{a***}$	$0.801 \pm 0.053^{b\,ns}$	$0.874 \pm 0.073^{b\,ns}$	$0.842 \pm 0.017^{b\,ns}$
Left Kidney	0.748 ± 0.017	$0.958 \pm 0.075^{a**}$	$0.758 \pm 0.019^{b**}$	$0.813 \pm 0.012^{b\,ns}$	$0.804 \pm 0.009^{b*}$

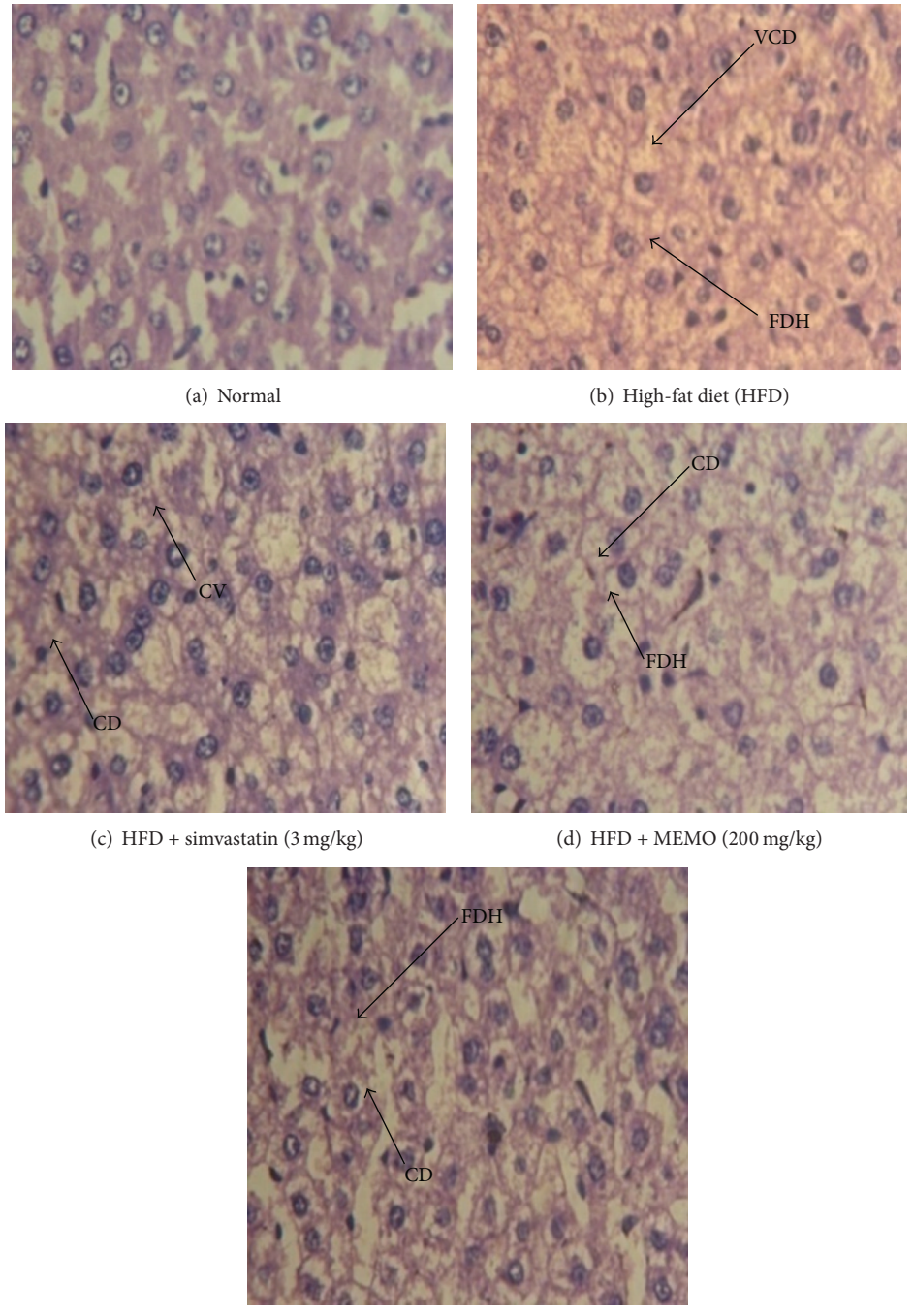
All values are expressed as Mean ± SEM ($n = 10$) $^{***}P < 0.001$ when compared with the normal control group, $^{*}P < 0.05$; $^{***}P < 0.001$; $^{**}P < 0.01$; $^{ns}P > 0.05$. [a]versus high fat diet-induced obesity; [b]versus standard control, one-way ANOVA followed by Tukey's post hoc test.

4. Discussion

The lethal dose (LD_{50}) value of the *M. oleifera* indicated that the extract (methanol) was safe and nontoxic up to 5 g/kg [33, 38]. Previous experiments have reported the antiulcer, diuretic, anti-inflammatory, antifertility, CNS depressant, and wound healing properties of leaves of *M. oleifera* [26, 38–41]. However, the results of the previous laboratory animal study indicated that crude extract of *M. oleifera* possesses hypocholesterolemic activity in rats [32]. Still no evidences are available for antiobesity potential of methanolic extract of *M. oleifera*. Hence, the study has been designed to demonstrate the effect of *M. oleifera* in high fat diet-induced obesity.

Obesity is a major risk factor for augmented morbidity and mortality and is associated with various medical ailments [42]. High fat diet-induced obesity has been considered as the most popular model among researchers due to its high similarity of mimicking the usual route of obesity episodes in human [43] and so why it is considered as a reliable tool for studying obesity as they will readily gain weight when feed high-fat diets [44]. Human studies have revealed that increased fat intake is associated with body weight gain, which can lead to obesity and other related metabolic diseases. This study thus proved that rats exposed to high-fat diet for 2 weeks cause a significant increase of animals' body weight, thus verifying the obese status [45]. Although there was a significant difference in the body weights between the high-fat and normal diet groups, no significant difference was observed in the daily food intake of animals. This observation provides us with the fact that an increase in body weight is independent of the amount of food consumed by the animals. Treatment of HFD rats with MEMOL at 200 mg/kg and 400 mg/kg p.o conversely causes a remarkable reduction of body weights when compared to the high-fat diet administered rats. The result also suggests that MEMOL supplementation at 200 mg/kg and 400 mg/kg are capable of preventing body weight gain, concomitantly helping in maintaining the current body weight. This result was in accordance with the results reported from the previous study where a dose dependent decrease in the body weight was observed [33]. Further, treatment with MEMOL remarkably decreases the organ weight of rats feed on high-fat diet. Thus it proved the weight reducing potential of MEMOL.

Further, dyslipidemia is another important hallmark in the pathogenesis of obesity characterized by hypertriglyceridemia with decreased level of LDL and VLDL [46, 47]. Chronic dyslipidemia has been characterized as a major risk factor for cardiovascular risk, including atherosclerosis [48, 49]. In the present study apart from reduction in weight, supplementation with MEMOL was observed to attenuate significantly the levels of total cholesterol and LDL and increased the level of HDL level in rats feed with HFD. The increase in the level of HDL was found to be in a dose dependent manner; that is, supplementation with MEMOL at a dose of 400 mg/kg shows a better effect in comparison to 200 mg/kg. Similar results were obtained by Ghasi et al. [32], where treatment with crude extract of *M. oleifera* led to an increased serum HDL level and decreased levels of total cholesterol, LDL, and triglyceride. Thus, it can be concluded that leaves of *M. oleifera* possess cardioprotective potential [50]. Further, atherogenic index is regarded as a marker for various cardiovascular disorders; the higher the value, the higher the risk of developing cardiovascular disease and vice versa [51, 52]. High-fat diet exposure resulted in the increased atherogenic index. Treatment with 200 mg/kg and 400 mg/kg significantly attenuated the atherogenic index and



(a) Normal

(b) High-fat diet (HFD)

(c) HFD + simvastatin (3 mg/kg)

(d) HFD + MEMO (200 mg/kg)

(e) HFD + MEMO (400 mg/kg)

Figure 3: Histopathology of liver showing ballooning degeneration and inflammation. (CD: cellular degeneration, VCD: vascular congestion fatty deposition, FDH: foamy degeneration of hepatocytes, CV: central vein, and N: necrosis).

thus provides cardioprotection. The decreased atherogenic index by MEMOL thus supports the cardioprotectant nature of *M. oleifera*.

In order to supplement the results, the histopathological studies were also performed. The literature review revealed that high fat diet-induced obesity and abnormal lipid metabolism all collectively are associated with inflammation, congestion, and nonalcoholic fatty liver disease (NAFLD) leading to hepatic failure causing a boost in SGOT, SGPT, and total bilirubin level in the serum [52–54]. Our results showed that consumption of high-fat diet may play a crucial role in the pathogenesis of fatty liver or hepatic steatosis associated with obesity depicted via ballooning degeneration. Elevated levels of liver enzymes are a monitor of hepatocellular damage and correlate with increased liver weight [55]. The results obtained in the present study established that

high-fat diet causes hepatocellular damage, as clearly seen by the marked elevation of serum enzymes (SGOT, SGPT, and total bilirubin) activities and histopathological studies of liver exaggerated with hepatic steatosis. However, treatment with MEMOL causes a momentary reduction in the enzyme levels, signifying the role of MEMOL in preventing liver damage caused by high-fat diet.

Insulin resistance is associated with a number of metabolic disorders such as obesity, hyperlipidemia, and hypertension. HFD intakes were shown to contribute to syndromes such as hyperlipidemia, glucose intolerance, hypertension, and atherosclerosis [56]. Numerous evidences indicated that in experimental animals, high-fat diets resulted in disturbance in glucose metabolism and impaired glucose tolerance [57, 58], and the present study also demonstrate the reduction in blood glucose level those treated with MEMOL (200 and 400 mg/kg). It has been reported that thermogenesis plays a crucial role in weight management [59, 60]. Changes in body temperature are associated with significant changes in metabolic rate [61]. In support for this, the theory has been shown in different animal models which were obese, and leptin-deficient *ob*/*ob* mouse and the polyphonic obese mouse exhibited hyperphagia, a decreased metabolic rate, and a decreased core body temperature [62, 63]. This contention is supported in our results where rats feed on HFD show decreased body temperature in comparison with normal rats. Treatment with MEMOL (200 mg/kg and 400 mg/kg) reflected a sharp increase in rectal body temperature. The increase in rectal body temperature may be attributed to the overall stimulant and thermogenic property of phytoconstituents of the extract.

Preliminary phytochemical studies of the extract of *M. oleifera* showed the presence of alkaloids, tannins, flavonoids and terpenoids, and steroids. *Moringa* leaves act as a good source of natural antioxidant due to the presence of various types of antioxidant compounds such as ascorbic acid, flavonoids, phenolics, and carotenoids [23, 64]. The high concentrations of ascorbic acid; oestrogenic substances and β-sitosterol; iron; calcium; phosphorus; copper; vitamins A, B and C; α-tocopherol; riboflavin; nicotinic acid; folic acid; pyridoxine; β-carotene; protein; and in particular essential amino acids such as methionine, cysteine, tryptophan, and lysine present in *Moringa* leaves and pods make it a virtually ideal dietary supplement [64]. The hypolipedemic potential is associated with the presence of β-sitosterol [32] in crude extract of *M. oleifera*. Therefore, further study needs to be carried out for identification of specific constituents present in *M. oleifera* for its observed effects.

The present study thus concludes that the extract of leaves of *M. oleifera* possess hypolipedemic and antiobesity potential that protects the body against adverse effects of high fat diet-induced obesity. Further, we demonstrated that the daily supplementation of *M. oleifera* leaves extract may reverse the formation of hepatic steatosis and nonalcoholic fatty liver disorder. The results in the present study established that high-fat diet causes elevation in body weight and reduces lipid metabolism as clearly seen by the marked elevation of liver enzymes and lipid level. However, supplementation with MEMOL reverses all the parameters thus suggesting its weight reducing potential.

5. Conclusion

Thus, from the present study it can be concluded that the methanolic extract of *M. oleifera* is beneficial to the weight management, which supports its traditional claim. Further, studies are carried out in order to determine the active principle of this plant, followed by the identification of the mechanistic approach of MEMOL that helps in weight management.

Conflict of Interests

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

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