

Pharmacological Evaluation Of Saussurea Obvallata Leaves Extract For Antihyperlipidemic And Antioxidant Effects In High-Fat Diet-Induced Rat Model

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Abstract

Hyperlipidemia, a metabolic disorder marked by increased blood lipid levels, is one of the main risk factors for cardiovascular illnesses. Although conventional therapies are effective, they often have adverse effects with prolonged use, prompting the search for safer, natural alternatives. This study examined the antihyperlipidemic and antioxidant properties of a methanolic extract of the leaves of the himalayan medicinal plant saussurea obvallata in wistar rats fed a high-fat diet. Ftir analysis and phytochemical screening verified the presence of bioactive substances such as phenolics, alkaloids, flavonoids, and saponins. Acute toxicity tests showed that the extract was safe at doses of up to 2000 mg/kg. A total of forty-two rats were allocated across different experimental sets to evaluate the effects of the extract in comparison with standard treatment and controls. Over six weeks, various parameters were assessed, including body weight, serum lipid profiles, liver enzyme markers, oxidative stress indicators (sod, cat, gsh, and mda), and histopathological changes. The high dose of s. Obvallata extract (400 mg/kg) showed significant improvement in the lipid profile, liver function, and oxidative stress markers compared to the disease control group ($p < 0.001$), and histological analysis demonstrated restored hepatic architecture. These findings support the therapeutic potential of s. Obvallata in managing hyperlipidemia and oxidative stress, advocating further studies to explore its mechanisms and clinical applicability.

Keywords: Brahma Kamal, Hyperlipidemia, Saussurea Obvallata, Methanolic Leaves Extract, Antihyperlipidemic Activity, Antioxidant Properties, Wistar Rats, Hepatoprotection.

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Introduction:

Elevated concentrations of blood lipids are well established as major contributors to cardiovascular disease. The framework for classifying hyperlipidemia and determining treatment thresholds has been outlined by the National Cholesterol Education Program (NCEP) through its Adult Treatment Panel III (ATP-III) guidelines, which remain the standard reference for clinical management [1]. Multiple factors are implicated in the pathophysiology of hyperlipidemia, including genetics, diet, physical inactivity, and metabolic

syndromes such as obesity and diabetes mellitus [2]. This study explored alternative treatments for lipid metabolism abnormalities caused by high-fat diets, using *S. obvallata* as a potential candidate, as it mimics human metabolic alterations in animal models [3]. Currently available hyperlipidemia therapies, such as fibrates, bile acid sequestrants, cholesterol absorption inhibitors, and statins, effectively lower lipid levels, but chronic use can cause side effects. Natural herbs offer potential for cholesterol reduction [4]. Wistar rats are used as hyperlipidemia models because of their

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metabolic pattern and responsiveness to pharmacological interventions, with plant-derived bioactive molecules showing promising antihyperlipidemic activity [5]. *S. obvallata*, also known as Brahma Kamal, is a medicinal herb from the Himalayan regions with potential therapeutic properties, such as antioxidant and antimicrobial activities [6]. *S. obvallata* has been studied for its pharmacological properties, but its antihyperlipidemic effects are limited, whereas *Saussurea hypoleuca* has shown antihyperlipidemic and antidiabetic activities in experimental models [7].

This study aimed to assess the safety and effectiveness of antihyperlipidemic potential by this approach in carefully monitored experimental settings. *S. obvallata* is an important genus in the Asteraceae family, used for treating paralysis, cerebral ischemia, wounds, heart abnormalities, and mental disorders, as well as for antibacterial and wound healing purposes [8]. The Changes in body weight, liver function markers, lipid parameters, and histopathological features were evaluated to determine the therapeutic efficacy of *Saussurea obvallata* leaves extract in the management of hyperlipidemia.

Materials and methods

Plant material

S. obvallata leaves were collected from Satara district, Maharashtra, India. The plant specimen was authenticated by Alarsin pharmaceuticals, Mumbai, Maharashtra. The methanolic extract was prepared using the Soxhlet extraction procedure, filtered, and dried at a temperature below 50°C [8]. Parts of the plant were cleaned of foreign particles, spread out on trays, and then individually dried in the shade before being ground into a fine powder using a mechanical grinder and then run through a 40-mesh screen before being extracted.

Phytochemical testing

Chemical tests were performed to screen and identify the phytochemicals in the methanolic leaves extract, such as saponins, phenols, tannins, terpenoids, flavonoids, glycosides, proteins and amino acids, alkaloids, and carbohydrates [9].

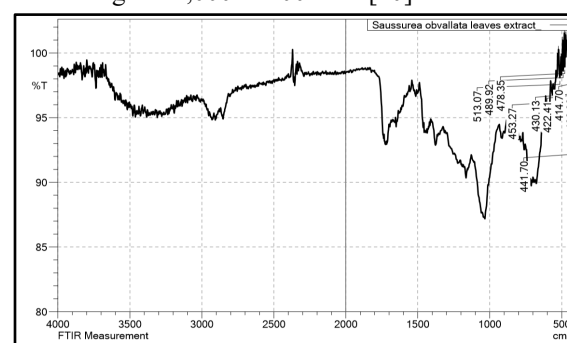
Table 1 Phytochemical analysis of methanolic extract of *Saussurea Obvallata*

Phytochemicals	Tests	Methanolic Extract Result
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Carbohydrates	Benedict's Test	+ Ve
	Fehling's Test	+ Ve
Glycosides	Legal Test	+ Ve
Flavonoids	NaOH Test	+ Ve
Tannins	Gallic acid Test	+ Ve
Alkaloids	Mayer Test	+ Ve
	Dragondroff's Test	+ Ve
Saponins	Foam Test	+ Ve
Proteins and Amino acids	Ninhydrin Test	- Ve
Phenolic compounds	Ferric Chloride Test	+ Ve

The Infrared Spectroscopy

FT/IR-4100 type A spectrophotometer 8000 series was used to perform IR spectroscopy. Following the crushing of the methanol extract of both *S. obvallata* into a thin pellet with KBr salt, scanning was carried out in the range of 4,000 to 400 cm⁻¹ [10].



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Fig 1. FTIR spectrum of *Saussurea Obvallata* methanolic extract

Table 2. Interpretation of *Saussurea Obvallata* methanolic extract using FTIR spectroscopy

Sr. No.	Peak Position (cm ⁻¹)	% Transmittance	Possible Functional Groups	Likely Phytochemicals Involved
1	406.98	97.5	C-Br (halo group)	Halogenated phenolics
2	414.7	98.18	C-Br / skeletal vibrations	Polyphenols
3	422.41	97.27	Aromatic ring bending	Flavonoids
4	430.13	97.34	Aromatic C-C/C-X vibrations	Phenolic compounds
5	441.7	92.66	C-Cl / ring deformation	Terpenoids
6	453.27	96.75	C-Cl (haloalkane)	Halogenated alkaloids
7	478.35	98.93	C-Cl or ring vibrations	Steroids
8	489.92	98.6	C-Cl / aromatic	Polyphenols
9	513.07	98.08	C-I / skeletal vibrations	Iodinated plant metabolites

Animals

Wistar female rats weighing between 200 and 250 g were procured. Standard housing conditions for the animals included a 12:12 light-dark cycle, a temperature of 25±2°C, and a relative humidity of 30 to 70%. The animals were provided a regular pellet meal and unlimited access to water. Approval from the Institutional Animal Ethics Committee (IAEC) was obtained (2166/PO/RcBi/S/22/CPCSEA).

Acute toxicity studies

Wistar rats were used in acute toxicity tests for the methanolic extract of *S. obvallata* leaves in accordance with OECD recommendations 423. The aqueous solution of the extract was administered orally to each animal. For the first two hours and up to twenty-four hours, the animals were regularly monitored for any changes in mortality [11].

Experimental protocol

Five groups of six Wistar rats were created from a total of forty-two rats. All five groups received a high-fat diet for three weeks. High-fat diet was prepared using Indian Vanaspati ghee and coconut oil in a 3:1 (v/v) ratio. It was administered to rats at a dose of 3 ml/kg body weight per day. The animals were numbered, weighed, and recorded before being randomly divided into five groups of six animals each [12].

Group 1: Animals received a standard pellet diet and purified water for 24 h over a period of 6 weeks and were considered as normal control group.

Group 2: Animals received a high-fat diet throughout the study period of 6 weeks and were considered the diseased group.

Group 3: Animals were fed a high-fat diet for the first 3 weeks and treated with standard drug atorvastatin (10 mg/kg) for the next 3 weeks and was considered as the standard control group.

Group 4: Animals were fed a high-fat diet for the first 3 weeks and treated with a Low Dose of *S. obvallata* leaves extract (200 mg/kg) for the next 3 weeks and was considered as Low Dose group.

Group 5: Animals were fed with high fat diet for first 3 weeks and treatment with High dose of *S. obvallata* leaves extract (400 mg/kg) for next 3 weeks and was considered as High Dose group.

Blood biochemical analysis

Blood was collected by retro-orbital puncture from the anesthetized rats and centrifuged to obtain serum. Serum lipid profiles containing Total Cholesterol, triglycerides, LDL cholesterol, HDL cholesterol, and VLDL cholesterol [13] along with liver function markers such as serum glutamic oxaloacetic transaminase (SGOT), serum glutamic pyruvic transaminase (SGPT), and alkaline phosphates (ALP) were assessed to develop dyslipidemia in the model [14].

Measurement of oxidative stress

Serum MDA levels, catalase activity, superoxide dismutase (SOD) levels, and glutathione (GSH) were evaluated using chemical procedures [12], [15].

Histopathology

A portion of liver tissue (liver slices) from the normal control, diseased control, standard control, SO (200 mg/kg), and SO (400 mg/kg) groups was stored in containers with neutral buffer solution (NBF) and subjected to histopathological studies [16]. The liver samples were examined and compared under a microscope for histological alterations, such as normal, injured, and recovered liver. The results were shown in Fig. 8

Statistical analysis

The mean ± S.E.M was used to express all results. The data were analyzed using two-way ANOVA and Bonferroni Post Hoc analysis. Statistical significance was set at p < 0.05 [17].

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Results

Effect on body weight:

Administration of a high-fat diet for 21 days resulted in a significant increase in body weight in the disease control group, indicating diet-induced metabolic disturbance. In contrast, animals treated with *S. obvallata* extract (200 and 400 mg/kg) during the subsequent 21 days showed a statistically significant attenuation in weight gain. The high-dose group (400 mg/kg) exhibited the highest reduction, with body weights nearing those of the normal control group by the end of the study ($p < 0.001$ vs. disease control) Fig. 2. This suggests that the extract may contribute to improved lipid utilization or prevention of adiposity.

Effect on the Serum Lipid Profile:

The high-fat diet induced marked dyslipidemia, as evidenced by elevated levels of total cholesterol (TC), triglycerides (TG), low-density lipoprotein (LDL), and very low-density lipoprotein (VLDL), and reduced high-density lipoprotein (HDL). Treatment with *S. obvallata* significantly ameliorated these alterations in a dose-dependent manner. The 400 mg/kg dose showed a robust reduction in TC, TG, LDL, and VLDL levels, while significantly elevating HDL levels ($p < 0.001$ vs. disease control), suggesting a strong antihyperlipidemic potential comparable to atorvastatin. Fig.3, Fig. 4.

Effect on Hepatic Enzymes

Liver function enzymes, such as SGOT, SGPT, and ALP, were significantly elevated in the disease control group, reflecting hepatic stress and possible damage due to lipid accumulation. Treatment with *S. obvallata* extract notably decreased the enzyme levels, with the 400 mg/kg group showing values closely aligned with those of the normal control and standard treatment groups Fig. 5. This indicates that the extract exerts a protective effect on liver function, likely through membrane stabilization and the attenuation of lipid-induced hepatotoxicity.

Effect on Oxidative Stress Markers

Oxidative stress was assessed by measuring antioxidant enzyme activities (SOD, CAT, and GSH) and lipid peroxidation products (MDA). The disease control animals showed significantly decreased antioxidant levels and elevated MDA levels, indicating oxidative damage due to high-fat feeding. Treatment with *S. obvallata*, particularly at 400 mg/kg, significantly restored SOD, CAT, and GSH levels and reduced MDA concentrations ($p < 0.001$) Fig. 6, Fig. 7 indicating

potent antioxidant activity and protection against oxidative damage.

Histopathological Evaluation

Histological examination of liver tissues in the disease control group revealed extensive steatosis, hepatocellular ballooning, and inflammatory infiltration in the liver. In contrast, rats treated with *S. obvallata* showed dose-dependent improvement. The low-dose group displayed a moderate reduction in fat accumulation, whereas the high-dose group demonstrated a well-preserved hepatic lobular architecture with minimal steatosis and inflammation Fig. 8. These findings support the biochemical evidence of hepatoprotection and highlight the therapeutic potential of *S. obvallata*.

Table 3. Effects of Saussurea obvallata leaves extract on Body Weights in high-fat diet induced hyperlipidemic Rats

Sr. No.	Treatment and Dose	Body weight (grams, Mean±SEM)		
		Day 0	Day 21	Day 42
1	Normal Control	188.83±2.89	200.17±2.57	209.67±2.25
2	Disease Control	193.50±2.43	204.83±2.41	222.50±8.08
3	Standard Control	188.17±2.7	200.67±2.4	173.50±3.1***
4	SO(200mg/kg)	189.33±3.42	200.50±3.42	185.00±3.4***
5	SO(400mg/kg)	190.00±2.25	200.83±2.34	175.83±2.01***

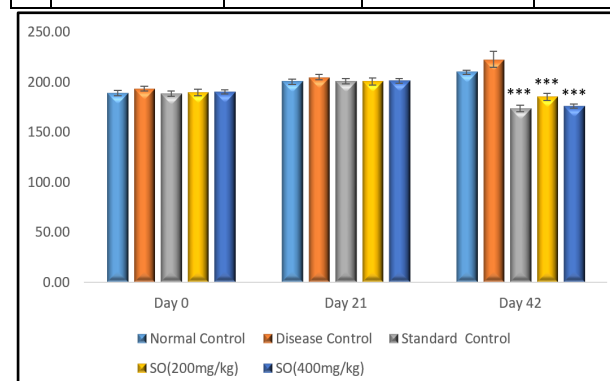


Figure 2. Effects of Saussurea obvallata leaves extract on body weight in high-fat diet-induced hyperlipidemic rats. Data are presented as mean ± SEM for six animals per group and were statistically evaluated using One-Way ANOVA followed by Bonferroni's post hoc test. A statistically significant

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difference was observed, indicated by ***P <0.001 when compared to the Disease Control.

Table 4. Effects of *Saussurea obvallata* leaves extract on Serum Lipid Profile Parameters (Total Cholesterol [TC] and triglycerides [TG]) in high-fat diet-induced hyperlipidemic rats.

Sr. No.	Treatment and Dose	Serum Lipid Profile Parameters (Mean ±SEM) mg/dl	
		TC	TG
1	Normal Control	63.50±2.28***	77.17±1.35***
2	Disease Control	202.50±4.28	171.00±5.61
3	Standard Control	112.33±3.60***	84.00±1.18***
4	SO(200mg/kg)	134.67±2.58***	108.00±6.78***
5	SO(400mg/kg)	123.00±2.18***	87.33±1.58***

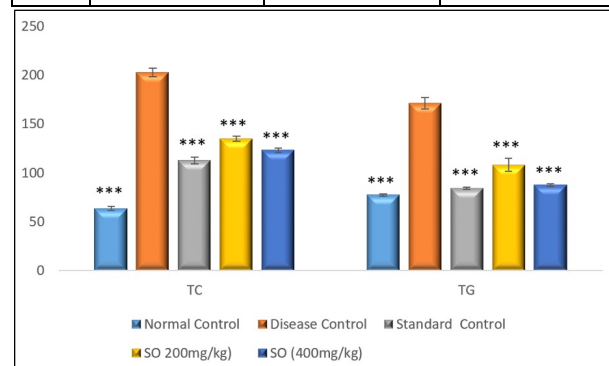


Figure 3. Effects of *Saussurea obvallata* leaves extract on Serum Lipid Profile Parameters Total Cholesterol [TC] and Triglycerides [TG] in high-fat diet-induced hyperlipidemic rats. Data are presented as Mean ± SEM for six animals per group and were statistically evaluated using One-Way ANOVA followed by Bonferroni's post hoc test. A statistically significant difference was observed, indicated by *** P<0.001 when compared to the Disease Control

Table 5. Effects of *Saussurea obvallata* leaves extract on Serum Lipid Profile Parameters (Low Density Lipoprotein [LDL], High-Density Lipoprotein [HDL] and Very Low-Density Lipoprotein [VLDL]) in high-fat diet-induced hyperlipidemic Rats

Sr. No.	Treatment and Dose	Serum Lipid Profile Parameters (Mean ±SEM)mg/dl		
		LDL	HDL	VLDL
1	Normal Control	33.17±1.19***	60.00±2.38***	
2	Disease Control	115.00±6.03	27.17±3.26	
3	Standard Control	42.83±2.12***	56.83±1.35***	
4	SO 200mg/kg)	70.50±3.88***	41.00±2.70**	
5	SO (400mg/kg)	53.67±1.76***	52.17±1.78***	

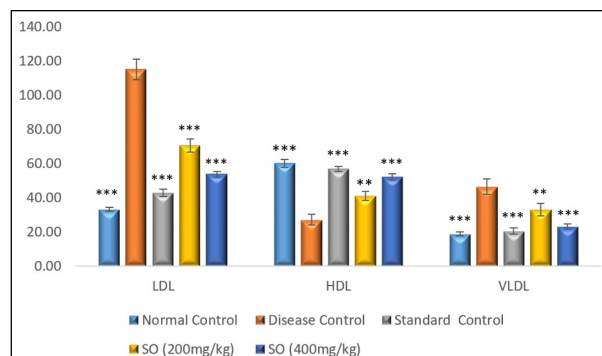


Figure 4. Effects of *Saussurea obvallata* leaves extract on serum lipid profile parameters: low-density lipoprotein [LDL], High-Density Lipoprotein and Very Low-Density Lipoprotein [VLDL] in high-fat diet-induced hyperlipidemic rats. Data are presented as Mean ± SEM for six animals per group and were statistically evaluated using One-Way ANOVA followed by Bonferroni's post hoc test. A statistically significant difference was observed, indicated by ***P < 0.001, **P < 0.01 when compared to the Disease Control

Table 6. Effects of *Saussurea obvallata* leaves extract on Liver Enzymes (Serum Glutamic Oxaloacetic Transaminase [SGOT], Serum Glutamic Pyruvic Transaminase [SGPT], and Alkaline Phosphatase [ALP]) in high-fat diet-induced hyperlipidemic rats.

Sr. No.	Treatment and Dose	(Mean ±SEM) IU/L	
		SGOT	SGPT
1	Normal Control	47.67±2.20***	38.33±2.85***
2	Disease Control	114.00±5.57	98.00±3.09
3	Standard Control	48.50±2.08***	47.50±2.06***
4	SO(200mg/kg)	71.00±2.76***	58.33±2.59***
5	SO(400mg/kg)	55.50±2.51***	44.17±2.30***

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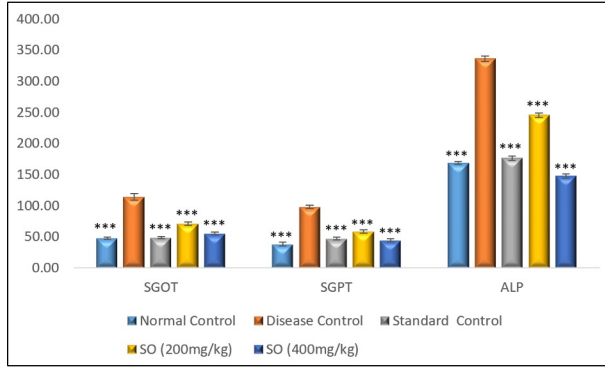


Figure 5. Effects of *Saussurea obvallata* leaves extract on Liver Enzymes (Serum Glutamic Oxaloacetic Transaminase [SGOT], Serum Glutamic Pyruvic Transaminase [SGPT], and Alkaline Phosphatase [ALP]) in high-fat diet-induced hyperlipidemic rats. Data are presented as Mean ± SEM for six animals per group and were statistically evaluated using One-Way ANOVA followed by Bonferroni's post hoc test. A statistically significant difference was observed, indicated by ***P < 0.001 when compared to the Disease Control

Table 7. Effects of *Saussurea obvallata* leaves extract on (Superoxide Dismutase [SOD], Catalase [CAT]) in high-fat diet induced hyperlipidemic Rats

Sr. No.	Treatment and Dose	(Mean ±SEM) IU/mg protein	
		SOD	CAT
1	Normal Control	5.93±0.09***	48.28±0.38***
2	Disease Control	2.52±0.15	21.20±1.21
3	Standard Control	5.17±0.07***	45.18±0.25***
4	SO(200mg/kg)	4.32±0.10**	38.02±0.29***
5	SO(400mg/kg)	4.97±0.07***	42.65±0.24***

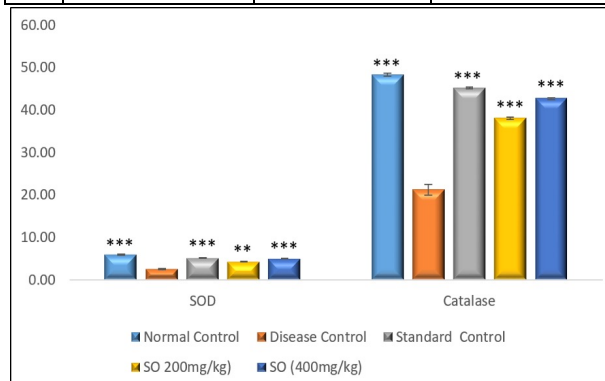


Figure 6. Effects of *Saussurea obvallata* leaves extract on (Superoxide Dismutase [SOD] and catalase [CAT]) in high-fat diet-induced hyperlipidemic rats. Data are presented as Mean ± SEM for six animals per group and were statistically evaluated using One-Way ANOVA followed by Bonferroni's post hoc test. A statistically significant difference was observed, indicated by ***P < 0.001 **P<0.01 when compared to the Disease Control

Table 8. Effects of *Saussurea obvallata* leaves extract on (glutathione [GSH] and malondialdehyde [MDA]) levels in high-fat diet-induced hyperlipidemic rats.

Sr. No.	Treatment and Dose	(Mean ±SEM) nmol/mg protein	
		GSH	MDA
1	Normal Control	6.25±0.15***	1.20±0.04***
2	Disease Control	2.42±0.17	4.87±0.19
3	Standard Control	5.98±0.19***	1.67±0.10***
4	SO(200mg/kg)	5.13±0.21***	2.35±0.16***
5	SO(400mg/kg)	5.67±0.09***	1.77±0.09***

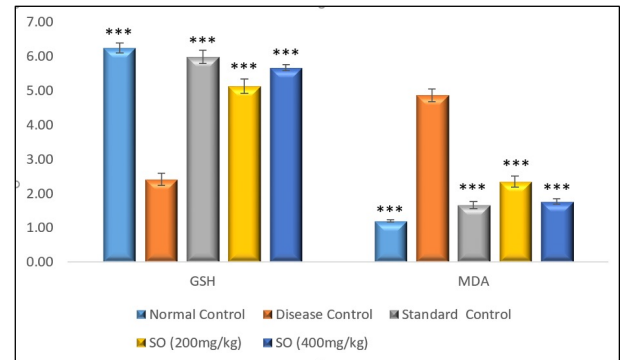


Figure 7. Effects of *Saussurea obvallata* leaves extract on (glutathione [GSH] and malondialdehyde [MDA]) levels in high-fat diet-induced hyperlipidemic rats. Data are presented as Mean ± SEM for six animals per group and were statistically evaluated using One-Way ANOVA followed by Bonferroni's post hoc test. A statistically significant difference was observed, indicated by ***P < 0.001 when compared to the Disease Control

Histopathological Studies

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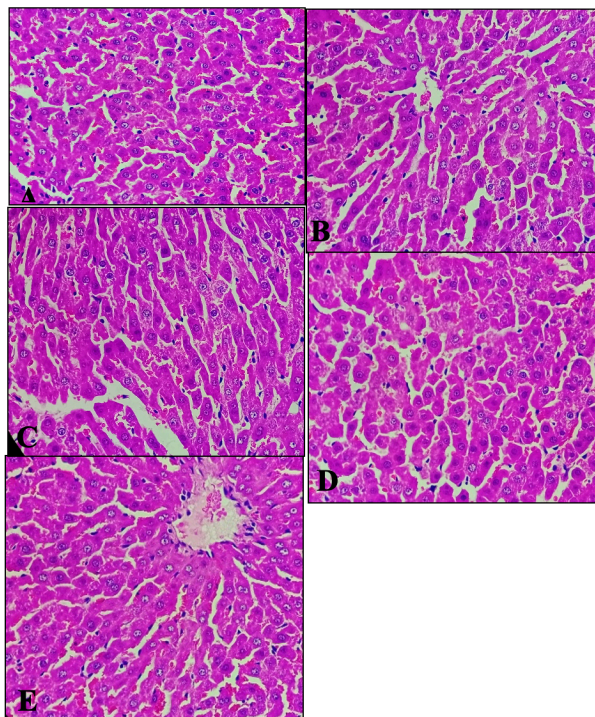


Fig. 8. Histopathological study of liver

A. Normal liver and adipose tissue histology

Liver sections exhibited intact hepatic architecture with polygonal hepatocytes arranged in cords radiating from the central vein. No signs of steatosis, inflammation, or necrosis were observed.

B. Diseased liver and adipose tissues showing pathological alterations

Liver tissues showed extensive steatosis with ballooned hepatocytes, inflammatory cell infiltration, and disorganized hepatic cords.

C. Liver and adipose histology of standard group showing significant recovery

Hepatic tissue exhibited almost normal lobular structure with slight fatty changes and minimal inflammation.

D. SO 200 mg/kg group – moderate improvement in liver and adipose morphology

Liver histology showed reduced fat accumulation and mild architectural restoration.

E. SO 400 mg/kg group – extensive histological recovery

Liver tissue demonstrated well-preserved histological architecture with minimal pathological alterations.

Discussion

The methanolic extract of *S. Obvallata* (Brahma Kamal) leaves exhibited potent antihyperlipidemic, antioxidant, and hepatoprotective effects in a high-fat diet (HFD)-induced hyperlipidemic Wistar rat model over six weeks, with the high dose (400 mg/kg) outperforming the low dose (200 mg/kg) and closely matching atorvastatin (10 mg/kg) across all parameters. HFD administration for the initial three weeks reliably induced dyslipidemia and metabolic perturbations, as evidenced by significant elevations in body weight (222.50 ± 8.08 g by day 42 vs. normal control 209.67 ± 2.25 g, $p < 0.001$), total cholesterol (TC: 202.50 ± 4.28 mg/dL), triglycerides (TG: 171.00 ± 5.61 mg/dL), low-density lipoprotein (LDL: 115.00 ± 6.03 mg/dL), and very low-density lipoprotein (VLDL: 46.50 ± 4.54 mg/dL), coupled with reduced high-density lipoprotein (HDL: 27.17 ± 3.26 mg/dL; all $p < 0.001$ vs. normal). Subsequent treatment with *S. obvallata* extract reversed these in a dose-dependent manner, with the high dose reducing TC to 123.00 ± 2.18 mg/dL, TG to 87.33 ± 1.58 mg/dL, LDL to 53.67 ± 1.76 mg/dL, VLDL to 23.17 ± 1.35 mg/dL, elevating HDL to 52.17 ± 1.78 mg/dL ($p < 0.001$ vs. disease control), and attenuating body weight gain to near-normal levels (175.83 ± 2.01 g). These lipid-lowering effects are primarily attributable to the extract's rich phytochemical profile including flavonoids, phenolics, alkaloids, saponins, terpenoids, and glycosides verified through qualitative screening (positive responses to NaOH, ferric chloride, foam, Mayer's, and Legal's tests) and FTIR spectroscopy (characteristic peaks at 406.98 cm^{-1} for C-Br halo groups in halogenated phenolics, 414.7 - 422.41 cm^{-1} for polyphenols and aromatic ring bending in flavonoids, 430.13 - 441.7 cm^{-1} for phenolic C-C-X vibrations and 441.7 cm^{-1} for terpenoids, also 478.35 - 513.07 cm^{-1} for C-Cl/steroids and iodinated metabolites). Such bioactives mechanistically inhibit lipogenic enzymes like HMG-CoA reductase and pancreatic lipase, upregulate LDL receptor expression, enhance fecal bile acid and cholesterol excretion, and promote reverse cholesterol transport via HDL, mechanisms well-documented in *Saussurea hypoleuca* root extracts (reducing TC by 40-50% in alloxan-diabetic rats through quercetin and kaempferol) and polyphenol-rich Himalayan herbs like *Rhinacanthus nasutus* [7], [18].

Parallel hepatic protection was profound, with disease controls displaying marked elevations in serum glutamic

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oxaloacetic transaminase (SGOT: 114.00 ± 5.57 IU/L), serum glutamic pyruvic transaminase (SGPT: 98.00 ± 3.09 IU/L), and alkaline phosphatase (ALP: 335.83 ± 4.47 IU/L; $p < 0.001$ vs. normal), signaling lipid-induced hepatocyte membrane disruption, fatty infiltration, and cholestasis. disease control), implying stabilization of plasma membranes, attenuation of lipotoxicity, and reduced transaminase leakage effects mirrored in HFD models treated with saponin/terpenoid-rich extracts like *Sanguisorba officinalis* and *Aloe succotrina*, where polyphenols inhibit ROS generation [19], [20]. Oxidative stress, a core driver of hyperlipidemia progression, was similarly ameliorated: HFD depleted endogenous antioxidants superoxide dismutase (SOD: 2.52 ± 0.15 IU/mg protein), catalase (CAT: 21.20 ± 1.21 IU/mg protein), and glutathione (GSH: 2.42 ± 0.17 nmol/mg protein) while elevating lipid peroxidation marker malondialdehyde (MDA: 4.87 ± 0.19 nmol/mg protein; $p < 0.001$). The 400 mg/kg dose restored SOD to 4.97 ± 0.07 IU/mg, CAT to 42.65 ± 0.24 IU/mg, GSH to 5.67 ± 0.09 nmol/mg, and lowered MDA to 1.77 ± 0.09 nmol/mg ($p < 0.001$), confirming direct free radical scavenging and indirect enzymatic upregulation. The antioxidant effects observed align with *S. Obvallata* reported antioxidant activity and free radical scavenging capacity, as demonstrated by its methanolic extracts showing concentration-dependent radical scavenging in DPPH assays [21]. These effects are attributable to the phenolic compounds and flavonoids confirmed in the extract by phytochemical screening and FTIR analysis, consistent with the general antioxidant properties [22]. Histopathological validation reinforced these biochemical shifts, disease control livers showed macro- and microvesicular steatosis, hepatocellular ballooning, periportal inflammation, and sinusoidal dilation, hallmarks of non-alcoholic fatty liver disease (NAFLD) in HFD models. Low-dose treatment yielded moderate clearance of fat vacuoles and reduced inflammation, while high-dose restored near-normal lobular architecture with polygonal hepatocytes radiating from central veins, minimal steatosis and absent necrosis corroborating membrane integrity and anti-inflammatory actions of FTIR-identified polyphenols. Notably, attenuated adiposity (evident in adipose histology improvements) suggests anti-obesogenic effects, possibly via leptin sensitization or adipocyte differentiation inhibition, as in ethanolic extracts of antihyperlipidemic plants like *Cinnamomum tamala* [23].

The extract's acute oral safety profile no mortality, lethargy, diarrhea, or organ histopathology changes up to 2000 mg/kg per OECD Guideline 423 affirms its non-toxicity and aligns with *S. obvallata*'s revered status in traditions for treating dyslipidemia, cardiac ailments, and inflammation without reported adverse effects [24]. Limitations include the absence of molecular docking, HPLC quantification of actives (e.g., quercetin derivatives), or chronic/subchronic toxicity assessments, which could refine dosing for translation.

Conclusion

In conclusion, Methanolic leaves extract of *S. obvallata* demonstrates broad therapeutic potential as a safe, natural intervention for high-fat diet induced hyperlipidemia, oxidative liver injury, and early-stage NAFLD. It shows efficacy at higher doses and performs comparably to atorvastatin, driven by synergistic phytochemicals that regulate lipid metabolism (via PPAR- α/γ , LXR, and AMPK pathways), counteract ROS, and protect hepatic tissue. This positions the extract as a promising alternative or adjunct to statins, which carry risks such as rhabdomyolysis and hepatotoxicity with prolonged use. Beyond its established anti-inflammatory and antidiabetic properties, this endangered Himalayan species now fills a crucial evidence gap in metabolic disease management. Moving forward, research should prioritize bioassay-guided fractionation to isolate active compounds, computational and laboratory validation of molecular targets assessing pharmacokinetics, and advancing through phased clinical trials to enable development of *S. obvallata* as a nutraceutical or phytopharmaceutical.

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