

EXPLORING THE AMELIORATIVE EFFECTS OF *ANETHUM GRAVEOLENS* AND *FOENICULUM VULGARE* SEEDS ON DYSLIPIDEMIA: A COMPARATIVE EFFICACY IN HIGH FAT DIET-INDUCED MODEL

Anum Urooj¹, Fatima Mumtaz², Aimen Shabbir³, Murium Sultan⁴,
Syeda Maryam Batool Tirmazi⁵, Muhammad Sajjad Sarwar⁶, Shabahaat Iqbal⁷, Muhammad Asif⁸

^{1,5,7}National Institute of Food Science and Technology, University of Agriculture, Faisalabad, Pakistan.

²Department of Biochemistry, Bahauddin Zakariya University, Multan, Pakistan

³NFC Institute of Engineering and Technology, Multan, Pakistan.

⁴College of Food Science and Technology, Huazhong Agricultural University, Wuhan, Hubei, China.

⁶Department of Zoology, University of Okara, Okara, Pakistan.

⁸Department of Food Science and Technology, UAF-Constituent College Burewala, Pakistan

¹anumurooj.uaf@gmail.com

DOI: <https://doi.org/10.5281/zenodo.18831840>

Keywords

Dyslipidemia; High-fat diet; *Anethum graveolens*; *Foeniculum vulgare*; Lipid profile; Antioxidant activity; Hepatoprotection; Hematological indices; Functional food

Article History

Received: 29 December 2025

Accepted: 14 February 2026

Published: 28 February 2026

Copyright @Author

Corresponding Author: *

Anum Urooj

Abstract

This study evaluated the comparative ameliorative effects of sowa dill (*Anethum graveolens*) and fennel (*Foeniculum vulgare*) seed powders on lipid profile, hematological indices, hepatic and renal biomarkers, and serum proteins in high-fat diet (HFD)-induced dyslipidemic rats. Eighteen albino Wistar rats were randomly allocated into six groups (n=3): normal control (G₀), dyslipidemic control (positive control; G₁), and four treatment groups (G₂-G₅) receiving sowa or fennel seed powders at a dosage of 250 mg or 500 mg for 28 days. Seed powders were characterized for physicochemical composition, functional properties, mineral profile, and antioxidant potential before in vivo evaluation. Significant ($p < 0.05$) compositional differences were observed between the two seeds, with fennel exhibiting a superior nutritional and mineral profile ($p < 0.01$). Hexane extracts of fennel demonstrated the highest antioxidant activity ($p < 0.01$), supporting its nutraceutical potential. Both sowa and fennel significantly ($p < 0.05$) improved dyslipidemia by reducing lipid profiles and enhancing HDL-cholesterol levels, with the most prominent effects observed in the fennel 500 mg group. Hematological parameters were markedly increased ($p < 0.01$), while liver enzyme activities, renal markers, and serum protein profiles were favorably modulated, particularly fennel 500 mg group. Overall, *Foeniculum vulgare* seed powder at 500 mg showed superior efficacy in ameliorating HFD-induced dyslipidemia and improving systemic biochemical and hematological health markers, supporting its potential as a natural therapeutic and functional food ingredient for dyslipidemia management.

INTRODUCTION

Traditional medicine, often referred to as indigenous or folk medicine, has evolved over generations in many cultures before the advent of modern medicine (Khan and Ahmad, 2019). In recent years, a global shift from conventional medicine to herbal therapy has been observed, often described as a "Return to Nature" (Najmi et al., 2022). Recent scholarly reviews indicate that global trade in medicinal and aromatic plants has expanded significantly in recent years, with global export and import values nearly doubling from 2010 to 2023, showing demand and strong market growth for plant-based products worldwide (Zamani et al., 2025). According to the World Bank. (2023) reports that trade in medicinal plants, botanical pharmaceuticals, and related agricultural products has been growing at an average annual rate of approximately 15%. The term nutraceutical was first introduced by Stephen DeFelice in 1989, who defined it as foods or food components that provide medical or health benefits beyond basic nutritional value. The global nutraceutical market is substantial, estimated at approximately USD 117 billion (Das et al., 2012).

Numerous studies have demonstrated that herbal nutraceuticals help maintain health and promote optimal longevity and quality of life (Dominguez et al., 2020; Taroncher et al., 2021). By 2020, the global nutraceutical market was valued at USD 320.0 billion and is expected to hit USD 658.11 billion by 2028 (Sachdev et al., 2020). Owing to the herbal plants' therapeutic efficacy, minimal side effects, and economic feasibility attracted significant scientific interest worldwide (Awuchi et al., 2019). Phytochemicals (flavonoids, alkaloids, saponins, terpenoids, glycosides, steroids, tannins, and volatile oils) naturally synthesized by plants cannot be produced by the human body, act as antioxidants and free radical scavengers help reduce oxidative stress, thereby lowering the risk of chronic diseases (Nafees et al., 2023; Mehra et al., 2021; Mallik et al., 2020). Pakistan's diverse topography has approximately 6,000 species of higher plants, with around 600 to 700 species reportedly used for therapeutic purposes (Iqbal et al., 2022; Noorka et al., 2022).

About 30% of these species are bi- or pluri-regional, while 70% are uni-regional (Ijaz et al., 2022; Khan et al., 2017). Historically, about 12% of Pakistan's higher plant species are used medicinally, with approximately 84% of the population in hilly areas (Hassan et al., 2017). Globally, approximately 40% of newly approved drugs over the past two decades are derived from natural sources (Halder et al., 2021). The global market for botanical pharmaceuticals was valued at \$19.5 billion in 2008 and was projected to grow to \$32.9 billion by 2013, with an annual growth rate of 11.0%. At this rate, the annual trade is expected to exceed \$5 trillion by 2050 (Awuchi et al., 2019; Erb and Kliebenstein, 2020).

In recent years, a new health paradigm has emerged, with cardiovascular disease (CVD) globally the leading cause of death (Khan and Ahmad, 2019). Elevated cholesterol 4.5% of all global deaths, contributing to 29.7 million disabilities, which raised cholesterol in adults was estimated at 39% (WHO, 2019; Du et al., 2022). In Pakistan, according to the WHO (2019), CVDs account for 29% of all deaths. This number is projected to increase significantly by 2030, potentially reaching 22.2 million (Alotaibi et al., 2021). Dyslipidemia reported rates in Pakistan range from 40% to 65% (Basit et al., 2021; Wen et al., 2019).

Hyperlipidaemia is a major risk factor strongly associated with diabetes, insulin resistance, and obesity (Piché et al., 2020; Iqbal et al., 2022). Currently, statins, fibrates, and nicotinic acid are among the most commonly prescribed allopathic drugs for treating hyperlipidaemia. However, statins can cause adverse effects, including liver damage. Medicinal herbs and spices are increasingly recognized for their potential to manage lipid disorders due to their lower toxicity, fewer side effects, and cost-effectiveness. (Liu et al., 2018; Parvin et al., 2022).

Anethum graveolens, commonly known as dill or sowa, is an annual aromatic herb from the Umbelliferae family, native to southern Europe and widely cultivated in the Mediterranean. Dill has been used as a culinary spice and medicinal

herb for more than 5,000 years (Hamza, 2017; Chahal et al., 2017). Dill seeds are rich in: essential oils, phenolic compounds, and secondary metabolites with pharmacological significance (Singletary, 2023). *Anethum graveolens* seed extracts have been reported to lower TC, TG, and LDL, and increase HDL levels. The active components, particularly carvone and limonene, contribute significantly to the reduction of lipid levels and improvement in liver function, play a key role in managing hyperlipidemia and dyslipidemia (Al-Sheddi et al., 2019).

Foeniculum Vulgare, widely known as Fennel, a highly valued medicinal and culinary herb belonging to the Apiaceae family, is traditionally used in Indian, Greek, Egyptian, and Chinese systems of medicine (Zulfiqar, 2019; Dheebishba and Vishwanath, 2020; Anka et al., 2020). Fennel seeds are widely used in culinary, pharmaceutical, and cosmetic industries, with the global market projected to grow from USD 909.41 million in 2026 to over USD 1.43 billion by 2032, reflecting a CAGR of 7.77% (Research and Markets, 2026). Fennel seeds are rich in bioactive constituents (anethole, estragole, and fenchone) that contribute to lowering serum total cholesterol, triglycerides, and LDL-C, while increasing HDL-C levels (Kaveh et al., 2022; Rezaq, 2021; Noreen et al., 2023).

By standardizing and evaluating the therapeutic potential of plant derived active compounds, herbal medicines can contribute to the emergence of a new era in healthcare for the treatment of diseases. The study aims to explore the antioxidant effects of sowa/dill and fennel seeds in high-fat diet-induced dyslipidemia. Additionally, check its nutritional profile and assess its hepatoprotective potential.

Materials and Methods

Procurement of raw materials

Antheum Graveolens L. (sowa/dill) seeds and *Foeniculum Vulgare* Mill. (fennel) seeds were purchased from a local herbal market in Multan, Pakistan. All chemicals and reagents used in this study were of analytical grade (Merck, Germany).

Preparation of seed powders

The seeds were manually sorted to remove impurities, thoroughly washed with distilled water, and sun dried to constant weight. The dried seeds were then ground into fine powders using an electric grinder. The powders were passed through an 80-mesh sieve to obtain a uniform particle size. The resulting powders were packed in polyethylene bags and stored under moisture-free conditions until further analysis. The overall procedure was followed as described by Ismail et al. (2026) (Figure 1).

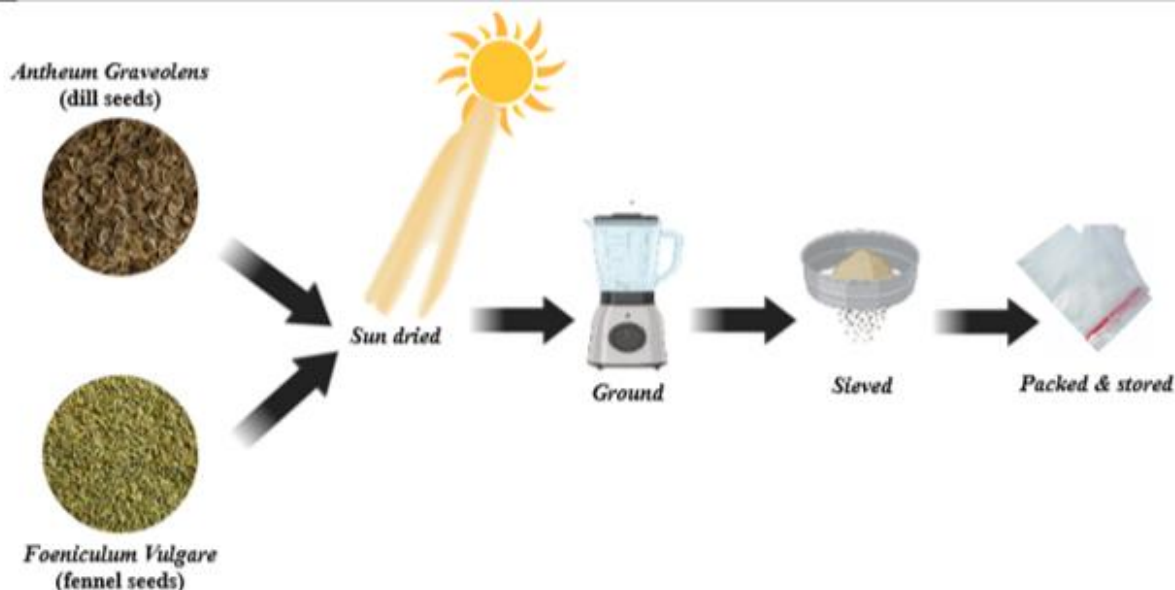


Figure 1: Standardized procedure for the preparation of *A. graveolens* and *F. vulgare* seed powders

Proximate composition analysis

The proximate composition of *A. graveolens* and *F. vulgare* seed powders, including moisture, ash, crude fat, crude fiber, protein, and nitrogen-free extract (NFE), was determined using standard methods as reported in the literature (Asif et al., 2025a).

Mineral analysis

The mineral composition of *A. graveolens* and *F. vulgare* seed powders was determined using wet digestion followed by instrumental quantification (colorimetric, spectrophotometric, and titrimetric methods). 5 g of each powdered sample was initially preheated over a Bunsen burner and subsequently incinerated in a muffle furnace at 550-600 °C until white ash was obtained. The resulting ash was digested in diluted acid, filtered, and the final volume was adjusted to 250 mL using distilled water. Mineral elements, including calcium (Ca), iron (Fe), zinc (Zn), and other selected minerals, were quantified using atomic absorption spectrophotometry (Agilent AA240, Varian, USA) based on the procedure described by Asif et al. (2023). Mineral concentrations were calculated using standard calibration curves and expressed as mg/100 g dry weight (DW).

Functional properties of seed powders

Water absorption capacity (WAC)

Water absorption capacity was determined following the procedures described by Chandra and Samsher (2013) and recently applied by Tsegay et al. (2024) with minor modifications by the centrifugation method. 3 g of sample was mixed with 25 mL of distilled water in pre-weighed Falcon tubes and centrifuged at 3000 rpm for 30 min. The mixture was allowed to stand for 5 min and centrifuged again under the same conditions. The supernatant was carefully decanted, and the residue was transferred to a Petri dish and dried in a hot-air oven at 55 °C for 20 min. Water absorption capacity was expressed as grams of water retained per gram of sample (dry basis).

Oil absorption capacity (OAC)

Oil absorption capacity was assessed by prescribed procedures (Zahid et al., 2025) with minor modifications. By mixing 5 g of the sample with 6 mL of refined corn oil. The mixture was stirred for 1 min, then allowed to stand for 5 min, and centrifuged at 3000 rpm for 30 min. The unbound oil was decanted, and the tube containing the residue was weighed. Oil

absorption capacity was expressed as grams of oil retained per gram of sample.

Foaming capacity (FC) and Foaming stability (FS)

Foaming properties were evaluated following a standard blending method Nwokeke et al. (2025) with modifications. A 1.5 g sample was mixed

with 50 mL of distilled water in a graduated cylinder and homogenized for 2 min. The total volume was recorded immediately to determine foaming capacity, while foaming stability was recorded after 10 min and 30 min. Foaming capacity and stability were calculated using the following equations:

$$\text{Foaming capacity (\%)} = \frac{V_1 - V_0}{V_0} \times 100$$

$$\text{Foaming stability (\%)} = \frac{V_{30}}{V_1} \times 100$$

Where:

V_0 = initial volume before whipping (mL)

V_1 = volume immediately after whipping (mL)

V_{30} = volume after 30 min (mL)

Bulk density (BD)

Bulk density was determined as the ratio of sample mass to the volume occupied (Asif et al., 2025b; Tsegay et al., 2024). 5 g of powder was

placed into a 50 mL graduated cylinder and the final volume was recorded. Bulk density was calculated using:

$$\text{Bulk Density (g/cm}^3\text{)} = \frac{\text{Sample weight}}{\text{Volume occupied}}$$

Emulsification activity (EA)

Emulsification activity was assessed based on the procedure described by Chandra et al. (2015). 0.5 g of the sample was mixed with 5 mL of distilled water and 5 mL of refined maize oil in a

The Falcon tube was vigorously shaken for 5 min. The mixture was left to stand and the height of the emulsion layer was measured. Emulsification activity was calculated as:

$$\text{Emulsification activity (\%)} = \frac{\text{Height of emulsion layer}}{\text{Total height of the mixture}} \times 100$$

Antioxidants activity

Preparation of seed extracts

The antioxidant potential of *A. graveolens* and *F. vulgare* seed extracts was assessed using solvents of varying polarity, including acetone, ethanol, hexane, and distilled water. Each powdered sample was extracted at 40 °C for 8-9 hrs under continuous agitation. The resulting mixture was

filtered to remove insoluble residues, and the filtrates were concentrated under reduced pressure using a rotary evaporator at 25 °C. The concentrated extracts were further dried to constant weight and stored in air-tight containers at room temperature (Naqvi et al., 2023; Sasidharan et al., 2020). The overall extraction procedure is illustrated in Figure 2.



Figure 2: Schematic illustration of solvent-based extraction of *A. graveolens* and *F. vulgare* seed powders using acetone, ethanol, hexane, and distilled water

Total phenolic content (TPC)

Total phenolic content was measured using the Folin-Ciocalteu (FC) colorimetric method as outlined by Ghafar et al. (2017) and Fatima et al. (2025). The FC reagent was diluted 10-fold with distilled water before use. For each sample, 1 mL of extract was mixed with 2 mL of diluted FC reagent, followed by the addition of 2 mL of 7.5% (w/v) Na_2CO_3 solution. The reaction mixture was incubated in the dark at room temperature for 30 min. Absorbance was measured at 760 nm using a UV-visible spectrophotometer. Total phenolic content was expressed as mg gallic acid equivalents per gram dry weight (mg GAE/g DW).

DPPH radical scavenging assay

The DPPH radical scavenging assay was performed to evaluate the antioxidant activity of the seed extracts according to the methods described by Atique et al. (2026) and Fejer et al. (2021). Various concentrations of each extract (100-500 μL) were mixed with 3 mL of 0.004% DPPH solution prepared in methanol. The mixtures were incubated in the dark at 27 °C for 20 min, and absorbance was recorded at 517 nm using a UV-visible spectrophotometer. Radical scavenging activity (RSA) was calculated using the following equation:

$$\text{Radical Scavenging Activity (\%)} = \frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \times 100$$

Where:

A_{control} = absorbance of the DPPH control (without extract)

A_{sample} = absorbance of the reaction mixture with extract

Ferric reducing antioxidant power (FRAP) assay

The FRAP assay was conducted to determine the reducing power of the seed extracts. The FRAP

reagent was freshly prepared by mixing 10 volumes of 300 mM sodium acetate buffer (pH 3.7), 1 volume of 10 mM 2,4,6-tripyridyl-s-triazine

(TPTZ) solution in 40 mM HCL, and 1 volume of 0.020 M ferric chloride ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) in a ratio of 10:1:1, following the procedure demonstrated by Sharma et al. (2024) and Patil et al. (2025). Approximately 25 mg of dried extract was dissolved in methanol, and 200 μL of FRAP reagent was added to each test tube. The reaction mixture was incubated, and the absorbance was measured at 593 nm using a UV-visible spectrophotometer. after incubation. Antioxidant capacity was expressed as $\mu\text{mol Fe}^{2+}$ equivalents per gram of dry weight ($\mu\text{mol Fe}^{2+}/\text{g DW}$) using a standard calibration curve prepared with ferrous sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$).

In vivo study: Comparative efficacy evaluation

Animal selection and housing conditions

The in vivo efficacy trial was conducted to explore the therapeutic potential of *A. graveolens*

and *F. vulgare* seed powders in ameliorating HFD-induced dyslipidemia in male Wistar albino rats.

Eighteen healthy male Wistar albino rats, aged 4-6 weeks and weighing between 150-190 g, were obtained from the Laboratory Animal House, University of Lahore, Pakistan. All animals were physically examined before the commencement of the experiment to ensure their health status. Rats were acclimatized for one week under standard laboratory conditions, during which they were fed a conventional chow diet to stabilize metabolic parameters. Animals were housed in well-ventilated polypropylene cages under controlled environmental conditions: temperature $22 \pm 2^\circ\text{C}$, relative humidity 40-60%, and a 12-h light/dark cycle. Filtered water was provided ad libitum throughout the study.

Diet formulation

Standard diet composition

Following acclimatization, rats were transitioned to either a standard or experimental diet. The standard diet was prepared with the following composition as shown in Table 1.

Table 1: Standard diet composition administered to experimental rats

Ingredients	Quantity (%)
Corn starch	70
Corn oil	10
Wheat bran	10
Casein protein	5
Mineral mixture	2
Vitamin mixture	1
Cellulose	2.5

The formulation of the standard diet was based on previously published purified diet models used in rodent metabolic studies (Aguilar et al., 2022).

Experimental diet formulation

The high-fat experimental diet was formulated to induce dyslipidemia. Composition of the high-fat and treatment diets is shown in Table 2. Rats were fed a diet enriched with fats, sugar, and

other components to promote dyslipidemia and metabolic impairment, following previously described rodent hyperlipidemia models (Munshi et al., 2014).

Table 2: Experimental diet composition administered to rats

Ingredients	Quantity (%)
Starch	70
Casein	5
Minerals	2
Corn oil	8

Vanaspati ghee	10
Vitamin	1
Carboxymethyl cellulose (CMC)	5
Wheat bran	5
Sugar	10
<i>F. vulgare</i> seed powder	250 mg, 500mg
<i>A. graveolens</i> seed powder	250mg, 500mg

Experimental design

Eighteen male Wistar albino rats were randomly assigned to six groups (n=3 per group). All groups except the normal control were fed an HFD for

one week to induce dyslipidemia. Subsequently, treatment with sowa/dill or fennel seed powders was administered according to the group design as shown in Figure 3.

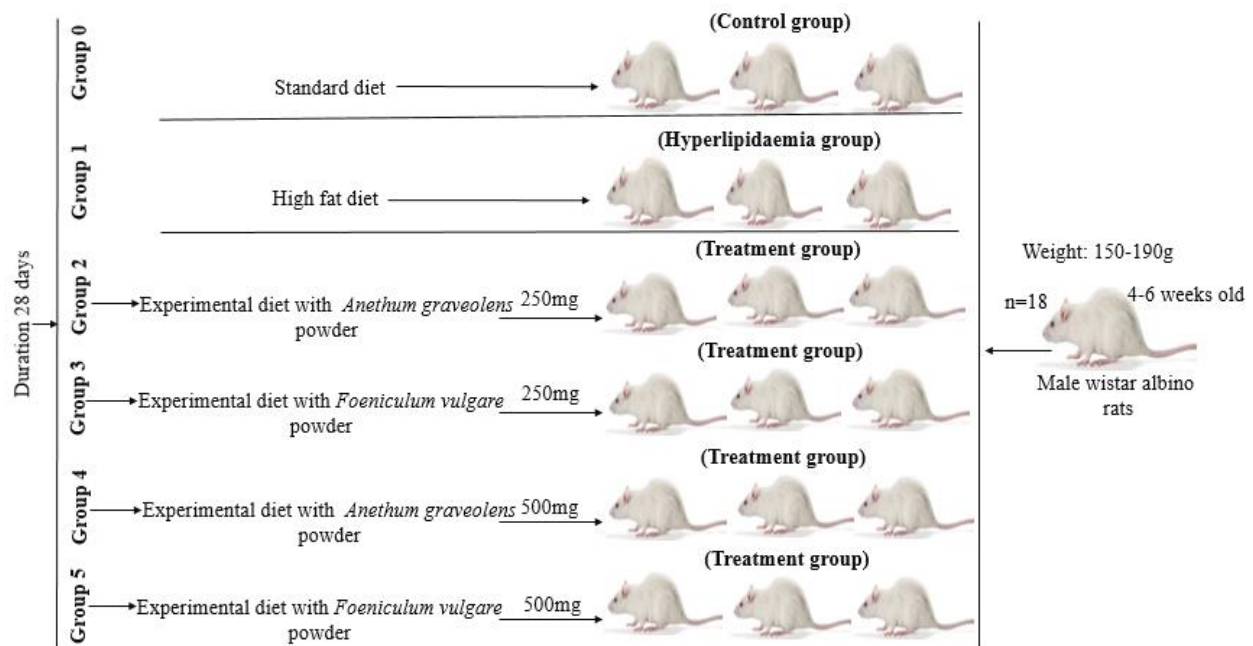


Figure 3: Experimental design for evaluating the effects of fennel and sowa/dill seed powders on dyslipidemia in Wistar albino rats

Feed intake, water consumption, and body weight were monitored regularly throughout the experimental period to monitor the animals' response to dietary interventions.

Physical monitoring and organ weight assessment

The nutritional and physiological status of the experimental animals was monitored throughout the study. Body weights were recorded weekly

using a digital precision balance, while daily feed and water intake were measured by calculating the difference between the amount provided and the leftover. General health and behavior of the rats were observed daily as qualitative indicators of well-being. At the end of the experimental period, rats were humanely euthanized following institutional ethical guidelines. Internal organs, including the heart, liver, kidneys, and spleen, were excised, freed of adherent tissues, and weighed individually. Relative organ weights were calculated as a percentage of total body weight to assess physiological responses and potential toxicological effects of the treatments.

Blood collection and sample preparation

At the end of the 28-day experimental period, blood sample were collected from the animals under chloroform-induced anesthesia via cardiac puncture, following the modified procedure outlined by Fagbohun et al. (2020). Collected samples were placed into two types of tubes: EDTA-coated tubes for hematological analysis and serum separator tubes for biochemical evaluation. Serum was isolated by centrifugation at 4200 rpm for 10 min and stored at -20 °C until further analysis.

Biochemical and hematological analysis

Biochemical parameters were analyzed as described by Al-Dedah et al. (2023) and included: lipid profile: total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and very-low-density lipoprotein (VLDL). Liver function enzymes: alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP), and bilirubin. Serum proteins: albumin, globulin, and total protein. Haematological parameters were determined using standard clinical analyzers as described by Shehri (2017) and included: hemoglobin (Hb), red blood cell count (RBC), white blood cell count (WBC), hematocrit (HCT), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), and mean corpuscular volume (MCV). These measurements were used to evaluate the

hematological impact of each therapeutic intervention.

Statistical analysis

Experimental data were analyzed using a completely randomized design and one-way analysis of variance (ANOVA) (Murid et al., 2023; Asif et al., 2024). Group means were compared using least significant difference tests to determine significant differences among treatments. Differences were considered statistically significant at $p < 0.05$. All statistical analyses were performed using Statistix 8.1 software (Analytical Software, USA).

1- Results and Discussion

Proximate composition

Table 3 shows the proximate composition of *A. graveolens* (sowa) and *F. vulgare* (fennel) seed powders. The findings revealed that sowa powder exhibited significantly ($p < 0.05$) higher levels of fat, fiber, and protein compared to fennel. Specifically, the fat content in sowa was $17.50 \pm 0.10\%$, which was 69.73% higher than that in fennel ($10.31 \pm 0.04\%$). Similarly, the fiber content of sowa increased by 31.37%, and protein content was approximately 47.80% higher than in fennel. These enhancements highlight the nutrient-dense nature of sowa seeds, particularly their lipid and protein profiles. In contrast, fennel showed significantly ($p < 0.05$) higher moisture, ash, and nitrogen-free extract (NFE) contents. Moisture content in fennel was $7.83 \pm 0.03\%$, slightly higher than sowa ($7.64 \pm 0.04\%$), while ash content was elevated by 50.07% which, showing a greater mineral density. NFE, representing total carbohydrates, was also 33.44% higher in fennel compared to sowa. These outcomes are consistent with previous findings by Zulfiqar (2019), and underscore the potential utilization of both seed powders in functional food development.

A significant difference was also observed in the mineral composition of the two seeds. Fennel possessed the highest concentration of lead (50.78 mg/100 g), followed by iron (49.20 mg/100 g) and zinc (39.47 mg/100 g), while cadmium was present in the lowest level (0.12

mg/100 g). Conversely, sowa was particularly rich in iron (273.50 mg/100 g), significantly exceeding the iron contents of fennel. However, the zinc and lead levels in sowa were comparatively lower at (14.76 mg/100 g and 16.06 mg/100 g, respectively), with cadmium detected at 2.09 mg/100 g. The high iron content in sowa aligns

with the findings of Saleh-e-In et al. (2017), who reported elevated iron levels (206.88 mg/kg) in dill seeds. Overall, both seeds are good sources of essential minerals, with sowa being especially rich in iron, whereas fennel provides higher levels of zinc and lead, indicating complementary nutritional mineral profiles.

Table 3: Proximate and mineral composition of *Anethum graveolens* (sowa) and *Foeniculum vulgare* (fennel) seed powders

Herbal plants	Moisture (%)	Fat (%)	Fiber (%)	Protein (%)	Ash (%)	Carbohydrates (%)	Zn (mg/100g)	Fe (mg/100g)	Cd (mg/100g)	Pb (mg/100g)
Sowa	7.64±0.04	17.50±0.10	25.15±0.13	17.53±0.25	7.59±0.04	29.58±0.14	14.76±0.41	273.50±2.85	2.09±0.06	16.06±0.58
Fennel	7.83 ± 0.03	10.31±0.04	19.14±0.04	11.86 ± 0.02	11.39 ± 0.04	39.47±0.08	39.47±0.60	49.20±1.12	0.12±0.01	50.78±1.03

Antioxidant activity

The antioxidant potential of sow and fennel powders varied significantly ($p < 0.05$) depending on the solvent used, as shown in Table 4. TPC of fennel was highest in the hexane extract (176.86 mg GAE/g), showing a 51.7%, 55.2%, and 89.1% increase over the ethanol, methanol, and water extracts, respectively. Notably, the fennel hexane TPC was approximately 2.78-fold higher than that of sowa, suggesting stronger phenolic-mediated antioxidant potential. FRAP also showed a significant difference. Sowa indicated the highest FRAP in hexane (903.67 µg Fe/g), which was 196.2%, 66.6%, and 68.5% greater than ethanol, methanol, and water extracts, respectively. In contrast, fennel's ethanol extract exhibited the highest FRAP (721.30 µg Fe/g), showing its methanol, water,

and hexane extracts by 27.6%, 44.3%, and 30.1%, respectively. DPPH radical scavenging activity showed that fennel revealed maximum activity in methanol (98.13%), which was 4.2% higher than ethanol, 35.8% than hexane, and 45.9% than water extracts, respectively. Conversely, sowa demonstrated the highest DPPH activity in water (89.82%), representing an 11% higher than ethanol, 17.1% than hexane, and 28.6% than methanol extracts, respectively. These outcomes align with Mehra et al. (2022) and Ahmed et al. (2019), indicating that fennel extracts, particularly in methanol, show higher antioxidant activity, while sowa aqueous extracts also possess substantial activity, likely due to water-soluble compounds such as carvone and dillapiol (Singh et al., 2017).

Table 4: Antioxidant activity of *Anethum graveolens* and *Foeniculum vulgare* seed powders extracts

Solvents	Herbal plants	TPC (mg GAE/g)	FRAP (µg Fe/g)	DPPH (%)
Water	Sowa/Dill	14.51 ± 0.068 ^s	521.99 ± 1.496 ^f	89.820 ± 0.103 ^c
	Fennel	19.21 ± 0.168 ^f	535.89 ± 1.398 ^e	67.273 ± 4.233 ^g
Hexane	Sowa/Dill	63.68 ± 0.091 ^d	903.67 ± 0.1549 ^a	76.730 ± 0.103 ^e
	Fennel	176.86 ± 0.962 ^a	499.14 ± 1.014 ^g	72.244 ± 0.103 ^f
Methanol	Sowa/Dill	8.94 ± 0.167 ^h	574.41 ± 1.6006 ^c	69.810 ± 0.014 ^f
	Fennel	79.14 ± 0.043 ^c	565.31 ± 0.1828 ^d	98.134 ± 0.125 ^a
Ethanol	Sowa/Dill	56.37 ± 2.029 ^e	305.00 ± 2.9325 ^h	81.022 ± 0.076 ^d
	Fennel	116.55 ± 0.269 ^b	721.30 ± 1.2338 ^b	94.194 ± 0.526 ^b

Functional properties

Table 5 summarizes the functional characteristics of *A. graveolens* and *F. vulgare* seed powders. Significant differences ($p < 0.05$) were observed across most measured parameters. Water Absorption Capacity (WAC) of sowa powder ($82.72 \pm 1.40\%$) was 17.7% higher compared to fennel ($70.28 \pm 0.95\%$), revealing a stronger hydrophilic nature and better water-binding ability. Emulsifying Stability (ES) was also greater in sowa ($71.42 \pm 1.35\text{m}^2/\text{g}$), showing a 7.0% increase over fennel ($66.76 \pm 0.5\text{m}^2/\text{g}$), suggesting more stable emulsion stability. Similarly, Emulsifying Activity (EA) was 15.5% higher in sowa ($81.72 \pm 1.20\text{m}^2/\text{g}$) compared to fennel ($70.80 \pm 0.48\text{m}^2/\text{g}$), likely due to higher protein or mucilage content enhancing interfacial film formation. Oil Absorption Capacity (OAC) of sowa ($70.33 \pm 1.23\%$) exceeded that of fennel ($60.84 \pm 0.03\%$) by 15.6%, indicating better fat retention potential, which can improve flavor

retention and texture in food formulations. In contrast, Bulk Density (BD) was lower in fennel ($63.58 \pm 1.18\text{g}/\text{cm}^3$) than sowa ($78.18 \pm 0.86\text{g}/\text{cm}^3$), exhibiting a difference of 18.7%, implying greater compressibility and a potentially larger volume required for packaging. Foaming Activity (FA) was higher in fennel ($76.50 \pm 0.70\%$) compared to sowa ($71.15 \pm 0.63\%$), indicating superior aeration capacity, whereas Foaming Capacity (FC) of both powders had statistically similar ($68.92 \pm 0.86\%$), suggesting comparable foam volume and stability. Collectively, these results indicate that sowa seed powder may be more suitable for applications suited for emulsification and water or oil retention, whereas fennel seed powder may be preferred for aeration and light-texture development in food formulations. These responses are consistent with earlier observations by Aćimović et al. (2020).

Table 5: Functional properties of *Anethum graveolens* and *Foeniculum vulgare* seed powders

Powders	WAC (%)	ES (m^2/g)	EA (m^2/g)	OAC (%)	BD (g/cm^3)	FA (%)	FC (%)
Sowa	82.72 ± 1.40^a	71.42 ± 1.35^a	81.72 ± 1.20^a	70.33 ± 1.23^a	78.18 ± 0.86^a	71.15 ± 0.63^b	68.92 ± 0.86^a
Fennel	70.28 ± 0.95^b	66.76 ± 0.54^b	70.80 ± 0.48^b	60.84 ± 0.03^b	63.58 ± 1.18^b	76.50 ± 0.70^a	68.92 ± 0.86^a

Institute for Excellence in Education & Research

Experimental results

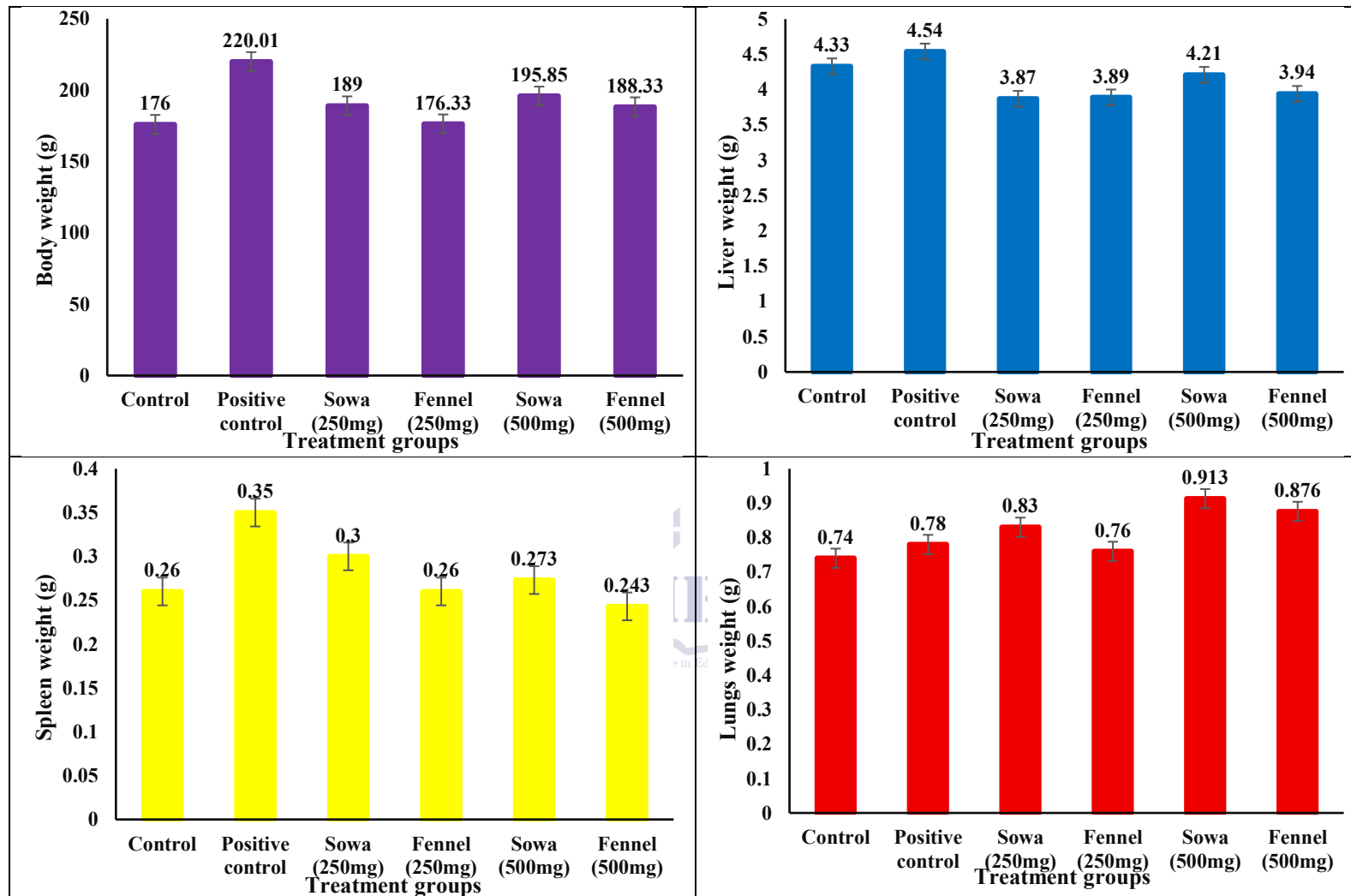
Body and organ weights

Figure 4 illustrates the effects of seed powder supplementation in the experimental diet on body and organ weights in dyslipidemic rats over 28 days. Statistically significant differences ($p < 0.05$) were observed among the treatment groups. The positive control group revealed a 1.25-fold increase in body weight compared to the normal control (220.01 g vs. 176.00 g), indicating weight gain induced by the HFD. Sowa supplementation at 500 mg (195.85 g) showed a 0.89-times reduction compared to the positive control, whereas 250 mg sowa led to (189.00 g) a 0.86-times reduction. Similarly, fennel-treated rats showed notable reductions, with 500 mg fennel (188.33 g) led to a 0.86-times reduction relative to the positive control. Liver weights did not differ significantly among groups. However, sowa 250 mg (3.87 g) and fennel 500 mg (3.94 g) showed slightly reductions relative to the positive

control (4.54 g), suggesting potential mild hepatoprotective effects. Kidney weights varied with treatments. The right kidney weight was lowest in the sowa 250 mg group (0.326 g) and highest in the sowa 500 mg group (0.480 g), representing a 0.67-times reduction. For the left kidney, the positive control showed the highest weight (0.45 g), while sowa 250 mg (0.380 g) and fennel 250 mg (0.37 g) demonstrated 0.84-times and 0.82-times reductions, respectively. Spleen weights were also significantly varied. The positive control group possessed the highest weight (0.35 g), whereas fennel 500 mg (0.243 g) and fennel 250 mg (0.26 g) showed 0.69-times and 0.74-times reductions, respectively. Sowa 250 mg (0.30 g) exhibited a 0.85-times reduction, suggesting possible immunomodulatory effects. Lung weights increased with supplementation. Sowa 500 mg (0.913 g) showed a 1.14-times increase relative to the fennel 250 mg group (0.800 g), while fennel 500 mg (0.876 g) showed a

1.09-times increase. Overall, the outcomes align with previous reports by Al-Amoudi (2017) and Luaibi et al. (2017), who reported that fennel

supplementation can improve organ function under metabolic stress conditions in rats.



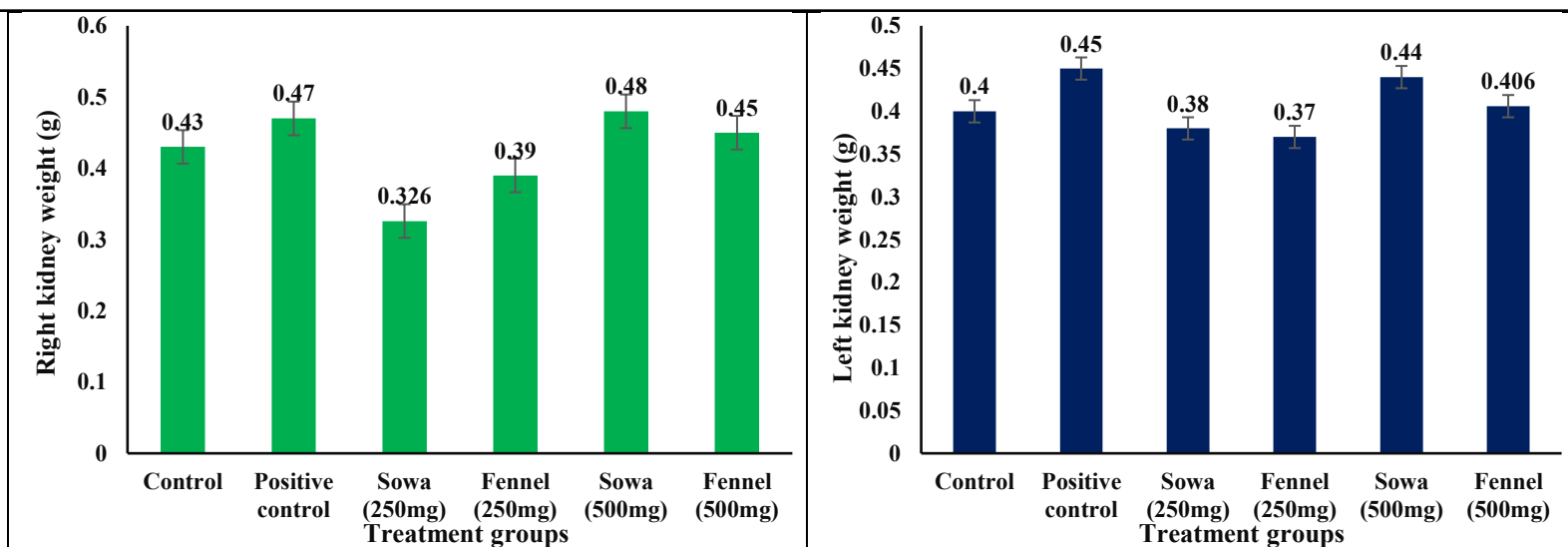


Figure 4: Comparative effects of *A. graveolens* and *F. vulgare* supplementation on body and organ weights

Lipid profile

Table 6 demonstrates statistically significant differences ($p < 0.05$) among the treatment groups for serum glucose and lipid profiles. The positive control group showed elevated glucose and dyslipidemic alterations, revealing metabolic impairment and insulin resistance. Supplementation with both seed powders modulated the lipid profile; however, *F. vulgare* indicated more consistent and pronounced improvements across most indices. A remarkable reduction in triglycerides (TG) was observed, with fennel (250 mg) showing the strongest effect (-20.1% vs positive control). Fennel (500 mg) and sowa (250 mg) revealed moderate reductions comparatively (-10.6% and -9.5% , respectively), whereas sowa (500 mg) possessed only a minimal change (-2.9%). Total cholesterol (TC) decreased across all supplemented groups, with the maximum reduction monitored in fennel (250 mg) (-25.7%), followed by fennel (500 mg) (-20.6%) and both sowa doses (-15.5% each). High-density lipoprotein cholesterol (HDL-C) increased significantly following supplementation, particularly in fennel-treated

rats. Fennel (500 mg) induced the highest rise in HDL-C ($+67.3\%$), followed by fennel (250 mg) ($+48.7\%$), sowa (500 mg) ($+43.4\%$), and sowa (250 mg) ($+38.1\%$) compared with the positive control group. Low-density lipoprotein cholesterol (LDL-C) was markedly minimized, with fennel (250 mg) and (500 mg) producing the strongest decreases (-45.9% each). Sowa (500 mg) and (250 mg) reduced LDL-C by -20.5% and -6.9% , respectively. Similarly, very low-density lipoprotein (VLDL) levels declined substantially, with fennel (250 mg/kg) producing the greatest reduction (-53.8%), followed by sowa (250 mg/kg) (-45.6%), fennel (500 mg/kg) (-45.6%), and sowa (500 mg/kg) (-40.6%). Overall, these results confirm that *F. Vulgare*, particularly at 250 mg, exerted notable effects on hypolipidemic activity compared with sowa, indicating its stronger potential to improve lipid metabolism under dyslipidemic conditions. These outcomes are consistent with the findings of Parsaeyan (2016), who also reported significant lipid profile improvements following fennel administration in diabetic rats.

Table 6: Effects of *Anethum graveolens* and *Foeniculum vulgare* powders on lipid profiles in dyslipidemic rats

Serum indices	Control	Positive control	Sowa (250 mg)	Fennel (250 mg)	Sowa (500 mg)	Fennel (500 mg)
Glucose (mg/dL)	106.0±15.1 ^b	120.45±1.63 ^a	107.67±3.80 ^b	139.67±1.53 ^a	112.00±3 ^b	112.33±9.61 ^b

TG (mg/dL)	55.00±2 ^{ab}	60.05±1.68 ^a	54.33±4.51 ^{ab}	48.00±1 ^b	58.33±2.52 ^a	53.66±2.90 ^{ab}
TC (mg/dL)	47.33±6.42 ^a	52.07±2.45 ^a	44.00±1 ^a	38.66±2.10 ^a	44.00±3 ^a	41.33±7.10 ^a
HDL (mg/dL)	16.66±4.93 ^a	12.55±1.04 ^b	17.33±1.53 ^b	18.66±1.53 ^b	18.00±1 ^a	21.00±2 ^{ab}
LDL (mg/dL)	13.00±1 ^{bc}	19.70±1.62 ^a	18.33±0.60 ^a	10.66±2.10 ^c	15.66±1.20 ^{ab}	10.66±1.53 ^c
VLDL (mg/dL)	11.66±1.53 ^a	20.21±1.09 ^a	11.00±1 ^a	9.33±1.53 ^a	12.00±1 ^a	11.00±1 ^a

Hematological indices

Table 7 shows that hematological parameters serve as essential biomarkers for detecting systemic disturbances. In these parameters, significant differences ($p < 0.05$) were observed in RBC count, hemoglobin (Hb), hematocrit (HCT), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC) across all treatment groups. The RBC count in dyslipidemic rats increased by 1.14-times compared to the normal control (7.52 vs. 6.58 million/ μ L), possibly due to abnormal stimulation of erythropoietin secretion under metabolic stress. However, RBC levels were reduced with treatment. Fennel 250 mg showed a 0.90-times reduction, sowa 500 mg a 0.95-times reduction, sowa 250 mg a 0.95-times reduction, and fennel 500 mg a 0.97-times reduction compared to the dyslipidemic group. Hemoglobin levels declined in dyslipidemic rats by 0.91 times compared to the control (12.52 g/dL vs. 13.81 g/dL), likely due to inflammation and compromised bone marrow function. Treatment improved Hb levels. Sowa 250 mg and 500 mg resulted in 1.05 and 1.01-times increases, respectively, while fennel 250 mg and 500 mg showed 0.98 and 1.00-times

increases, respectively, compared to the dyslipidemic group. Hematocrit (HCT) and mean corpuscular volume (MCV) were elevated in the dyslipidemic group but decreased with supplementation. The HCT value was reduced by 0.89-times in fennel 250 mg and 0.9 times in sowa 500 mg. Likewise, MCV decreased by 0.94-times in fennel 250 mg and 0.92-times in sowa 500 mg groups compared to the dyslipidemic rats. MCH showed a mild increase in the dyslipidemic group but declined post-treatment in all groups except fennel 250 mg, where it remained elevated (19.10 picograms per cell (pg)). MCHC values increased in the dyslipidemic group but showed a slight reduction (0.97-0.99 times) in treated groups, although still slightly higher than the normal control. These hematological improvements reflect the potential of fennel and sowa seed powders in restoring blood indices disrupted by hyperlipidemia. The observed effects may be attributed to the antioxidant and anti-inflammatory constituents, particularly polyphenols, present in these medicinal seeds. This aligns with findings by Mansouri et al. (2015) and Qasim et al (2022), who reported similar hematological and blood serum modulation in rats treated with fennel.

Table 7: Effects of *Anethum graveolens* and *Foeniculum vulgare* powders on lipid profiles in dyslipidemic rats

Blood indices	Control	Positive control	Sowa (250 mg)	Fennel (250 mg)	Sowa (500 mg)	Fennel (500 mg)
RBCs ($10^6/\mu$ L)	6.53±0.40 ^b	7.52±0.73 ^a	7.14±0.29 ^{ab}	6.79±0.03 ^{ab}	7.11±0.22 ^{ab}	7.31±0.33 ^a
Hb (g/dL)	13.81±1.42 ^a	12.52±1.05 ^a	12.66±0.28 ^a	12.53±0.32 ^a	13.13±0.25 ^a	12.26±0.35 ^a
HCT (%)	33.5±2.80 ^a	39.61±0.98 ^c	35.86±2.59 ^a	35.78±1.96 ^a	38.12±0.92 ^a	35.90±3.69 ^a
MCV (fL)	52.3±1.52 ^a	54.35±1.02 ^a	51.33±2.30 ^a	53.00±1 ^a	51.00±2 ^a	51.33±1.52 ^a
MCH (pg)	17.1±1.04 ^a	18.38±1.08 ^a	17.80±0.56 ^a	19.10±1.2 ^a	18.60±1.08 ^a	16.93±0.71 ^a
MCHC (g/dL)	34.1±0.61 ^a	36.41±2.02 ^a	35.53±0.74 ^a	36.13±2.01 ^a	36.30±2.31 ^a	36.16±1.72 ^a

Serum proteins

Significant differences ($p < 0.05$) were observed in the serum proteins, as shown in Table 8. Compared to the control group, the dyslipidemic group showed a 1.29-times increase in total protein levels, indicating systemic inflammation and insulin resistance. However, treatment with fennel and sowa at 500 mg led to 0.86-times reductions in total protein levels, while fennel and sowa at 250 mg showed 0.87 and 0.7-times reductions, respectively. Serum albumin levels also declined in all treated groups. The greatest reduction, a 0.83-times decrease, was observed in the sowa 250 mg, indicating improved inflammatory control. Globulin levels varied:

sowa 500 mg showed a 0.85 times reduction compared to the dyslipidemic group, while fennel 500 mg and sowa 250 mg) showed 1.35 and 1.07-times increases, respectively. The albumin/globulin (A/G) ratio, which had decreased to 0.63 in the dyslipidemic group, improved with treatment. Fennel 500 mg increased the A/G ratio by 2.57-times, while sowa 250 mg resulted in a 1.22 times increase. These results suggest that both sowa and fennel powders exert hepatoprotective and anti-inflammatory effects, with fennel showing more favorable modulation of serum protein fractions. These findings are consistent with the results reported by Helal et al. (2019).

Table 8: Effects of *Anethum graveolens* and *Foeniculum vulgare* powders on serum proteins in dyslipidemic rats

Serum indices	Control	Positive Control	Sowa (250 mg)	Fennel (250 mg)	Sowa (500 mg)	Fennel (500 mg)
Total protein (g/dL)	3.38±0.16 ^{ab}	4.36±0.02 ^d	3.23±0.21 ^b	3.73±0.21 ^a	3.73±0.15 ^a	3.73±0.15 ^a
Albumin (g/dL)	3.16±0.50 ^a	3.23±0.53 ^d	2.93±0.15 ^a	2.60±0.2 ^a	2.733±0.15 ^a	2.70±0.1 ^a
Globulin (g/dL)	2.20±0.30 ^a	2.29±0.06 ^a	2.10±0.1 ^a	2.10±0.2 ^a	1.96±0.60 ^a	2.66±0.15 ^a
A/G ratio	1.00±0.5 ^{ab}	0.63±0.04 ^c	0.77±0.112 ^b	0.90±0.2 ^{ab}	1.40±0.3 ^{ab}	1.62±0.10 ^a

Liver functions

Table 9 summarizes hepatic function biomarkers in dyslipidemic groups following supplementation with *A. graveolens* and *F. vulgare* seed powders. The positive control group indicated elevated hepatic markers, showing liver sunder dyslipidemic conditions. Serum bilirubin increased markedly in the positive control group compared with the normal control (1.30 vs. 0.26 mg/dL). Supplementation with both seed powders significantly reduced bilirubin levels, with the strongest reductions observed in sowa (250 mg) (−76.9%) and fennel (250 mg) (−72.3%) relative to the positive control. Fennel (500 mg) also lowered bilirubin substantially (−74.6%), whereas sowa (500 mg) produced a comparatively smaller reduction (−61.5%). Alanine aminotransferase (ALT) showed variable responses across treatments. ALT remained comparable to the positive control in sowa (250 mg), whereas it increased markedly in sowa (500 mg) (+50.1%) and in both fennel-treated groups,

particularly fennel (250 mg) (+17.6%) and fennel (500 mg) (+34.2%), suggesting a dose-dependent and treatment-specific hepatic response. Similarly, aspartate aminotransferase (AST) was reduced in sowa (250 mg) (−14.7%) and fennel (500 mg) (−14.3%), while fennel (250 mg) resulted in a slight elevation (+3.8%) compared with the positive control. Alkaline phosphatase (ALP) showed the most pronounced divergence between treatments. ALP was markedly elevated in fennel (250 mg) (+65.4%), whereas fennel (500 mg) significantly reduced ALP (−35.9%) relative to the positive control. Both sowa doses produced moderate reductions, with sowa (250 mg/kg) and sowa (500 mg/kg) lowering ALP by −7.9% and −3.2%, respectively. Overall, the findings show that both seed powders exert hepatomodulatory effects; however, the response was biomarker- and dose-dependent. Sowa (250 mg) demonstrated more consistent normalization of bilirubin and AST, while fennel (500 mg) showed the greatest overall improvement in bilirubin and ALP. These results are consistent with Samadi Noshahr et al.

(2021), Shawky et al. (2020), Shnain & Ezzat (2022), Oshaghi et al. (2017), and Naderi et al. (2019), describing hepatoprotective effects of

fennel and sowa under metabolic stress conditions.

Table 9: Effects of *Anethum graveolens* and *Foeniculum vulgare* powders on liver enzymes in rats

Serum indices	Control	Positive control	Sowa (250 mg)	Fennel (250 mg)	Sowa (500 mg)	Fennel (500 mg)
Bilirubin (mg/dL)	0.26±0.10 ^a	1.30±0.04 ^a	0.30±0.1 ^a	0.36±0.21 ^a	0.50±0.01 ^a	0.33±0.10 ^a
ALT (U/L)	43.33±3.10 ^a	48.17±0.15 ^a	48.33±2.10 ^{cd}	56.66±5.03 ^{bc}	72.33±3.10 ^a	64.66±2.52 ^{ab}
AST (U/L)	153.33±45.10 ^a	180.12±0.22 ^a	153.67±5.686 ^a	187.00±2 ^a	176.00±1 ^a	154.33±0.577 ^a
ALP (U/L)	133.00±19.16 ^c	183.13±4.40 ^a	168.67±1.53 ^b	303.00±2.00 ^a	177.33±1.53 ^b	117.33±1.53 ^b

2- Conclusion

This study demonstrated that both *A. graveolens* (sowa) and *F. vulgare* (fennel) seed powders

possess significant effects in a dyslipidemic rat model, including modulation of lipid metabolism, improvement in antioxidant activity, favorable changes in hematological indices, and partial normalization of hepatic and systemic biomarkers. Overall, fennel supplementation at the 500 mg dose consistently showed significant improvements in lipid profile indices, particularly reductions in triglycerides, total cholesterol, LDL-C, and VLDL, along with a marked elevation in HDL-C, revealing stronger antihyperlipidemic potential compared with sowa. Notably, the extent of response varied by dose and biomarker. While fennel showed superior overall performance, especially for lipid-related outcomes. While sowa also exhibited therapeutic potential, particularly at a 250 mg, dose for specific hepatic and renal biomarkers. Collectively, these comparative findings highlight fennel as a potential natural dietary ingredient for intervention for mitigating hyperlipidemia-associated metabolic disturbances likely due to the combined and synergistic actions of its bioactive constituents. Moreover, the synergistic action of its bioactive constituents may offer broader therapeutic benefits. From a perspective, the functional and nutritional characteristics of both seed powders further support their suitability for incorporation into functional foods or nutraceutical formulations aimed at improving

cardiovascular and metabolic health. These outcomes suggest that fennel seed powder, especially at higher doses, could be strategically incorporated into dietary interventions or nutraceutical formulations aimed at cardiovascular and metabolic health improvement.

Funding

This research received no external funding.

Acknowledgments

We are thankful to National Institute of Food Science and Technology, University of Agriculture, Faisalabad for providing research facilities.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

5-REFERENCES

- Aćimović, M. G., Dojčinović, B., & Stojanović-Radić, Z. (2014). Functional properties of Apiaceae plants: Coriandrum, dill, cumin, fennel, anise and caraway. *Journal of Food Science and Technology*, 51, 240–248.

- Aguiar, L. M., Moura, C. S. de, Ballard, C. R., Roquette, A. R., Maia, J. K. da S., Duarte, G. H. B., Costa, L. B. E. da, Torsoni, A. S., Amaya-Farfan, J., Maróstica Junior, M. R., & Cazarin, C. B. B. (2022). Metabolic dysfunctions promoted by AIN-93G standard diet compared with three obesity-inducing diets in C57BL/6J mice. *Current Research in Physiology*, 5, 436–444. <https://doi.org/10.1016/j.crphys.2022.11.001>
- Ahmed, A. F., Shi, M., Liu, C., & Kang, W. (2019). Comparative analysis of antioxidant activities of essential oils and extracts of fennel (*Foeniculum vulgare* Mill.) seeds from Egypt and China. *Journal of Food Science and Human Wellness*, 8, 67–72.
- Al-Amoudi, W. M. (2017). Protective effects of fennel oil extract against sodium valproate-induced hepatorenal damage in albino rats. *Saudi Journal of Biological Sciences*, 24, 915–924.
- Al-Dedah, R. M., Al-Ghanimi, H. H., Mashrea, D. S., & Alnasawi, T. H. (2023). Evaluation of haematological and biochemical parameters and lipid profile in patients with type 2 diabetes mellitus in Kerbala holy city. In *2nd International Conference on Engineering and Advanced Technology (ICEAT 2022)* (Vol. 2787, p. 090028).
- Alotaibi, B. S., Ijaz, M., Buabeid, M., Kharaba, Z. J., Yaseen, H. S., & Murtaza, G. (2021). Therapeutic effects and safe uses of plant-derived polyphenolic compounds in cardiovascular diseases: A review. *Drug Design, Development and Therapy*, 15, 4713–4732.
- Al-Sheddi, E. S., Al-Zaid, N. A., Al-Oqail, M. M., Al-Massarani, S. M., El-Gamal, A. A., & Farshori, N. N. (2019). Evaluation of cytotoxicity, cell cycle arrest and apoptosis induced by *Anethum graveolens* L. essential oil in human hepatocellular carcinoma cell line. *Saudi Pharmaceutical Journal*, 27, 1053–1060.
- Anka, Z. M., Gimba, S., Nanda, A., & Salisu, L. (2020). Phytochemistry and pharmacological activities of *Foeniculum vulgare*. *IOSR Journal of Pharmacy*, 10, 1–10.
- Asif, M., Khan, M. K. I., Khan, M. I., Maan, A. A., Helmick, H., & Kokini, J. L. (2023). Effects of citrus pomace on mechanical, sensory, phenolic, antioxidant, and gastrointestinal index properties of corn extrudates. *Journal of Food Biosciences*, 55, 103012.
- Asif, M., Khan, M. K. I., Khan, M. I., & Maan, A. A. (2024). Effect of citrus pomace and chickpea on physicochemical, biofunctional and organoleptic properties of corn extrudates. *Journal of Tianjin University Science and Technology*, 57, 49–65.
- Asif, M., Abbas, M., Fatima, K., Ahmad, N., Ahmed, S., Meghwar, P., Hosseini, E., Nasir, A., & Hassan, S. A. (2025a). Innovative corn extrudates incorporating barley-oat flour blends: Nutritional, functional, and sensory evaluation. *Applied Food Research*, 100812.
- Asif, M., Maan, A. A., Nazir, A., Khan, M. I. M., & Khan, M. K. I. (2025b). Effect of chickpea on the physicochemical, nutritional, antioxidant, and organoleptic characterization of corn extrudates. *Journal of the Science of Food and Agriculture*, 105, 2059–2067.
- Atique, Z., Aftab, M., Usman, A., Ahmed, S., Faryad, A., Sultan, M., Almas, B., Fatima, K., & Asif, M. (2026). Fabrication and characterization of granola bar supplemented with flaxseed and banana peel powder for compositional, biofunctional, and sensorial attributes. *Policy Research Journal*, 4, 233–242.
- Awuchi, C. G. (2019). Medicinal plants: The medical, food, and nutritional biochemistry and uses. *International Journal of Advanced Academic Research*, 5, 220–241.
- Awuchi, C. G., Igwe, V. S., & Echeta, C. K. (2019). The functional properties of foods and flours. *International Journal of Advanced Academic Research*, 5, 139–160.

- Basit, A., Askari, S., Zafar, J., Riaz, M., Fawwad, A., & NDSP Members. (2021). NDSP 06: Prevalence and risk factors for obesity in urban and rural areas of Pakistan: A study from second National Diabetes Survey of Pakistan (NDSP), 2016–2017. *Obesity Research & Clinical Practice*, 15, 19–25.
- Chahal, K. K., Kumar, A., Bhardwaj, U., & Kaur, R. (2017). Chemistry and biological activities of *Anethum graveolens* L. (dill) essential oil: A review. *Journal of Pharmacognosy and Phytochemistry*, 6, 295–306.
- Chandra, S., & Samsher. (2013). Assessment of functional properties of different flours. *African Journal of Agricultural Research*, 8(38), 4849–4852. <https://doi.org/10.5897/AJAR2013.6905>
- Chandra, S., Singh, S., & Kumari, D. (2015). Evaluation of functional properties of composite flours and sensorial attributes of composite flour biscuits. *Journal of Food Science and Technology*, 52(6), 3681–3688. <https://doi.org/10.1007/s13197-014-1427-2>
- Das, L., Bhaumik, E., Raychaudhuri, U., & Chakraborty, R. (2012). Role of nutraceuticals in human health. *Journal of Food Science and Technology*, 49, 173–183.
- Dheebisha, C., & Vishwanath, Y. C. (2020). Advances in cultivation of fennel. *Journal of Pharmacognosy and Phytochemistry*, 9, 1295–1300.
- Domínguez Díaz, L., Fernández-Ruiz, V., & Cámara, M. (2020). The frontier between nutrition and pharma: The international regulatory framework of functional foods, food supplements and nutraceuticals. *Critical Reviews in Food Science and Nutrition*, 60, 1738–1746.
- Du, H., Shi, Q., Song, P., Pan, X. F., Yang, X., Chen, L., & Li, S. (2022). Global burden attributable to high LDL-C from 1990 to 2019. *Frontiers in Cardiovascular Medicine*, 9, 1327.
- Erb, M., & Kliebenstein, D. J. (2020). Plant secondary metabolites as defenses, regulators, and primary metabolites: The blurred functional trichotomy. *Journal of Plant Physiology*, 18, 39–52.
- Fagbohun, O. F., Awoniran, P. O., Babalola, O. O., Agboola, F. K., & Msagati, T. A. M. (2020). Changes in biochemical, hematological and histopathological parameters in STZ-induced diabetic rats and the ameliorative effect of *Kigelia africana* fruit extract. *Heliyon*, 6, e03989.
- Fatima, K., Asif, M., Hassan, S. A., Naveed, M., Alvi, T., & Abbas, M. (2025). Fabrication and characterization of protein fortified corn extrudates for nutritional, bio-functional, structural and organoleptic properties. *Food Biophysics*, 20, 1–12.
- Fejér, J., Kron, I., Grulova, D., & Eliášová, A. (2021). In vitro antioxidant activity of two different extracts of *Moringa oleifera* leaves from Caribbean St. Lucia Island. *Acta Horticulturae*, 1306, 143–148.
- Ghafar, F., Nazrin, T. T. N. N., Salleh, M., Hadi, N. N., Ahmad, N., Hamzah, A. A., et al. (2017). Total phenolic content and total flavonoid content in *Moringa oleifera* seed. *Galeri Warisan Sains*, 1, 23–25.
- Halder, S., Anand, U., Nandy, S., Oleksak, P., Qusti, S., Alshammari, E. M., & Dey, A. (2021). Herbal drugs and natural bioactive products as potential therapeutics: A review on pro-cognitives and brain boosters' perspectives. *Saudi Pharmaceutical Journal*, 29, 879–907.
- Hamza, L. F. (2017). *Anethum graveolens*: Physicochemical properties, medicinal uses, antimicrobial effects, antioxidant effect, anti-inflammatory and analgesic effects: A review. *World Journal of Pharmaceutical and Pharmaceutical Sciences*, 5, 1–7.

- Hassan, N., Wang, D., Shuaib, M., Zhong, Z., Nisar, M., Ahmad, W., Ahmad, & Khan, A. (2017). Identification and ethnobotanical survey of profitable medicinal plants used as remedy in Sangina, Pakistan. *International Journal of Herbal Medicine*, 5, 117-123.
- Helal, E. G., Al Jalaud, N. A. A., El-Aleem, M. A., & Ahmed, S. S. (2019). Effect of phytoestrogen (fennel) on some sex hormones and other physiological parameters in male albino rats. *Egyptian Journal of Hospital Medicine*, 74, 1616-1620.
- Ijaz, S., Perveen, A., & Ashraf, S. (2022). Anthropogenic threats and their impact assessment on medicinal flora of western Himalaya-Neelum Valley (Azad Jammu and Kashmir). *Pakistan Journal of Botany*, 54, 1827-1839.
- Iqbal, Z., Aftab, A., Swar, S. O., Hussain, R., & Mohiuddin, M. (2022). Determination of lipid-lowering effect of corn flour in hyperlipidemic albino mice. *Pakistan Veterinary Journal*, 42, 49-53.
- Ismail, N., Elhassaneen, Y. A. E. E., & El Kholey, H. (2024). Effect of Mixing Date Seed Powder with Wheat Flour on the Rheological Parameters, Nutrients, Bioactive Compounds Content, and Antioxidant Activity of the Egyptian Balady Bread. *Alexandria Science Exchange Journal*, 45(3), 455-477. doi: 10.21608/asejaiqjsae.2024.378235
- Jitřreanu, A., Trifan, A., Vieriu, M., Caba, I. C., Mărțu, I., & Agoroaei, L. (2023). Current trends in toxicity assessment of herbal medicines: A narrative review. *Processes*, 11, 83.
- Kaveh, R., Naghmachi, M., Motaghi, M. M., Amirmahani, F., & Danaei, M. (2022). Antibacterial and antioxidant activities and anticancer effects of fennel seeds (*Foeniculum vulgare*) against lung cancer cells. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, 92, 1-6.
- Khan, M. S. A., & Ahmad, I. (2019). Herbal medicine: Current trends and future prospects. In *New Look to Phytomedicine* (pp. 3-13). Academic Press.
- Khan, S., Ur Rehman, T., Mirza, B., Ul Haq, I., & Zia, M. (2017). Antioxidant, antimicrobial, cytotoxic and protein kinase inhibition activities of fifteen traditional medicinal plants from Pakistan. *Pharmaceutical Chemistry Journal*, 51, 391-398.
- Lin, C. F., Chang, Y. H., Chien, S. C., Lin, Y. H., & Yeh, H. Y. (2018). Epidemiology of dyslipidemia in the Asia Pacific region. *International Journal of Gerontology*, 12, 2-6.
- Liu, S. P., Zhang, Z. Q., & Liu, G. Y. (2018). Research progress of traditional Chinese medicine for reducing blood lipid. *Health Vocational Education*, 36, 74-75.
- Luaibi, N. M., Al Tamimi, A. A., & Shafiq, A. A. (2017). Physiological and histological effects of fennel seeds (*Foeniculum vulgare*) on kidneys in male rats. *Journal of Pharmaceutical, Chemical and Biological Sciences*, 5, 45-55.
- Mallik, S., Sharangi, A. B., & Sarkar, T. (2020). Phytochemicals of coriander, cumin, fenugreek, fennel and black cumin: A preliminary study. *Proceedings of the National Academy of Sciences, India Section A*, 43, 477-480.
- Mehra, N., Tamta, G., & Nand, V. (2021). A review on nutritional value, phytochemical and pharmacological attributes of *Foeniculum vulgare* Mill. *Journal of Pharmacognosy and Phytochemistry*, 10, 1255-1263.
- Mehra, N., Tamta, G., & Nand, V. (2022). Phytochemical screening and in vitro antioxidant assays in *Foeniculum vulgare* Mill. (fennel) seeds collected from Tarai region in Uttarakhand. *Indian Journal of Natural Products and Resources*, 13, 213-222.

- Munshi, R. P., Joshi, S. G., & Rane, B. N. (2014). Development of an experimental diet model in rats to study hyperlipidemia and insulin resistance, markers for coronary heart disease. *Indian Journal of Pharmacology*, 46(3), 270-276. <https://doi.org/10.4103/0253-7613.132156>
- Murid, M., Khan, M. K. I., Maan, A. A., Asif, M., & Sablani, S. S. (2023). Preferential binding effect of cocoa powder on fried donuts through the electrostatic coating method. *International Journal of Food Science and Technology*, 58, 720-729.
- Naderi, G. A., Roghani, M., Jamaat, E. E., Zahedi, E., & Sanaeirad, A. (2019). The effect of *Foeniculum vulgare* (fennel) hydroalcoholic extract on serum lipid profiles and liver enzymes in male rats fed a high-cholesterol regimen. *Journal of Basic Clinical Pathophysiology*, 7, 20-27.
- Nafees, S., Nafees, H., Nizamudeen, S., & Rather, R. A. (2023). Pharmacological profile of active phytometabolites from traditional medicinal plants. In *Phytohormones and Stress Responsive Secondary Metabolites* (pp. 75-88). Academic Press.
- Najmi, A., Javed, S. A., Al Bratty, M., & Alhazmi, H. A. (2022). Modern approaches in the discovery and development of plant-based natural products and their analogues as potential therapeutic agents. *Molecules*, 27, 349.
- Naqvi, S. N. U. A., Jameel, F., Ahmad, B., Wasi, N., Asif, M., Zaman, M., Yasmeen, T., & Bakar, M. A. (2023). Characterizing the vegetables enriched pasta for nutritional and sensorial attributes. *RADS Journal of Food Biosciences*, 2, 28-33.
- Noorka, I. R., Behnassi, M., Khan, Z. I., Manzoor, E., & Ali, S. S. (2022). Potential of the medicinal flora in Pakistan and the risk of extinction: The need for a conservation strategy. In *The Food Security, Biodiversity, and Climate Nexus* (pp. 267-277). Springer International Publishing.
- Noreen, S., Tufail, T., Badar Ul Ain, H., & Awuchi, C. G. (2023). Pharmacological, nutraceutical, functional and therapeutic properties of fennel (*Foeniculum vulgare*). *International Journal of Food Properties*, 26, 915-927.
- Nwokeke, B. C., Adedokun, I. I., Ekeocha, P. N., & Ekebor, M. F. N. (2025). Effect of processing methods on physical properties of gum extracts from selected legume seeds. *World Journal of Food Science and Technology*, 9(2).
- Oshaghi, E. A., Khodadadi, I., Mirzaei, F., Khazaei, M., Tavailani, H., & Goodarzi, M. T. (2017). Methanolic extract of dill leaves inhibits AGEs formation and shows potential hepatoprotective effects in CCl₄-induced liver toxicity in rat. *Journal of Pharmacy*, 2017, 1-8.
- Parsaeyan, N. (2016). The effect of *Foeniculum vulgare* (fennel) extract on lipid profile, lipid peroxidation and liver enzymes of diabetic rat. *Iranian Journal of Diabetes and Obesity*, 8, 24-29.
- Parvin, R., Muna, F. Z., Jahan, S., Hossain, N., & Sampa, S. R. (2022). The pattern of dyslipidemia and its association with dietary habits in individuals attending BSMMU outpatient department. *Scholar International Journal of Obstetrics and Gynecology*, 5, 247-253.
- Patil, S. A., Pagariya, M. C., Kulkarni, A. J., et al. (2025). Phytochemical insights and antioxidant capabilities of rose cultivars: Implications for traditional medicine and modern industry. *Discover Agriculture*, 3, 23.
- Piché, M. E., Tchernof, A., & Després, J. P. (2020). Obesity phenotypes, diabetes, and cardiovascular diseases. *Circulation Research*, 126, 1477-1500.
- Purva, A., Sharma, K., & Khan, M. S. (2020). A review on dyslipidemia: Types, risk factors and management. *Asian Journal of Pharmaceutical Research and Development*, 8, 96-98.

- Qasim, D., Al-Ghazali, L. H., & Hameed, R. A. (2022). The antioxidant effect of *Anethum graveolens* (dill) on some biochemical parameters in blood serum of male rats. *International Journal of Health Sciences*, 6, 10299–10308.
- Rezq, A. A. (2012). Beneficial health effects of fennel seeds (*shamar*) on male rats fed a high-fat diet. *Medical Journal of Cairo University*, 80, 101–113.
- Research and Markets. (2026). Fennel seeds market – global forecast 2026–2032. 360iResearch. <https://www.researchandmarkets.com>
- Sachdeva, H., Khaturia, S., & Chahar, M. (2022). Nutraceuticals as therapeutic agents for prevention and treatment of diseases. In *Prebiotics, probiotics and nutraceuticals* (pp. 45–68). Springer Nature Singapore.
- Sachdeva, V., Roy, A., & Bharadvaja, N. (2020). Current prospects of nutraceuticals: A review. *Current Pharmaceutical Biotechnology*, 21, 884–896.
- Saleh, E. I. M. M., & Choi, Y. E. (2021). *Anethum sowa* Roxb. ex Fleming: A review on traditional uses, phytochemistry, pharmacological and toxicological activities. *Journal of Ethnopharmacology*, 280, 113967.
- Samadi Noshahr, Z., Hadjzadeh, M. A., Moradi Marjaneh, R., & Khajavi Rad, A. (2021). The hepatoprotective effects of fennel seed extract and trans-anethole in streptozotocin-induced liver injury in rats. *Journal of Food Science and Nutrition*, 9, 1121–1131.
- Sasidharan, D., Namitha, T. R., Johnson, S. P., Jose, V., & Mathew, P. (2020). Synthesis of silver and copper oxide nanoparticles using *Myristica fragrans* fruit extract: Antimicrobial and catalytic applications. *Sustainable Chemistry and Pharmacy*, 16, 100255.
- Sharma, S., Mehmood, Y., Sharma, V., Kumar, A., Kumar, S., & Bhat, Z. (2024). Antioxidant potential of *Tinospora cordifolia*: Insights into its therapeutic significance. *International Journal of Advanced Biochemistry Research*, 8(Special Issue), 425–427. <https://doi.org/10.33545/26174693.2024.v8.i2Sf.616>
- Shawky, S. M., Fathalla, S. I., Zahran, I. S., Gaafar, K. M., Hussein, M. K., & Abu Alya, I. S. (2020). Immunological stimulant effect of linseed oil and fennel oil supplemented diet on broilers. *Advances in Animal and Veterinary Sciences*, 8, 771–776.
- Shehri, Z. S. A. (2017). The relationship between some biochemical and hematological changes in type 2 diabetes mellitus. *Journal of Biomedical Research and Therapy*, 4, 1760–1774.
- Shnain, W. Z., & Ezzat, H. N. (2022). Effect of adding different levels of dill seeds to the diet on physiological traits of broilers. *Iraqi Journal of Market Research and Consumer Protection*, 14, 103–109.
- Siddiq, M., Ravi, R., Harte, J. B., & Dolan, K. D. (2010). Physical and functional characteristics of selected dry bean (*Phaseolus vulgaris* L.) flours. *LWT – Food Science and Technology*, 43, 232–237.
- Singh, S., Das, S., Singh, G., Perotti, M., Schuff, C., & Catalan, C. (2017). Comparative studies of chemical composition, antioxidant and antimicrobial potentials of essential oils and oleoresins obtained from seeds and leaves of *Anethum graveolens* L. *Journal of Toxicology*, 2017, 2–9.
- Singletary, K. W. (2023). Dill: Potential health benefits. *Journal of Nutrition*, 58, 128–136.
- Taroncher, M., Vila-Donat, P., Tolosa, J., Ruiz, M. J., & Rodriguez-Carrasco, Y. (2021). Biological activity and toxicity of plant nutraceuticals: An overview. *Current Opinion in Food Science*, 42, 113–118.

Tsegay, N., Admassu, H., Zegale, B., & Gosu, A. (2024). Nutritional and functional potentials of wheat, cowpea, and yam composite flours on bread formulations: Effect of blending ratio and baking parameters. *Journal of Agriculture and Food Research*, 18, 101294. <https://doi.org/10.1016/j.jafr.2024.101294>

Wen, J., Huang, Y., Lu, Y., & Yuan, H. (2019). Associations of non-high-density lipoprotein cholesterol, triglycerides and the total cholesterol/HDL-C ratio with arterial stiffness independent of low-density lipoprotein cholesterol in a Chinese population. *Hypertension Research*, 42, 1223–1230.

Wikipedia contributors. (2026, February 11). *Medicinal plants*. Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/wiki/Medicinal_plants

World Bank. (2023). *Global trade outlook and economic prospects*. World Bank Publications.

World Health Organization. (2019). *Noncommunicable diseases country profiles 2018*. World Health Organization.

Zahid, T., Nooreen, S., Asif, M., Maqsood, S., Saddiqa, A., Nazar, M., Alvi, T., & Rafiq, M. (2025). Development and characterization of protein-rich cookies fortified with red kidney beans: A nutritional approach to combat malnutrition. *Journal of Pure and Applied Agriculture*, 10, 21–29.

Zamani, S., Fathi, M., Ebadi, M.-T., & Máthé, Á. (2025). Global trade of medicinal and aromatic plants: A review. *Journal of Agriculture and Food Research*, 21, 101910. <https://doi.org/10.1016/j.jafr.2025.101910>

Zulifqar, S. (2019). Influence of *Foeniculum vulgare* Mill. in the management of hyperglycemia. *International Journal of Innovative Science and Research Technology*, 4, 1117–1122.

