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Research article

The protective effects of some herbs on mitigating HFD-induced obesity via enhancing biochemical indicators and fertility in female rats

Ahmed Sabry S. Abdoon [a], Amany M. Hegazy [b], Amal S. Abdel-Azeem [b], Ahmed M. Al-Atrash [c], Dina Mostafa Mohammed [b,*]

[a] Animal Reproduction, Veterinary Research division, National Research Centre, Dokki, Giza, Egypt
[b] Nutrition and Food Sciences Department, National Research Centre, Dokki, Giza, Egypt
[c] Medical Administration, Nuclear Materials Authority, Kattmya, Cairo, Egypt

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ABSTRACT

The potential of plant-based diets and drugs to prevent and control obesity has been attributed to the presence of several biologically active phytochemicals. The study aimed to assess herb consumption's impact on alleviating the risks and hazards associated with obesity induced by a high-fat diet (HFD) and the promotion of fertility. Eighty rats were allocated into four distinct groups. Group 1 (G1) was provided with a basal diet and acted as the control group. Group 2 (G2) was provided with an HFD. Group 3 (G3) was provided with HFD supplemented with chia seeds and Hibiscus sabdariffa L. The fourth group of subjects was provided with HFD supplemented with Foeniculum vulgare (fennel) and Coriandrum sativum L. (coriander). The feeding session was sustained for 10 weeks, and the biochemical parameters were evaluated. The administration of Foeniculum vulgare (fennel) and Coriandrum sativum L. (coriander) (G4) resulted in a more significant reduction in all biochemical parameters compared to G3, which received a diet consisting of chia seeds and Hibiscus sabdariffa L. Additionally, the average number of embryonic lobes and the average number of offspring after birth were found to be considerably more significant in the normal control group (G1) and group (G4) compared to the HFD group (G2) and group (G3) ($P < 0.01$). Group 4 (G4) was administered a diet enriched with Foeniculum vulgare (fennel) and Coriandrum sativum L. (coriander), which demonstrated superior outcomes in many biochemical indicators and the promotion of fertility in obese female rats.

1. Introduction

Obesity is a significant issue within the realm of public health. The terms "overweight" and "obesity" denote the atypical or disproportionate buildup of adipose tissue, which can detrimentally affect an individual's overall well-being. The prevalence of obesity is increasing globally, affecting individuals of all age groups, including youngsters [1,2]. Multiple studies have shown that women with excess weight or obesity had more challenges in achieving pregnancy compared to those with average body weight. Additionally, it should be noted that obese women had a heightened incidence of pregnancy loss after conception. Ovulation, menstruation,

* Corresponding author. Researcher of Biochemistry, Nutrition and Food Sciences Department, National Research Centre, Egypt.
E-mail address: dina_ganna@yahoo.com (D.M. Mohammed).

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implantation, and parturition were examples of reproductive processes often regulated by specific receptor-linked signalling pathways that regulate the synthesis of inflammatory cytokines, chemokines, and lipid mediators [3–5]. The precise management of these signalling pathways is crucial for maintaining proper physiological activities, while any disruption in their oversight may lead to pathophysiological states and illnesses. The alterations above had the potential to impact the regulation of typical reproductive processes, leading to potential disturbances in the menstrual cycle [6].

Additionally, these alterations have been shown to contribute to the development of infertility in individuals with endometriosis, as well as complications such as intrauterine growth restriction and preeclampsia during pregnancy [7]. Furthermore, repeated abortions have been linked to these modifications and preterm birth [8]. Empirical data suggests that obesity can disrupt insulin signalling within the ovary and pituitary glands, affecting metabolic activity [9]. **Fernandez et al.** [10] propose that disturbances in regular reproductive behavior might be attributed to atypical adipogenesis and mitochondrial malfunction within the ovarian follicular cells [11,12]. In contemporary times, there has been a growing recognition on a global scale that obesity, in both people and experimental animals, is often linked to a prolonged condition characterized by a state of mild inflammation. Nevertheless, more investigation is necessary to elucidate the molecular mechanism behind the impact of obesity on fertility in animal models. Although some studies have shown a potential association between an inflammatory state and female obesity, a comprehensive understanding is still lacking [6,7].

Various natural products, such as crude extracts and separated pure natural components, could elicit a decrease in body weight and serve as preventive measures against diet-induced obesity. Consequently, they have garnered significant use in the management of obesity. Various pharmacological activities, including cytotoxic, anti-inflammatory, antioxidant, antiproliferative, antimicrobial, hypolipidemic, hypoglycemic, and anti-obesity properties, were demonstrated by plant seeds, including Chia seeds, Hibiscus sabdariffa L., Foeniculum vulgare (fennel) and Coriandrum sativum L. (coriander) [13,14].

Roselle, scientifically called Hibiscus sabdariffa L., was important as a valuable reservoir of bioactive chemicals. Extensive research has been conducted to assess its antioxidant qualities, explicitly focusing on components such as anthocyanins, flavonoids, phenolic acids, and organic acids. A significant amount of hydroxy citric acid indicates the potential for antiobesogenic effects since this organic acid has been shown to inhibit fatty acid production in obese rats and promote weight loss in overweight individuals. Additionally, reports indicate that flavonoids and phenolic acids had antiobesogenic properties, including blocking adipogenesis and suppressing leptin expression. Adipocytes release leptin and diminish food consumption while augmenting energy expenditure [15].

Chia seeds were recognized as a prominent dietary source of omega-3 fatty acids, vital in maintaining normal cholesterol levels, promoting brain development, supporting immune system function, and exhibiting anti-inflammatory effects. For treating obesity, chia seeds were preferable to other pharmaceutical medications and natural plants as chia seeds resulted in a reduction in overall cholesterol levels while simultaneously increasing LDL cholesterol levels. Chia seeds were a notable dietary fibre source known for their ability to decrease appetite. Additionally, they contain omega-3 fatty acids, which play a vital role in emulsifying and absorbing liposoluble vitamins A, D, E, and K. Using chia seeds in meals can enhance their nutritional composition and mitigate the risk of various illnesses [16,17].

Coriandrum sativum L., often known as coriander, is an annual herbaceous plant belonging to the Apiace L.C. sativum family. It is a hairless, fragrant, herbaceous plant that completes its life cycle within a year [18]. Various volatile phytochemical elements had been identified and extracted from diverse components of Coriandrum sativum L. The abovementioned components include a range of bioactive substances, including essential oils, flavonoids, fatty acids, sterols, isocaumarins, and phenolic compounds such as caffeic acid, protocatechuic acid, and glycerin. Coriandrones and other compounds were also present [19]. The culinary, beverage, pharmaceutical, and ethnomedical industries depend on the coriander's essential oils and phytochemical ingredients [19,20]. The compound exhibits a range of pharmacological characteristics, including antioxidant, antidiabetic, anticholinesterase, antihelminthic, sedative-hypnotic, anticonvulsant, and cholesterol-lowering effects, anti-cancer, and hepatoprotective activity [21].

Due to its economic significance and use in the pharmaceutical sector, fennel is one of the oldest spice plants and is often grown in dry and semi-arid environments. This herb effectively treats gastrointestinal disorders and had anti-inflammatory and analgesic properties [22]. It treats neurological problems and had antioxidant and anti-ulcer characteristics [23]. Foeniculum vulgare, often known as fennel plants, had been extensively used as a traditional medicinal resource [24]. The fruits of Foeniculum vulgare, often known as fennel, and its essential oil were flavor enhancers in many culinary items. In addition, they had applications as components in cosmetic and medicinal formulations [25,26].

Hence, the objective of the current study was to evaluate the synergetic effects of the combination of Chia seeds, *Hibiscus sabdariffa* L., Foeniculum vulgare (fennel), and Coriandrum sativum L. (coriander) on ameliorating the hazards linked to obesity induced by HFD and enhancing reproductive capabilities in an experimental rat model of obesity.

2. Materials and methods

2.1. Materials

Chia seeds, Hibiscus sabdariffa L., Foeniculum vulgare (fennel), and Coriandrum sativum L. (coriander) were procured at a local market located in Giza. Fat, sucrose, and maize starch for rats' diets were provided at a local market. The analytical and laboratory-grade chemicals and solvents used in the study were procured from Sigma Chemical Company, located in St. Louis, USA. The spectrophotometry kits used for quantitative determination were procured from Egypt's Egyptian Company for Biotechnology. The ELISA kits were obtained from kits were purchased from Sunlong Biotech, China, and MyBioSource, California, USA. Merck Chemicals (64293, Darmstadt, Germany) supplied other chemicals.

2.2. Methods

2.2.1. Plant material

Chia seeds, *Hibiscus sabdariffa* L., Foeniculum vulgare (fennel), and Coriandrum sativum L. (coriander) were identified by Dr. Ahmed Ali Muhammed, Department of Horticultural Crops Technology, National Research Centre (NRC). Relevant permissions were obtained for the collection of Chia seeds, *Hibiscus sabdariffa* L., Foeniculum vulgare (fennel), and Coriandrum sativum L. (coriander) in accordance with relevant institutional, national, and international guidelines and legislation.

2.2.2. Determination of total phenolic (TP) and total flavonoids (TF) contents

2.2.2.1. Total phenolic content. The total phenolic contents in dry matter were ascertained using a spectrophotometer [27]. The absorbance was measured at 765 nm. The calibration curve was developed using gallic acid [28].

2.2.2.2. Total flavonoid content. According to **Pai et al.** [29], the total flavonoid content was calculated using a 2 % aluminium chloride ($AlCl_3$) solution in methanol. Using quercetin as the reference, the absorbance was measured at 368 nm.

2.2.3. Experimental animals

Eighty mature female Sprague Dawley rats, weighing between 100 and 120 g, were acquired from the National Center for Radiation Research and Technology (NCRRT) in Cairo, Egypt. The animals were placed in a regulated environment and exposed to a 12-h alternating pattern of light and darkness while kept at a constant temperature of 25 °C. Throughout one week, the animals were provided with unrestricted food and water.

2.2.4. Diet formulation

Two diets were established, including a balanced diet, which was produced based on the guidelines provided by **Ezzat et al.** [30] and **Reeves** et al. [31]. The HFD was formulated using the methodology outlined by **Panchal and Brown** [32] (Table 1).

2.2.5. Experimental Design

Eighty rats were randomly allocated into four groups (n = 20) as follows.

- **Normal control (G1):** Rats receiving normal balanced diet.
- **HFD group (G2):** Rats received HFD for 10 weeks.
- **Group (3):** Rats received HFD supplemented with Chia seeds (5 gm/kg diet) and *Hibiscus sabdariffa* L. (5 gm/kg diet) for 10 weeks.
- **Group (4):** Rats received HFD supplemented with *Foeniculum vulgare* (Fennel) (5 gm/kg diet) and *Coriandrum Sativum* L. (Coriander) (5 gm/kg diet) for 10 weeks.

2.2.6. Blood samples collection

Following a feeding period of 10 weeks, ten rats from each group were subjected to anaesthesia by intramuscular injection using ketamine hydrochloride at a dosage of 35 mg/kg. Blood samples were then taken using a retro-orbital puncture. Blood samples were obtained by using the posterior vena cava after the sacrificial procedure was performed on all animals. The samples were centrifuged at a speed of 4000 rpm for 15 min using a Sigma Labor Centrifuge GMBH, Germany, model 2–153360 osterode/Hertz. Subsequently, the centrifuged samples were stored at a temperature of −20 °C.

2.2.7. Female rat fertility evaluation

The remaining ten rats from each group were paired with sexually mature males (10 weeks old) for ten consecutive days, after which they were subsequently separated. Daily throughout cohabitation, all females were subjected to examinations to identify the presence of vaginal plugs, which served as a tangible indication of mating activity. After seven days, female rats who were pregnant were euthanized to determine the number of embryonic sacs present inside their uteruses. Approximately three weeks later, the

Table (1)
Composition of balanced diet and high fat diet.

Ingredients	Balanced diet (gm)	High fat diet (HFD) (gm)
Casein	12	12
Safflower oil	10	–
Lard	–	15
Sucrose	10	10
Starch	59	49
Vitamin Mixture	1	1
MineralMixture	4	4
Cellulose	4	4
Cholesterol	–	5
Bile salts	–	0.25

quantity of offspring produced by each female was tracked and calculated.

2.2.8. Ovarian and uterine examination

The uteruses and ovaries were removed from the euthanized animals. The measurements were conducted to assess the weight of the whole reproductive system and the weight of the uterus and ovaries to identify any differences between the groups. The follicles and corpus luteum present on the isolated ovaries were quantified using the OLYMPUS SZ61-SET Stereo Microscope.

2.2.9. Biochemical parameters

Plasma alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP) [33,34], **γ-**GT [35],bilirubin, total plasma protein, plasma albumin [36,37], urea, creatinine, uric acid [38,39], lipid peroxide, catalase activity, total plasma antioxidants [40,41], the lipid profiles, including total cholesterol, HDL, triglycerides, LDL and total lipids [42–47], were ascertained by colorimetric methods. Leptin, insulin, and ghrelin were assessed by ELISA kits (Fine Test, China).

2.2.10. Statistical analysis

Each value was the means ± SD or means ± SE (n = 10). All biochemical parameters' variations were assessed statistically using one-way analyses of variance (ANOVA) and post hoc multiple comparisons with the Duncan test in the SPSS/PC software (version 20; SPSS Inc., Chicago, IL, USA). P values < 0.05 were considered statistically significant.

3. Results and discussion

3.1. Total phenolics (TP) and total flavonoids (TF) contents of chia seeds, Hibiscus sabdariffa L., Foeniculum vulgare (fennel), and Coriandrum sativum L. (coriander)

The results in Table (2) showed that Chia seeds, *Hibiscus sabdariffa* L., *Foeniculum vulgare* (fennel), and *Coriandrum sativum* L. (coriander) contain high concentrations of both total phenolics and flavonoids contents which characterized by possessing powerful antioxidant properties that had the power to combat free radicals and inhibit cell deterioration brought on by free radicals [48]. A diet high in vegetables and, eventually, antioxidant components was widely established to lessen the incidence of numerous illnesses such as cancer and coronary artery disease. Identification of the substances that promote a healthy diet was thus crucial [49].

3.2. In vivo study results

3.2.1. Nutritional parameters

Obesity may be attributed to a combination of environmental and hereditary variables. Among the environmental causes, the consumption of HFD was recognized as a prominent contributor to the development of obesity. The study has shown that the intake of a diet rich in high levels of fat may significantly contribute to the development of obesity and overweight disorders. This was primarily due to its role in promoting a positive energy balance, subsequently leading to visceral fat accumulation. Consequently, this aberrant increase in adipose tissue contributes to the manifestation of obesity, particularly in individuals [50].

Table (3) displays the results of body weight gain, food intake, and the feed efficiency ratio in rats, categorized by various groups. Regarding body weight increase and feed efficiency ratio variables, the collected data revealed statistically significant disparities between the HFD group (G2) and the two other groups under investigation (G3 and G4). In contrast, the rats in Group 4 (G4) that were administered HFD supplemented with Foeniculum vulgare (fennel) and Coriandrum sativum L. (coriander) exhibited a comparatively lower rate of body weight gain compared to the rats in Group 3 (G3) that were given an HFD supplemented with Chia and Hibiscus sabdariffa L. The observed reduction in body weight in rats administered Foeniculum vulgare (fennel) and Coriandrum sativum L. (coriander) aligns with the findings reported by **Schöne et al.** [51]. In this regard, it was postulated that trypsin inhibitors present in Foeniculum vulgare (fennel) can diminish food consumption and enhance the release of cholecystokinin, thus promoting satiety. This relationship between Foeniculum vulgare and weight management might be attributed to these effects [52].

Foeniculum vulgare (fennel) has been shown to enhance the metabolic processes of lipids and carbohydrates in the liver and pancreas, resulting in weight reduction. It can disintegrate adipose tissue inside the circulatory system, facilitating its use as an energy substrate. The combination of these factors and its inherent diuretic properties and ability to decrease hunger make it a commendable solution for achieving weight reduction goals [53]. The current research has observed that *Foeniculum vulgare* (fennel) significantly reduces weight gain. The potential explanation for this phenomenon might be attributed to several isoflavones found in *Foeniculum*

Table (2)
The total phenolic and total flavonoids contents.

Samples	Total phenolics content (mg GAE/g DW)	Total flavonoids content (mg CE/g DW)	CE/GAE (%)
Chia seeds	1.21 ± 0.08	0.52 ± 0.02	42.98
Hibiscus sabdariffa L.	80.71 ± 1.28	31.11 ± 1.97	38.55
Foeniculum vulgare (fennel)	45.36 ± 1.35	31.09 ± 0.91	68.53
Coriandrum sativum L. (coriander)	31.69 ± 1.57	21.49 ± 0.86	67.81

Values were presented as means ± SD (n = 3). GAE = gallic acid equiv. CE = catechin equiv.

Table (3)
Body weight gain, food intake, and feed efficiency ratio of the different experimental groups.

Groups	Initial body weight (g)	Final body weight (g)	Body weight gain (g)	Food intake (g)	Feed efficiency ratio
Normal Control (G1)	117 ± 2.41[a]	161 ± 3.08[a]	44 ± 0.67[a]	11985 ± 2.65[a]	0.004 ± 0.25[a]
HFD group (G2)	116 ± 2.37[a]	259 ± 3.99[b]	143 ± 1.62[b]	11980 ± 2.53[a]	0.011 ± 0.64[b]
Group (3)	116 ± 2.29[a]	195 ± 4.12[c]	79 ± 1.83[c]	11975 ± 2.61[a]	0.007 ± 0.7[c]
Group (4)	115 ± 2.23[a]	177 ± 3.45[d]	62 ± 1.22[d]	11985 ± 2.67[a]	0.005 ± 0.46[d]

Values were the mean ± SD (n = 10). The same letters in each column reflect a no significant difference across treatments, whereas different letters reflect a significant difference (*P*< 0.05). Feed efficiency ratio = body weight gain/total food intake.

vulgare (fennel), which possess phytoestrogenic properties. Like estradiol, these compounds can influence the serotonergic system by preventing serotonin reuptake. Consequently, this action leads to an elevation in serotonin levels inside the synaptic clefts, thus enhancing satiety and perhaps contributing to weight gain [54]. The capacity of the active components in *Foeniculum vulgare* (fennel) extracts to down-regulate the expression of sterol regulatory element binding protein 1 may account for the extracts' propensity to reduce body fat percentage in obese rats, thereby impeding lipid accumulation and suppressing the expression of lipogenic genes. Consequently, this mechanism leads to a reduction in overall body fat. Furthermore, it was plausible that the modulation of satiation and the modification of gut hormone production were potential processes behind the weight reduction and control of body mass index (BMI) seen in obese rats treated with *Foeniculum vulgare* (Fennel) extract [51].

The study by **Zeb et al.** [55] aimed to examine the impact of *Coriandrum sativum* L. (Coriander) on the body mass index of individuals diagnosed with hyperlipidemia. This study investigated the effects of two botanical species, *Coriandrum sativum* L. (commonly known as coriander) and garlic, both separately and in combination. In conclusion, the research found that all the supplements substantially reduced the body mass index (BMI). However, it was seen that *Coriandrum sativum* L. (Coriander) had a more noticeable influence on blood pressure compared to its effect on BMI. The data also indicated a noteworthy reduction in the rate of body weight gain among the rats in group (3) that were given HFD, together with the inclusion of chia seeds and *Hibiscus sabdariffa* L., in comparison to the rats in group (2) who were only fed HFD. Previous studies have shown that the administration of an aqueous extract derived from *Hibiscus sabdariffa* L. for 60 days resulted in a significant reduction in body weight gain (22 %) in rats with obesity [56]. Furthermore, a study revealed that the administration of a 1 % w/w infusion of *Hibiscus sabdariffa* L. (ad lib) for 16 weeks in obese rats induced with HFD diet resulted in a significant reduction in both body weight (10 %) and adipose tissue weight (22 %), as compared to the obese control group [57]. Clinical studies have shown an anti-obesity benefit of *Hibiscus sabdariffa* L. A study by **Chang et al.** [58] revealed that the use of *Hibiscus sabdariffa* L. extracts for 12 weeks led to a reduction in body weight, body mass index (BMI), body fat, and waist-to-hip ratio in individuals with a BMI of 27 or higher and aged between 18 and 65 years. Additionally, dietary fibre from chia seeds is abundant and helps suppress appetite. They also include omega-3 fatty acids, crucial in emulsifying and absorbing liposoluble vitamins A, D, E, and K.

3.2.2. Biochemical parameters

Table (4) details the liver and renal functions observed in the various experimental groups. The management of obesity was found to correlate with significant elevations in ALT, AST, ALP, urea, creatinine, bilirubin, and albumin. Rats in groups G3 and G4 showed substantial enhancements in the levels of many biochemical indicators related to liver and kidney functioning. However, the administration of *Foeniculum vulgare* (fennel) and *Coriandrum sativum* L. (coriander) (G4) led to a more significant reduction in these parameters compared to (G3), which received a diet of chia seeds and *Hibiscus sabdariffa* L, suggesting potential benefits for liver and kidney health.

The present investigation demonstrates that HFD positively impacts kidney functioning, specifically blood urea and creatinine levels. The findings presented here align with the findings of **Abrass** [59], who observed that the HFD group had elevated blood cholesterol levels and triacylglycerol. Lipid problems often accompany renal disease. Individuals who were classified as obese had a heightened susceptibility to developing proteinuria and chronic renal disease. A study conducted by **Elghazaly et al.** [22] revealed that *Foeniculum vulgare* (commonly known as fennel) exhibited a noteworthy reduction in creatinine and uric acid levels. These

Table (4)
Changes in serum hepatic enzyme activities and renal functions in various experimental groups.

Groups Parameters	Normal control (G1)	HFD group (G2)	Group (3)	Group (4)
ALT (U/L)	21.8 ± 1.9[a]	34.5 ± 2.65[b]	25.9 ± 2.35[c]	23.1 ± 2.59[d]
AST (U/L)	32.5 ± 2.95[a]	54.3 ± 3.75[b]	36.9 ± 4.25[c]	35.5 ± 6.45[d]
ALP (U/L)	9.35 ± 1.11[a]	16.46 ± 2.39[b]	11.21 ± 1.92[c]	10.44 ± 1.61[d]
Bilirubin (mg/dL)	0.19 ± 0.01[a]	0.37 ± 0.01[b]	0.25 ± 0.02[c]	21.4 ± 0.01[d]
Albumin (g/dL)	2.58 ± 0.07[a]	3.72 ± 0.02[b]	2.61 ± 0.04[c]	2.57 ± 0.03[d]
γ-GT (g/dL)	75.4 ± 1.13[a]	94.6 ± 9.36[b]	54 ± 0.07[c]	55.9 ± 0.2[d]
Total protein (mmol/L)	6.75 ± 0.37[a]	5.63 ± 0.21[b]	5.98 ± 0.26[c]	6.09 ± 0.14[d]
Creatinine (mg/dL)	0.58 ± 0.11[a]	0.69 ± 0.09[b]	0.63 ± 0.07[c]	0.61 ± 0.05[d]
Urea (mg/dL)	33.8 ± 0.15[a]	48.5 ± 0.28[b]	35.2 ± 0.19[c]	34.7 ± 0.18[d]

Data was expressed as mean ± SD, (n = 10). Different superscripts in the same rawindicatesignificance at (p < 0.05).

findings were previously documented by **Fassett et al.** [60]. The groups subjected to HFD (G2) showed increased liver function. These findings align with the research conducted by **Choi** [61], which suggested that elevated concentrations of hepatic enzymes in the circulatory system may be associated with increased hepatic steatosis. Essential oils of *Foeniculum vulgare* (fennel) have been shown to have hepatoprotective properties [62].

A study by **Morales-Luna et al.** [15] showed that the aqueous extracts obtained from Hibiscus sabdariffa L had positive effects on liver function, explicitly targeting the accumulation of lipids in hepatocytes, often known as steatosis. The injection of aqueous extract significantly reduced hepatic triglyceride buildup and prevented the development of lipid vacuoles. According to research by **Nyakudya et al.** [63], consuming Coriandrum sativum L. (coriander) seeds in the diet does not lead to fat buildup in the liver and viscera. As a result, these seeds have potential advantages in terms of hepatic and visceral lipid metabolism.

Table (5) illustrates the impact of adding the investigated herbs to HFD on antioxidant capacity. The findings demonstrated a significant elevation in the catalase and malondialdehyde concentrations in the rats' serum in the HFD group (G2) compared to the normal rat group (G1). Furthermore, the findings revealed a significant reduction in the overall antioxidant content of Group 2 (G2) compared to Group 1 (G1), as HFD intake elevates oxidative stress levels. Furthermore, **Diniz et al.** [64] documented a correlation between obesity and oxidative stress. There was an increasing recognition within the scientific community that obesity was a substantial risk factor for the development of a dyslipidemic pattern. Additionally, it has been suggested that oxidative stress may contribute to the manifestation of different detrimental consequences associated with obesity [2].

According to **Hegazy et al.** [65], antioxidants are crucial for maintaining bodily homeostasis because they scavenge free radicals and upregulate antioxidant genes. Adding *Hibiscus sabdariffa* L., Chia, *Foeniculum vulgare* (fennel), and *Coriandrum sativum* L. (coriander) to HFD resulted in noteworthy improvements in the aforementioned biochemical parameters. The observed enhancement may be attributed to the antioxidant properties of the herbs under investigation. Chia seeds and *Hibiscus sabdariffa* L. possess a substantial number of bioactive components, including total phenolics and flavonoids contents, which have the potential to safeguard cellular integrity against oxidative stress induced by free radicals [14,15].

The rats that were administered the Foeniculum vulgare (fennel) herb exhibited a noteworthy reduction in oxidative stress. This finding aligns with the research conducted by **Choi and Hwang** [66], who observed a significant decrease in serum malondialdehyde (MDA) levels in obese rats treated with Foeniculum vulgare (Fennel) extract. The decline may be ascribed to the anti-lipid peroxidative characteristics of the components found in Foeniculum vulgare (fennel). Foeniculum vulgare, often known as fennel, was a plant species with flavonoid antioxidants such as kaempferol and quercetin. These chemicals can remove detrimental free radicals from the human body. The seeds of Coriandrum sativum L., often known as coriander, contain a significant amount of essential oils that have been shown to exhibit antioxidant capabilities. These qualities reduce oxidative stress, which is usually linked to obesity [63,67].

The data presented in Table (6) display the blood total lipids, total cholesterol, triglycerides, LDL cholesterol, and HDL cholesterol levels for the groups under investigation. The findings demonstrated a statistically significant elevation in all lipid markers, except for HDL cholesterol, within the HFD group (G2) compared to the normal control group (G1).

The obtained results indicate a notable correction in the dysregulation of lipid metabolism. This was shown by the reported reductions in blood levels of total lipids, total cholesterol, triglycerides, and LDL-cholesterol, as well as the observed rise in HDL-cholesterol values in the treated groups (G3 & G4). The current investigation revealed a significant enhancement in the performance of (G4) (*Foeniculum vulgare* and *Coriandrum sativum* L. (Coriander)) compared to (G3) (Chia seeds and *Hibiscus sabdariffa* L.). The findings of this study align with the observations made by **Choi and Hwang** [66], who reported that administering methanolic extract of *Foeniculum vulgare* (Fennel) seeds resulted in a substantial reduction in serum LDL levels and an increase in serum HDL levels in obese rats. The findings of this study suggest that the composition of *Foeniculum vulgare* (Fennel) seeds significantly enhances the blood lipid profile. The observed effect may be attributed to the administration of *Foeniculum vulgare* (Fennel) methanolic extract, which had been shown to elevate high-density lipoprotein (HDL) levels dramatically. This particular lipoprotein can induce reverse cholesterol transport, transporting cholesterol from the bloodstream to the liver [68]. Multiple studies have documented the antiobesogenic, hepatoglyceridemic, and hypocholesterolemic effects of aqueous and methanolic extracts derived from *Hibiscus sabdariffa* L. The extracts had shown efficacy in mitigating hepatic lipid build-up in obese animals resulting from HFD. This beneficial impact was attributed to bioactive compounds such as anthocyanins, flavonoids, and organic acids within the extracts [69].

Moreover, previous studies have shown that using *Foeniculum vulgare* (commonly known as Fennel) in herbal formulations may effectively prolong the transit time of the upper gastrointestinal tract, hence facilitating a reduction in fat content and absorption [70]. According to some research, the capacity of *Coriandrum sativum* L. (coriander) to both increase and inhibit lipid breakdown has been linked to its hypolipidemic impact [71]. Therefore, *Coriandrum sativum* L., often known as coriander, may be an affordable and readily available solution for treating hyperlipidemia. *Coriandrum sativum* L., often known as coriander, has historically been used and endorsed as a therapeutic intervention for diabetes and cholesterol reduction owing to its observed hypoglycemic and hypolipidemic

Table (5)
Concentration of catalase, total antioxidant capacity (TAC) and malondialdehyde (MDA) in the different experimental groups.

Groups Parameters	Normal control (G1)	HFD group (G2)	Group (3)	Group (4)
Catalase (mg/dL)	42.62 ± 1.19^{a}	54.34 ± 1.37^{b}	48.97 ± 1.22^{c}	49.19 ± 1.11^{d}
Malondialdehyde(mg/dL)	8 ± 0.29^{a}	19 ± 0.23^{b}	11 ± 0.43^{c}	12 ± 0.35^{d}
Total antioxidants (mM/L)	2.99 ± 0.06^{a}	1.27 ± 0.04^{b}	1.79 ± 0.09^{c}	1.54 ± 0.05^{d}

Data was expressed as mean ± SD, (n = 10). Different superscripts in the same raw indicate significance at ($p < 0.05$).

Table (6)
Concentration of serum lipid profile in the different experimental groups.

Groups Parameters	Normal control (G1)	HFD group (G2)	Group (3)	Group (4)
Total cholesterol (mg/dL)	99.7 ± 3.36[a]	352.5 ± 9.45[b]	179.4 ± 3.15[c]	166.9 ± 2.93[d]
HDL (mg/dL)	46.9 ± 1.24[a]	26.7 ± 3.69[b]	42.6 ± 2.47[c]	44.01 ± 2.36[d]
LDL (mg/dL)	38.9 ± 1.42[a]	279.8 ± 2.73[b]	85.4 ± 1.29[c]	79.2 ± 1.18[d]
Triglycerides (mg/dL)	75.4 ± 2.39[a]	109.3 ± 1.22[b]	88.3 ± 1.46[c]	81.7 ± 1.02[d]
Total lipids (mg/dL)	314.9 ± 21.03[a]	565.8 ± 23.15[b]	397.1 ± 29.33[c]	367.5 ± 26.67[d]

Data was expressed as mean ± SD, (n = 10). Different superscripts in the same raw indicate significanceat ($p < 0.05$).

properties in animal models [72].

Chia seeds are a valuable nutritional source of fatty acids, dietary fibre, protein, minerals, and antioxidants. Food products may include chia seed oil [73]. Chia seeds were more effective than herbal plants and pharmaceutical medications in addressing obesity. Consuming chia seeds caused a drop in total cholesterol levels, as the seed extract of chia had anti-obesity properties.

The administration of aqueous extracts derived from *Hibiscus sabdariffa* L. effectively inhibited the build-up of lipid vacuoles and resulted in a considerable reduction in the accumulation of hepatic triglycerides. In their study, **Huang et al.** [74] reduced hepatic triglyceride content was observed in hamsters given HFD and treated with an aqueous red *Hibiscus sabdariffa* L.—variety extract. The reduction was ascribed to the elevated concentration of anthocyanins found in the extract. These bioactive compounds achieve their desired effects by boosting fatty acid β-oxidation and suppressing hepatic lipogenesis [75].

Table (7) presents the insulin, leptin, and ghrelin concentrations among the groups under investigation. There was an increase in leptin concentration in (G2), which consisted of rats fed HFD, as compared to (G1) (normal rats). However, the treated groups (G3 & G4) exhibited reduced leptin concentrations in comparison to (G2) (HFD group). In contrast, the groups that received treatment (G3 and G4) showed a significant rise in ghrelin levels compared to HFD (G2).

The mean values of serum insulin, as shown in Table (7), indicate that the serum insulin level was lower in (G2) (HFD group) in comparison to (G1) (normal rats). Conversely, a substantial rise in insulin levels was seen in Groups (G3 and G4). The study conducted by **Cusi** [76] aimed to analyze the association between metabolic dysregulation in adipose tissue in obese individuals and the onset of insulin resistance, specifically emphasizing serum insulin findings. He provided evidence indicating that obesity leads to many physiological changes, including the enlargement of adipocytes, infiltration of macrophages, and the development of insulin resistance in adipocytes. These changes were believed to be associated with malfunction in pancreatic B cells [77].

Resistance to the hormones ghrelin and leptin was a characteristic of obesity. Consequently, the potential use of leptin and ghrelin as targets for pharmaceutical intervention in treating obesity might be explored [78]. The findings of this study indicate that *Foeniculum vulgare* (Fennel) can potentially enhance serum insulin levels in obese rats (G4). This effect can be attributed to its ability to reduce fat accumulation, thereby improving the glycemic status of obese rats. This improvement was achieved by lowering gluconeogenesis and enhancing insulin's effectiveness in glucose disposal [52]. The serum leptin levels exhibited a statistically significant rise in the HFD group (G2) compared to the group (G1) (normal group). Leptin, a polypeptide resembling a cytokine, was synthesized by adipocytes and exhibited excessive production in obesity [79,80]. The results of this study demonstrate a significant reduction in serum leptin levels in obese rats after the administration of *Foeniculum vulgare* (fennel). This suggests that *Foeniculum vulgare* (fennel) seeds can decrease fat mass in the experimental group.

Consequently, the decrease in adipose tissue was attributed to the administration of *Foeniculum vulgare* (fennel) [66]**.** The attenuation of the proinflammatory milieu linked to obesity reduces leptin synthesis, decreasing serum leptin levels [81]. Concerning the impact of chia seeds on blood insulin levels, a study by **Chicco et al.** [82] revealed that chia seeds could mitigate the development of dyslipidemia and insulin resistance in rats.

3.2.3. Fertility evaluation

Table (8) and Fig. (1 A&B) present the impact of various food types on the weight of the reproductive system. The presented data does not demonstrate any statistically significant variations in the weight of the reproductive tract among the normal control group (G1), HFD group (G2), group (G3), or group (G4) based on the dietary conditions ($P > 0.05$). Furthermore, no statistically significant variations were seen in the ovaries' weight. However, the weight of the uterus showed a substantial difference in the HFD group (G2) and group (G3) compared to the normal control group (G1) ($P < 0.01$). Group (G4) did not demonstrate any effects from consuming various diets.

Table (7)
Concentration of insulin, leptin and ghrelin inthe different experimental groups.

Groups Parameters	Normal control (G1)	HFD group (G2)	Group (3)	Group (4)
Insulin (μU/ml)	16.78 ± 0.32[a]	9.36 ± 0.19[b]	15.08 ± 0.37[c]	15.68 ± 0.43[d]
Leptin (ng/ml)	9.79 ± 0.3[a]	11.29 ± 0.23[b]	10.18 ± 0.15[c]	10.09 ± 0.2[d]
Ghrelin (pg/ml)	68.57 ± 11.2[a]	33.08 ± 10.9[b]	54.19 ± 9.2[c]	59.23 ± 7.4[d]

Data was expressed as mean ± SD, (n = 10). Different superscripts in the same raw indicate significanceat ($p < 0.05$).

Table (8)
Effect of types of diet on reproductive system weight.

Groups	Reproductive tract weight (g)	Right ovary weight (g)	Left ovary weight (g)	Uterus weight (g)
Normal Control (G1)	1.3 ± 0.07^a	0.27 ± 0.02^a	0.23 ± 0.02^a	0.87 ± 0.04^a
HFD group (G2)	1.4 ± 0.05^a	0.27 ± 0.01^a	0.27 ± 0.02^a	0.77 ± 0.06^b
Group (3)	1.2 ± 0.05^a	0.26 ± 0.01^a	0.28 ± 0.02^a	0.68 ± 0.05^b
Group (4)	1.4 ± 0.06^a	0.25 ± 0.01^a	0.28 ± 0.02^a	0.84 ± 0.04^a

Data was expressed as mean ± SE, (n = 10). Different superscripts in the same column indicate significanceat (p < 0.05).

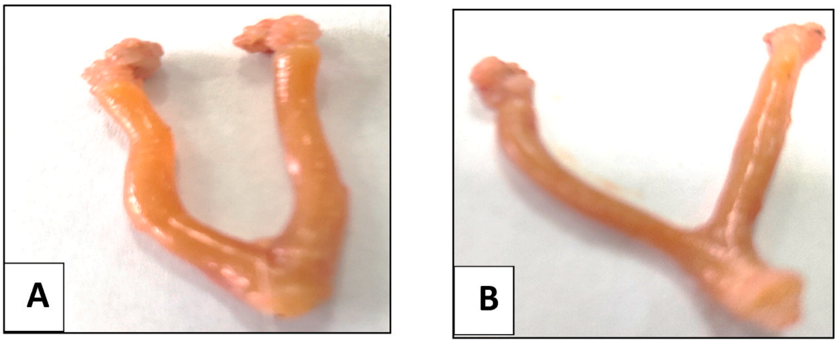

Fig. 1. Photographs of Reproductive system removed from female rats. A: uterus from normal control (G1), B: uterus from HFD diet (G2).

Table (9) presents the average values for the combined count of follicles in the right and left ovaries and the corpus luteum (CL) count. The data analysis revealed no statistically significant disparities in the follicle counts across the groups. Furthermore, there was no significant variation in the quantity of CL across the groups as a result of the dietary composition.

The quantification of fetal lobes was conducted on the seventh-day post-conception to investigate the impact of different dietary interventions on the gestation of female rats and the resulting number of embryos, as shown in Table (10) and Fig. (2 A&B). The data obtained indicate a clear correlation between the type of diet consumed and the observed variations in the number and size of subjects in the normal control (G1), HFD (G2), and group (G3) ($P < 0.05$). Additionally, there were significant statistical differences ($P < 0.01$) in the number of offspring born between the normal control (G1) and HFD (G2), as well as group (G3).

Obesity is a complex condition influenced by several variables, including genetic predisposition and consumption of high-fat foods. The combination of excessive caloric consumption and inadequate physical activity contributes to obesity, whereas hereditary factors play a role in determining an individual's vulnerability to food intake [83,84]. Common features of obesity include an elevated body mass and excessive consumption of nutrient-rich substances abundant in fat, which were subsequently retained rather than processed for energy requirements [5]. Gynaecological diseases, including endocrine dyscrasia, polycystic ovarian syndrome (PCOS), amenorrhea, and infertility, were often seen in female patients who were classified as obese [85–87]. The findings from the breeding experiments indicated that while there was a significant amount of fat buildup around the general viscera, there was no substantial variation in the weight of the reproductive organs (ovaries and uterus) as compared to the normal control group (G1) ($P > 0.05$). In mouse models with DIO, the ovarian tissue had an increased presence of apoptotic follicles, while the oocytes had reduced size and decreased likelihood of reaching maturity [86]. Upon more thorough analysis of these atypical oocytes in DIO mice, it becomes evident that meiotic aneuploidy had a significant prevalence. This condition was characterized by fragmented and disorderly meiotic spindles and chromosomes that were not appropriately oriented on the metaphase plate [88]. The total number of follicles was assessed in the present research, and no statistically significant difference was seen ($P < 0.05$). The average number of embryonic lobes and the average number of offspring after birth were found to be considerably more significant in the normal control group (G1) and group (G4) compared to the HFD group (G2) and group (G3) ($P < 0.01$). The findings were consistent with a prior investigation, indicating that the quantity of offspring produced by obese mice in the HFD group (G2) was considerably lower compared to the normal control group (G1), as shown in earlier research [5].

4. Conclusion

Our study's results indicate that using Chia seeds, *Hibiscus sabdariffa* L., *Foeniculum vulgare* (Fennel); *Coriandrum sativum* L. (Coriander) in a combination together provides an efficient approach in mitigating the adverse consequences associated with obesity. The diet enriched with Foeniculum vulgare (fennel) and *Coriandrum sativum* L. (coriander) exhibited the most favourable outcomes across all the assessed biochemical measures and reproductive parameters and that could be attributed to the unique active constituents. Therefore, these outcomes could provide an innovative and valuable treatment for obesity. Further clinical research will be required to be successful in humans.

Table (9)
Effect of different diets on follicles and Corpus Luteum (CL) number.

Groups	NO. follicles/ovary		Total follicles NO.	CL/ovary NO.		Total CL NO.
	Right ovary	Left ovary		Right ovary	Left ovary	
Normal Control (G1)	5.9 ± 0.8^a	4.2 ± 0.5^a	9.1 ± 0.8^a	4.8 ± 0.6^a	4.2 ± 0.4^a	9.0 ± 0.5^a
HFD group (G2)	5.2 ± 0.5^a	5.0 ± 0.8^a	10.2 ± 0.9^a	3.0 ± 0.5^b	4.6 ± 0.5^a	7.6 ± 0.7^a
Group (3)	4.2 ± 0.9^a	4.6 ± 0.5^a	8.9 ± 0.9^a	3.6 ± 0.6^a	3.8 ± 0.6^a	7.4 ± 1.0^a
Group (4)	4.6 ± 0.6^a	5.3 ± 0.9^a	10.0 ± 1.1^a	3.3 ± 0.5^a	5.0 ± 0.5^a	8.3 ± 0.7^a

Data was expressed as mean ± SE, (n = 10). Different superscripts in the same column indicate significance at ($p < 0.05$).

Table (10)
Effect of types of diet on conception, embryos number and offspring number.

Groups	NO. Embryonic lobes (sacs)	NO. offspring
Normal Control (G1)	8.4 ± 0.3^a	7.3 ± 0.4^a
HFD group (G2)	6.5 ± 0.5^b	4.7 ± 0.4^b
Group (3)	6.1 ± 0.6^b	5 ± 0.5^b
Group (4)	8.6 ± 0.4^a	7.2 ± 0.3^a

Data was expressed as mean ± SE, (n = 10). Different superscripts in the same column indicate significance at ($p < 0.05$).

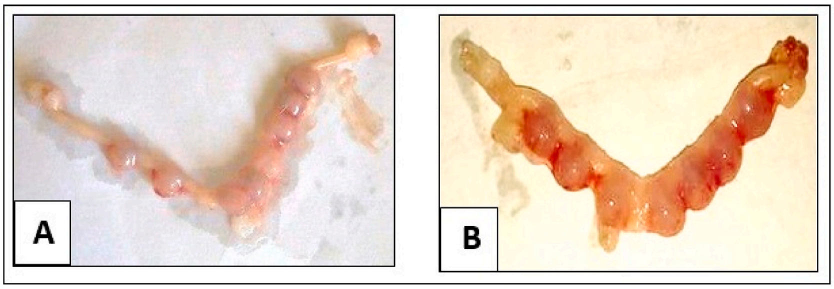

Fig. (2). Photographs of reproductive system removed from pregnant female rats. A: shows female rat uterus with suffered from obesity with reduced embryonic sacs in one horn. B: healthy uterus from normal control (G1) with good conception.

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Data availability statement

Data will be made available on request.

Ethical declaration

The protocol of this study received approval from the Research Ethics Committee (REC-NCRRT) at the National Center for Radiation Research and Technology (Approval No. 38A/23). The approval was obtained in compliance with the Animals (Scientific Procedures) Act of 1986 and its associated recommendations, as well as the European Union Directive 2010/63/EU for animal research (Publication No. 85-23, updated 1985). The study was reported in accordance with the ARRIVE (Animal Research: Reporting of In Vivo Experiments) guidelines, a set of guidelines developed to improve the reporting of research using animals. All methods were carried out in accordance with relevant guidelines and regulations.

CRediT authorship contribution statement

Ahmed Sabry S. Abdoon: Writing – review & editing, Writing – original draft, Supervision, Data curation, Conceptualization. **Amany M. Hegazy:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Amal S. Abdel-Azeem:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Ahmed M. Al-Atrash:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Dina Mostafa Mohammed:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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.

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