Study the Potential Effect of Dietary Intervention with Strawberry and Cauliflower Leaves on Oxidative Stress, Inflammation, Insulin Resistance and Histological Alterations in Diet-Induced Obese Rats

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ABSTRACT

The present study investigated the effects of dietary interventions using strawberry leaf powder (SLP) and cauliflower leaf powder (CLP) on oxidative stress, inflammation, insulin resistance, and histological changes in diet-induced obese rats. Thirty-six rats were divided into two main groups: Group 1 (6 rats) received a basic diet (BD), while Group 2 (30 rats) was fed a high-fat diet to induce obesity over 8 weeks. Group 2 was then further divided into four subgroups: subgroup 2 served as the obese control (DIO), while subgroups 3, 4, and 5 were fed a BD supplemented with 10% CLP, 10% SLP, and a combination of CLP and SLP, respectively. At the end of the 8-week period, the normal group's body weight (BW) gain was 0.95%, food intake (FI) was 13.94 g/day/rat, and the feed efficiency ratio (FER) was 0.079. In contrast, the obese control group saw increases of 58.49%, 30.27%, and 23.59%, respectively. Supplementation with CLP, SLP, and the combined mix led to a significant ($p \leq 0.05$) reduction in BW, FI, and FER among obese rats. Furthermore, CLP and SLP effectively improved obesity-related conditions by lowering serum glucose and insulin levels, protecting the liver by reducing serum enzyme activity, increasing antioxidant levels (GSH and GSSG), and improving inflammatory markers (TNF-α, IL-6, and NO). Additionally, they reduced the production of reactive oxygen species (ROS) and malondialdehyde (MDA), indicating lower lipid peroxidation and oxidative stress. The study also highlighted the positive effects of these supplements on obesity-related histological changes in adipose and liver tissues. These findings suggest that dietary modifications with plant-based components can help mitigate obesity-related complications, including oxidative stress, inflammation, and insulin resistance.

Keywords: body weight, liver function, glucose, glutathione, malondialdehyde, ROS, TNF-α, IL-6, NO.

INTRODUCTION

Obesity is a complex, chronic condition with multiple causes that lead to excess body fat and poor health, reducing lifespan (Nammi *et al.,* 2004 and Kim, 2016). Body Mass Index (BMI) is the primary measure used, with overweight classified as a BMI over 25, and obesity as a BMI over 30 (Taylor *et al.,* 1998). Studies, such as Yu *et al.* (2016), show a link between BMI and mortality in the elderly. Obesity stems from genetic, physiological, environmental factors, and lifestyle choices. It is rising globally and causes 4.7 million premature deaths annually, making it the 5th leading preventable cause of death.

In Egypt, obesity poses a significant public health challenge and negatively impacts the essential aspects of the country's economy. The "100 million Seha" initiative reveals that 39.8% of adults in Egypt experience obesity (Sedky *et al.,* 2021). Furthermore, it functions as a risk contributor for several non-communicable diseases (NCD) alongside various complications like type 2 diabetes, heart diseases, obstructive sleep apnea, specific cancer types, osteoarthritis, and asthma, along with both neurological and immunological conditions (Elhassaneen & Salem, 2014; Mehram *et al.,* 2021b; Shalaby & Elhassaneen, 2021 and Elhassaneen *et al.,* 2019, 2020a, 2022 a, b). Additionally, those with obesity encounter a greater chance of illness and death when placed alongside individuals who uphold an optimal body weight (Birdsall *et al.,* 2009). Consequently, the WHO and Dini (2006) indicated that a weight loss of 5–10% from the initial body weight correlates with meaningful improvements in a broad spectrum of comorbid conditions.

In recent years, several pharmacological approaches have been studied for treating and preventing obesity. However, only a few medications have proven both effective and safe, with many treatments being costly and associated with side effects, leading to patient noncompliance. This highlights the need for alternative, natural, and cost-effective medicines with minimal side effects. Numerous studies have explored plant-based components, including crude medications, powders, extracts, and herbal formulations, as anti-obesity agents (Elhassaneen *et al.,* 2018, 2019 & 2023b; Mahran *et al.,* 2018; Elhassaneen *et al.,* 2020 c; 2022 a, b and Shalaby & Elhassaneen, 2021). These plant components have shown positive effects in preventing or treating obesity

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in animal models, encouraging further research and exploration of diverse plant parts from various environments with anti-obesity properties.

The agricultural industry is a sector that generates large quantities of agricultural solid waste, and while this can be left to accumulate and pose health risks to humans and compromise food security, it can also be used for bio-economy. The benefits of recycling agricultural solid waste include the reduction of greenhouse gas emissions, use of fossil energy, and more significant inputs to developing the new green economy, employment opportunities, and biopower production, among others (McCormick and Kautto, 2013). Consequently, fresh avenues concerning the utilization of these wastes for enhanced production of food additives, supplements, and innovative foods with elevated nutritional profiles have attracted growing attention, as these represent high-value products and their recovery could prove to be economically beneficial. It is widely acknowledged that numerous agricultural wastes are abundant in dietary fibers, proteins, significant amounts of colorants, bioactive compounds, and other elements that offer beneficial health effects (Vasso & Constantina, 2007; Elhassaneen *et al.,* 2016 a,b; Mashal, 2016 and Sayed Ahmed, 2016).

Strawberry (Fragaria × ananassa), a perennial plant from the Rosaceae family, is native to the Mediterranean region (Lim, 2012). Its leaves contain essential nutrients such as protein (13.45%), fat (5.38%), ash (9.22%), fiber (12.35%), and carbohydrates (55.80%) (Moustafa *et al.,* 2021). The leaves are also rich in bioactive compounds like polyphenols, terpenoids, essential oils, and tocopherols (Katalinic *et al.,* 2006; Alexandre *et al.,* 2020 and Zitouni *et al.,* 2020), which contribute to various beneficial activities including antioxidant, antibacterial, antifungal, and anti-inflammatory effects (Mariotto *et al.,* 2008; Ferreira *et al.,* 2010; Malheiro *et al.,* 2012 and Pečivová *et al.,* 2014). These bioactive compounds indicate the potential of strawberry leaves in treating illnesses like diabetes, hypertension, and cancer (Hung *et al.,* 2004; Mareš *et al.,* 2008; Oliveira *et al.,* 2011; Bouzabata, 2013; Badawy, 2022 and Elhassaneen *et al.,* 2022b).

Cauliflower (*Brassica oleracea*), from the Cruciferae family, includes cabbage, broccoli, and turnips. Its leaves, often considered waste during processing, account for 40–50% of the plant and pose environmental challenges. These leaves are rich in protein, fiber, minerals, and beneficial compounds like polyphenols, carotenoids, and dietary fiber (Elhassaneen *et al.,* 2016a and Sayed Ahmet, 2016). Studies show that incorporating cauliflower leaves into animal diets improves blood count, serum lipid profiles, liver and kidney functions, and glucose levels (Lima *et al.,* 2002; Elhassaneen *et al.,* 2016b and Kashaf, 2018).

Despite the benefits of strawberry and cauliflower leaves, many countries, including Egypt, continue to cultivate strawberries solely for their fruits and cauliflowers for their flowers, discarding the majority of the green leaves as waste, which leads to environmental problems. To address this issue, the current study aims to explore the potential effects of dietary interventions using these plant leaves, which are abundant in Egypt, on oxidative stress, inflammation, insulin resistance, and histological changes in diet-induced obese rats.

MATERIAL AND METHODS

Plant parts

Cauliflower (*Brassica oleracea*) leaf samples were collected during December 2023, in fresh condition and through an arrangement with some farmers, Qena City, Qena Governorate, Egypt. Strawberry (*Fragaria ananassa*) leaf samples were collected during Nov. 2023 by special arrangements with some farmers in Kafer Dawood, Sadat City, Menoufia Gov., Egy. The gathered samples were transported to the laboratory and used right away to prepare leaf powder.

Chemicals

Sigma Chemical Co. in St. Louis, Missouri, supplied the thiobarbituric acid (TBA). Casein was acquired from Morgan Company for Chemicals. El-Ghomhorya Company for Trading Drugs, Chemicals, and Medical Instruments, AlSawah, provided analytical-grade vitamin and salt combinations, organic solvents, buffers, and other chemicals. Both companies are in Cairo, Egypt.

Kits

The test kits for Alanine amino-transferase ALT, aspartate aminotransferase AST, alkaline phosphatase ALP, malondialdehyde MDA, and serum glucose were bought from BIODIAGNOSTIC in Dokki, Giza, Egy. Reduced glutathione (GSH) and oxidized glutathione (GSSG) were measured using kits provided by My BioSource, Inc., San Diego, CA, USA. IL-6 was determined using specific kits of BPS purchased from Bioscience (PBS) Co., San Diego, CA, USA.

Instruments

Absorbance (Abs) for various tests was measured using a Labo-med Inc. spectrophotometer, CA, USA. Immunoassay analyzers for ELISA was measured using Beckman Coulter Life Sci. Indiana, USA.

Preparation of agricultural ruminant powder

Healthy leaves of strawberry and cauliflower were collected and immediately transported to the laboratory. Leaves collected for this experiment were washed with water to remove any form of impurities. in a hot air

oven (Horizontal Forced Air Drier, Velp Inc., Italy) was dried at 60°C for 8 hours, the final moisture content being 8%. The dried material was ground to a fine powder and done using a high-speed mixer that was purchased from Moulinex Egypt, ElAraby Co., Benha Egypt. The talc that was finer than the 80-mesh sieve was set in labeled polyethylene packs and stored at 4°C for chemical and biological experiments. The aqueous extracts were prepared based on the method described in the paper of Gharib *et al.* (2022). To summarize, 20 grams of sample were combined with 180 ml of water and then transferred to a beaker and agitated at 200 rpm on an orbital shaker (Unimax 1010, Heidolph Instruments GmbH & Co. KG, Germany) for 60 minutes at a temperature of 23±3 °C. The extract was then filtered through Whatman No. 1 filter paper to isolate the extract from the residue. The remaining solid residue was subjected to extraction once more, yielding another two portions of extract that were pooled together. The solvent was then evaporated under a vacuum at 55°C using a rotary evaporator (Laborata 4000; Heidolph Instruments GmbH & Co. KG, Germany). All aqueous extracts could be ready for analytical studies.

Biological Experiments

Animals

The study employed mature male albino rats (145±4.5g) from the Research Institute of Ophthalmology's Medical Analysis Dep. in Giza, Egypt.

Basal Diet (BD)

The BD was made using the following formula, as stated by AIN (1993): protein (10%), corn oil (10%), vitamin mixture (1%), mineral mixture (4%), choline chloride (0.2%), methionine (0.3%), cellulose (5%), and corn starch (69.5%). The vitamin combination component and salt mixture were made following Reeves *et al.* (1993).

Diet-induced obesity (DIO)

Diet-induced obesity (DIO)/high-fat diets were made using the typical global formulas per kg as indicated by Farley *et al.* (2003) as follows: Casein, 80 mesh (200 g), L-cystine (3g), corn starch (72.8g), maltodextrin (100g), sucrose (172.8g), cellulose (50g), soybean oil (25g), sheep fat (177.5g), vitamin mixture (10 g), mineral mixture (10 g), dicalcium phosphate (13g), calcium carbonate (5.5g), potassium citrate (16.5g), and choline bitartrate (0.2%). The vitamin combination component and salt mixture were made by Reeves *et al.* (1993).

Experimental design

All biological trials executed conformed to the regulations established by the Institute of Laboratory Animal Resources, Commission on Life Sci., National Research Council (NRC, 1996). Rats (n = 36) were individually housed in wire cages within a room maintained at a temperature of 24 ± 3 °C and were kept under standard healthy conditions. All animals were provided BD for two weeks before the commencement of the experiment for acclimatization. Post the two weeks, the rats were distributed into two central divisions: the initial division (Group 1, 6 rats) persisted with BD, whereas the second key division (30 rats) followed a diet-induced obesity (DIO) strategy for 8 weeks, which was additionally divided into four sub-divisions as outlined: Division (2) received DIO as a positive reference point; divisions (3, 4, and 5) were administered BD augmented with 10% cauliflower powder (CLP), 10% strawberry leaf powder (SLP), and a blend of CLP and SLP in equal ratios, respectively. The amount of diet consumed was documented daily, and body weight measurements were taken weekly throughout the experimental duration (8 weeks). The body weight (BW), food intake (FI), and food efficiency ratio (FER) were calculated by Chapman *et al.* (1959) using the following formulas: BWG (%) = ((Final weight – Initial weight)/ Initial weight×100, FER= Gained bodyweight (g/28 day)/ feed consumed (g/28 day).

Blood and organs sampling

At the end of the 8-week experimental phase, following a 12-hour fasting period, the rats were anesthetized with ether, after which blood specimens were collected via the abdominal aorta. The blood specimens were gathered in sterile, dry centrifuge tubes and allowed to coagulate at room temperature, subsequently undergoing centrifugation for 10 minutes at 4000 rpm to separate the serum, following the methodology outlined by Drury and Wallington (1980). The serum was carefully extracted, transferred to sterile capped vials, and stored at -18°C until further examination. Samples of liver and adipose tissue were collected immediately after the euthanasia of the rats and were preserved in 10% buffered formalin for subsequent histological evaluation.

Hematological analysis

Liver functions

The activities of serum alanine aminotransferase (ALT) and aspartate aminotransferase (AST) were assessed utilizing the modified kinetic technique established by Tietz (1976), whereas the activity of alkaline phosphatase (ALP) was evaluated employing the modified kinetic method proposed by Vassault *et al.* (1999).

Serum glucose and insulin

Blood glucose level was determined by the colorimetric method described by Tietz (1976). Insulin

was determined by the colorimetric detection method described by Mirsalari and Elhami (2020).

Glutathione fractions

GSH and GSSG were measured, in calories, in serum samples as described by Ellman (1959).

Serum oxidant status

Malondialdehyde (MDA) concentration was determined using the colorimetric technique published by Buege and Aust (1978), which is based on the interaction of thiobarbituric acid (TBA) with MDA, one of the aldehyde products of lipid peroxidation. Erel (2005) describes a colorimetric technique for determining reactive oxygen species (ROS).

Inflammation parameters assay

Timor Necrosis Factor-alpha (TNF-α) levels were quantified employing a sandwich enzyme-linked immunosorbent assay (ELISA), using two distinct monoclonal antibodies that target different antigenic sites on rat TNF-α, following the protocol established by Petrovas *et al.* (1999). Interleukin-6 (IL-6) concentrations were assessed via colorimetric ELISA methodology as outlined by Tanaka *et al.* (2014). The quantification of nitric oxide (NO) was performed by calculating the total of NO_2 and NO_3 as described by Miranda *et al.* (2001). NO levels were determined utilizing the Classical Griess Reaction (comprising 1% sulfanilamide, 1% naphthyl ethylene diamine dihydrochloride, and 2.5% phosphoric acid). Serum samples were combined with Griess reagent and subsequently analyzed using a spectrophotometer, and their absorbance values (Abs) were documented. A standard curve was constructed, and the absorbance values of the rat samples were measured and compared against this standard curve.

Histological examination

Liver and adipose tissue samples were obtained promptly post-slaughter of the animals and immersed in a 10% neutral buffered formalin solution. The specimens were then meticulously trimmed, subjected to dehydration through progressively higher concentrations of alcohol, cleared with xylene, and embedded in paraffin. The samples were sectioned to a thickness of 4-6 µm, stained using hematoxylin and eosin, and viewed under a microscope (Carleton, 1978).

Statistical Analysis

All assessments were conducted in triplicate and documented as mean ± SD. Statistical evaluation was executed using the Student t-test alongside the MINITAB 12 software (Minitab Inc., State College, PA).

RESULTS AND DISCUSSION

Effect of dietary intervention with selected plant parts from agricultural remnants on body weight (BW), feed intake (FI) and feed efficiency ratio (FER) of obese rats

Table (1) and Fig. (1) illustrate the effects of a dietary intervention with selected plant components from agricultural residues on obese rats' body weight (BW), feed intake (FI), and feed efficiency ratio (FER). The findings show that feeding diet-induced obese (DIO) rats (model control) led to increases in BWG, FI, and FER compared to the normal group. At the end of the 8-week trial, rats in the normal group had BW, FI, and FER values of 0.95%, 13.94 g/day/rat, and 0.079, respectively, while the model control group exhibited increases of 58.49%, 30.27%, and 23.59%. After 8 weeks of intervention with cauliflower leaves powder (CLP), strawberry leaves powder (SLP), and a Mix (1:1 w/w), the BW, FI, and FER of obese rats decreased significantly ($p \leq 0.05$) by 19.87%, 14.57%, and 25.15% for CLP, 16.24%, 12.71%, and 18.79% for SLP, and 12.63%, 8.49%, and 14.87% for Mix, compared to the normal group. The Mix had the most significant effect in reducing BW, FI, and FER, followed by CLP and SLP. These results align with findings from Sayed Ahmed (2016) and Elhassaneen *et al.* (2022a,b) on feeding interventions using CLP and SLP, respectively. Similar reductions in BW, FI, and FER in obese rats have been observed in various other studies involving different plant-based feeding interventions (Sayed Ahmed, 2016; Elbasouny *et al.*, 2019; Elhassaneen *et al.*, 2019; Almutairiu, 2020; Alqallaf, 2021; Elhassaneen *et al.*, 2020 a,c; Essa, 2021; Elhassaneen *et al.*, 2022 a, b and Elhassaneen *et al.*, 2023 a, b). The beneficial effects of these plant components in obesity prevention and treatment are attributed to their high content of bioactive compounds, such as phenolics, carotenoids, flavonoids, anthocyanins, alkaloids, terpenoids, phytosterols, essential oils, and organosulfur compounds. These compounds may regulate obesity through mechanisms like antioxidant and anti-inflammatory activities, scavenging reactive species, inhibiting lipid oxidation, modulating oxidative stress-related pathways, reducing fat accumulation, lowering leptin and resistin levels, enhancing lipolysis, increasing adiponectin levels, inhibiting adipocyte differentiation, and decreasing adipogenesis (Bonet *et al.*, 2015; Sayed Ahmed, 2016; Elhassaneen *et al.*, 2021 a, b; Arafa, 2021 and Elhassaneen *et al.*, 2023 a , b).

Effect of dietary intervention with selected plant parts from agricultural remnants on liver function of obese rats

The effect of food intervention with chosen plant components from agricultural residues on liver function

in obese rats is demonstrated in Table (2) and Fig. (2). Obesity resulted in substantial increases ($p \leq 0.05$) in AST (46.26%), ALT (40.06%), and ALP (34.32%) compared to the control group. Dietary intervention with CLP, SLP, or their mixture (Mix) on the diet by 10% resulted in substantial decreases in liver AST, ALT, and ALP activities by the ratios of -15.57, -12.32, and -17.27%; -16.41, -15.81, and -22.11; and -7.22, -7.13, and -15.37%, respectively, compared to the model control group. Thus, the Mix had the greatest effect in manipulating hepatic enzyme activity abnormalities caused by obesity in rats, followed by CLP and SLP. Such data are following that observed by Sayed Ahmed (2016) and Elhassaneen *et al.*, (2022 a,b) as the result of feeding intervention with CLP and SLP, respectively. Also, obtained data are in partially match with that observed by several authors where control/treatment of obesity by feeding intervention with the different plant parts (Abd El-Rahman, 2013; Elhassaneen *et al.*, 2016b; Fayez, 2016; Badawy, 2017; Mahran *et al.*, 2018; Sayed-Ahmed *et al.*, 2020; Almutairiu, 2020; Alqallaf, 2021; Elhassaneen *et al.*, 2021 a, d; Essa, 2021 and Elhassaneen *et al.*, 2022b, 2023a).

Table 1. Effect of a dietary intervention with selected plant parts from agricultural remnants on obese rats

Value	Normal control	Model control	Agricultural remnants (10%, w/w)		
			CLP	SLP	Mix
		Body weight (BW, %)			
Mean	0.95^{d}	1.51^{a}	1.21^{bc}	1.29^{b}	1.13^{c}
SD	0.06	0.07	0.06	0.09	0.07
% of Change	0.00	58.49	-19.87	-14.57	-25.15
		Feed intake (FI, g/day/rat)			
Mean	13.94^{c}	18.16^{a}	15.21^{b}	15.85^{b}	14.75^{bc}
SD	0.69	0.75	0.91	1.04	0.86
% of Change	0.00	30.27	-16.24	-12.71	-18.79
		Feed efficiency ratio (FER)			
Mean	0.079^{c}	0.097^{a}	0.085^{b}	0.089^{b}	0.083^{bc}
SD	0.003	0.006	0.006	0.003	0.005
% of Change	0.00	23.59	-12.63	-8.49	-14.87

* Means with different superscript letters in the same row are significantly different ($p \leq 0.05$). Normal control, healthy rats without intervention; Model control, diet-induced obesity (DIO) rats without intervention; BD, basal diet; CLP, cauliflower leaves powder; SLP, strawberry leaves powder; Mix, mixture powder of CLP and SLP by equal parts.

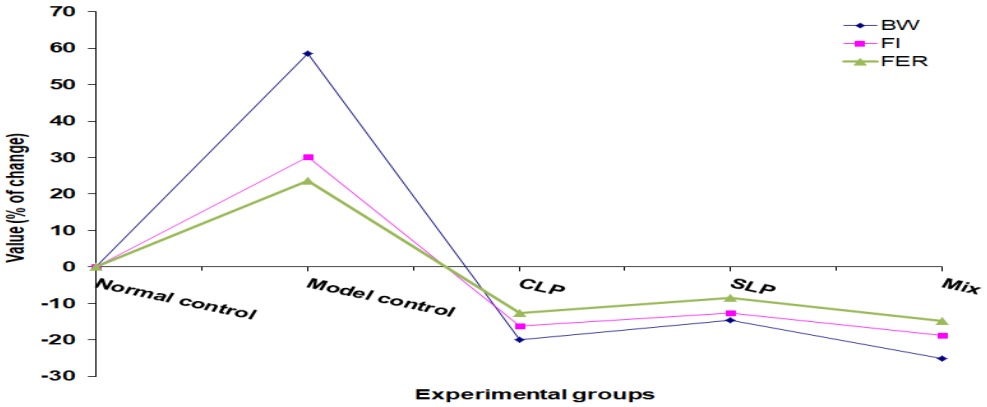

Fig. 1. Effect of a dietary intervention with selected plant parts from agricultural remnants on obese rats. Each data point represents the mean value of six rats. The significance of the experimental groups is shown in Table 1

AST and ALT are typically found within cells, and their presence in plasma indicates cellular injury in tissues where these enzymes are abundant (Mahran and Elhassaneen, 2023). Elevated levels of these enzymes are common in liver disorders, particularly those involving significant cellular death. Enzymatic assays for AST and ALT are crucial for monitoring liver injury (Pagana & Pagana, 1997; Elbasouny *et al.,* 2019; Elsemelawy *et al.,* 2021; Mahran & Elhassaneen, 2023; Elhassaneen and Mahran, 2024). Alkaline phosphatase (ALP) facilitates the hydrolysis of phosphate esters, producing inorganic phosphate and other compounds, and is concentrated in the liver, biliary tract, epithelial tissues, and bone (Pagana and Pagana, 1997). Elevated serum and leukocytic ALP levels have been observed in Hodgkin's and non-Hodgkin's lymphoma patients (Elhassaneen and Salem, 2014). Research suggests that various plant parts are rich in bioactive constituents like phenolics, carotenoids, anthocyanins, alkaloids, phytosterols, terpenoids, volatile compounds, and organosulfur compounds (El-Safty, 2008; Elhassaneen & Sanad, 2009; Elhassaneen *et al.,* 2014; Hallabo *et al.,* 2018; Ahmed, 2019; Elbasouny *et al.,* 2019; Abd Elalal *et al.,* 2021; Elhassaneen *et al.,* 2022b,c; Gharib *et al.,* 2022; Elhassaneen *et al.,* 2023b; Mahran & Elhassaneen, 2023 and Elhassaneen *et al.,* 2024a,b,c). These bioactive compounds may help manage liver function disorders induced by substances like carbon tetrachloride, benzo(a)pyrene, nitrosamines, and high-fat diets. For example, El-Nashar (2007) found that cinnamon extract reduced serum levels of AST, ALT, and ALP after 12 weeks compared to controls. Similarly, apricot kernel extracts reduced liver damage in rats treated with nitrosamines (Hassan, 2011). Plant components such as Henada, lemon balm, hawthorn, rose of Jericho, and corn cob silk improved serum AST, ALT, and ALP levels when used with CCl4 (Abd El-Rahman, 2013). Sweet violet (*Viola odorata* L.) flower powder also reduced serum levels of these enzymes following CCl4 injection (Abd El-Fatah, 2013 and Elhassaneen *et al.,* 2013). Flavonoids in these plants can inhibit bile acid uptake in hepatocytes and improve antioxidant capacity (Beattic *et al.,* 2005 and Elhassaneen & Mahran, 2024). El-Nashar (2007) noted that flavonoids have significant antioxidant activity, scavenging reactive oxygen species (ROS) in vitro. Apricot kernel extract, similar to the plant components in this study, reduced liver damage by enhancing antioxidant defenses in red blood cells (Hassan, 2011 and Mahran & Elhassaneen, 2023). Bioactive compounds in Ashwagandha, brown algae, cabbage, radish leaves, green tea, green coffee, ginger, and flaxseed have also been shown to affect AST, ALP, and ALT levels related to obesity (Elbasouny *et al.,* 2019; Elhassaneen *et al.,* 2019; Elhassaneen *et al.,* 2020a,b; Mehram *et al.,* 2021a; Shalaby & Elhassaneen, 2021; Elhassaneen *et al.,* 2022a and Elhassaneen *et al.,* 2023b). Taking into account all of these modes of action, the larger improvement in liver function measures obtained in obese rats fed Mix samples may have synergistic effects due to their composition of several bioactive chemical categories.

Table 2. Effect of dietary intervention with selected plant parts from agricultural remnants on liver function of obese rats

Value	Normal control	Model control	Agricultural remnants (10%, w/w)		
			CLP	SLP	Mix
Serum Aspartate aminotransferase (AST)activity (U/L)					
Mean	40.48 ^{c}	59.20^{a}	49.99 ^{b}	51.91 ^{b}	48.98^{b}
SD	3.46	5.07	4.28	4.44	4.19
% of Change	0.00	46.26	-15.57	-12.32	-17.27
Serum alanine aminotransferase (ALT) activity (U/L)					
Mean	26.10 ^{c}	36.56 ^{a}	30.55 ^{b}	30.77 ^{a}	28.47 ^{bc}
SD	2.23	3.13	2.62	2.63	2.44
% of Change	0.00	40.06	-16.41	-15.81	-22.11
Serum alkaline phosphatase (ALP,U/L)					
Mean	131.76 ^{d}	176.97 ^{a}	164.19 ^{b}	164.36 ^{b}	149.77 ^{c}
SD	11.28	15.15	14.05	14.07	12.82
% of Change	0.00	34.32	-7.22	-7.13	-15.37

* Means with different superscript letters in the same row are significantly different ($p \leq 0.05$). The significance of the experimental groups is as in Table 1.

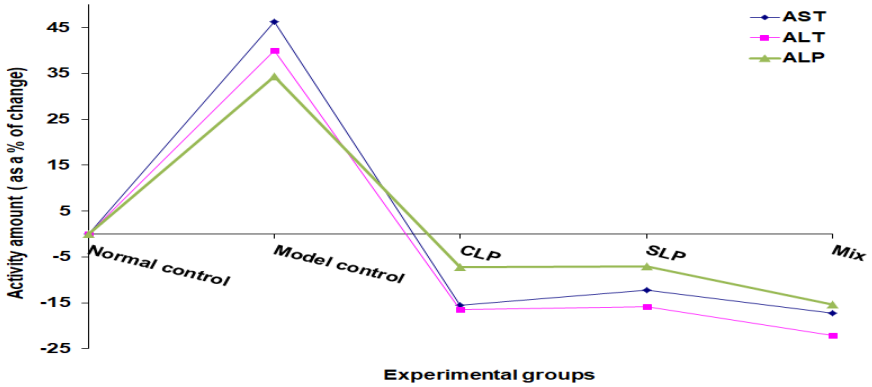

Fig. 2. Effect of dietary intervention with selected plant parts from agricultural remnants on liver function (as a % of change) of obese rats. Each data point represents the mean value of six rats. The significance of the experimental groups is as in Table 1

Effect of dietary intervention with selected plant parts from agricultural remnants on serum glucose and plasma-free insulin concentration of obese rats

Table (3) and Fig. (3) display the effects of dietary intervention with selected plant parts from agricultural remnants on blood glucose and plasma free insulin concentrations in obese rats. Obesity significantly increased blood glucose (35.61%) and plasma free insulin (87.72%) compared to the normal control group. Intervention with cauliflower leaves powder (CLP), strawberry leaves powder (SLP), and their mixture (Mix) at 10% of the diet led to significant decreases in blood glucose and plasma free insulin. The reductions were -14.07%, -12.38%, and -18.26% for blood glucose and -21.10%, -20.09%, and -24.75% for plasma free insulin, respectively, compared to the model control group. The mixture exhibited the greatest effect, followed by CLP and SLP. These results align partially with studies on obesity treatment using plant parts with similar bioactive compounds (Sayed Ahmed, 2016; Elbasouny *et al.*, 2019; El-Nassag *et al.*, 2019; Almutairiu, 2020; Alqallaf, 2021; Essa, 2021 and Elhassaneen *et al.*, 2021b; 2022b; 2023a). CLP and SLP are known for their vital nutrients, including glycemic and non-glycemic carbohydrates, minerals, vitamins, and various phytochemicals (Sayed Ahmed, 2016; Badawy, 2022 and Elhassaneen *et al.*, 2022a), which play significant roles in improving elevated blood levels (Elhassaneen *et al.*, 2014 and Essa, 2021). The bioactive compounds in these plants, such as phenolics, carotenoids, flavonoids, anthocyanins, alkaloids, terpenoids, phytosterols, and organosulfur compounds, have antioxidant properties that protect tissues from oxidative damage in diabetic conditions (El-Nassag *et al.*, 2019; Elsemelawy *et al.*, 2021 and Elhassaneen *et al.*, 2022c). The combination treatment produced the highest hypoglycemic effect, likely due to the synergistic action of these diverse bioactive compounds. The study also highlights that obesity is associated with insulin resistance, diabetes, and altered insulin secretion.

Table 3. Effect of dietary intervention with selected plant parts from agricultural remnants on serum glucose and plasma-free insulin concentration of obese rats*

Value	Normal control	Model control	Agricultural remnants (10%, w/w)		
			CLP	SLP	Mix
		Blood glucose concentration (mg/dL)			
Mean	97.40 ^{c}	132.09^{a}	113.54 ^{b}	115.74 ^{b}	107.94 ^{bc}
SD	8.28	11.23	9.65	9.84	9.18
% of Change	0.00	35.61	-14.07	-12.38	-18.26
		Plasma-free insulin Level (µU/ml))			
Mean	9.04 ^{b}	16.97 ^{a}	13.39 ^{a}	13.56 ^{a}	12.77 ^{a}
SD	1.09	2.11	1.86	1.05	1.11
% of Change	0.00	87.72	-21.10	-20.09	-24.75

* Means with different superscript letters in the same row are significantly different ($p \leq 0.05$). The significance of the experimental groups is shown in Table 1.

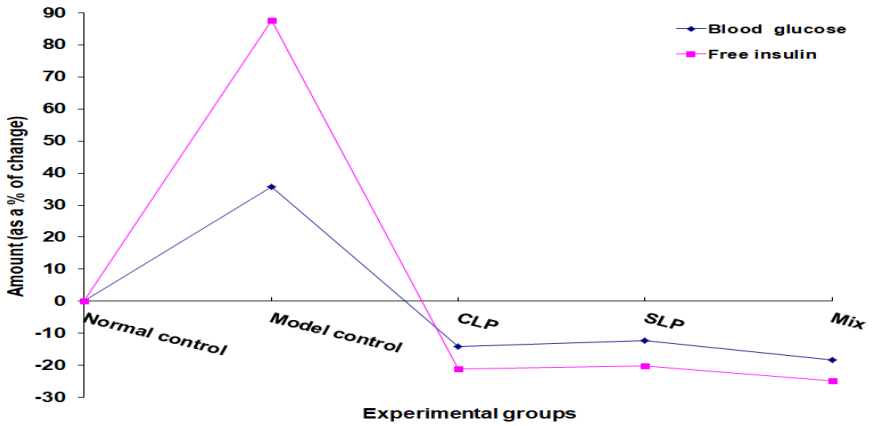

Fig. 3. Effect of dietary intervention with selected plant parts from agricultural remnants on serum glucose and plasma free insulin concentration (as a % of change) of obese rats. Each data point represents the mean value of six rats. The significance of the experimental groups is shown in Table 1

This is consistent with other research linking insulin resistance to chronic inflammation, glucotoxicity, lipotoxicity, and disrupted adipokine levels (Cheng *et al.*, 2014). Oxidative stress further exacerbates insulin resistance and contributes to diabetic complications by damaging pancreatic β-cells and precipitating metabolic disorders. The antidiabetic effects of CLP and SLP may involve reducing insulin resistance, regulating hepatic glucose production, lowering serum lipids, preventing visceral fat accumulation, enhancing lipolysis, reducing gluconeogenesis, promoting β-cell regeneration, and mitigating oxidative stress by modulating the activity of antioxidant enzymes such as superoxide dismutase, catalase, and glutathione peroxidase (Elhassaneen *et al.*, 2021d).

Effect of dietary intervention with selected plant parts from agricultural remnants on serum biological antioxidant macromolecules (glutathione fractions) level of obese rats

Table (4) and Fig. (4) illustrate the effects of dietary intervention with selected plant parts from agricultural remnants on serum glutathione (GSH) and glutathione disulfide (GSSG) levels in obese rats. Obesity significantly decreased serum GSH (-39.25%) and GSSG (-21.05%) compared to the normal control group. Dietary intervention with cauliflower leaves powder (CLP), strawberry leaves powder (SLP), and their mixture (Mix) at 10% of the diet led to significant increases in serum GSH and GSSG levels by 36.76%, 29.25%, and 42.07% for GSH, and 11.82%, 7.88%, and 8.11% for GSSG, respectively, compared to the model control group. The mixture had the greatest effect on reversing the decline in GSH and GSSG, followed by CLP and SLP. These findings are consistent with previous studies on the effects of plant parts rich in bioactive compounds on oxidative stress and antioxidant defense (Elbasouny *et al.*, 2019; Elhassaneen *et al.*, 2019; Almutairiu, 2020; Alqallaf, 2021; Essa, 2021 and Mehram *et al.*, 2021b). Glutathione (GSH) is a crucial antioxidant that detoxifies reactive metabolites and scavenges free radicals. It also plays a significant role in the activity of the GSH enzyme family, including glutathione peroxidase (GSH-Px) and glutathione reductase (GSH-Rd) (Elhassaneen *et al.*, 1997 and Halliwell & Gutteridge, 1985). GSH also acts as a nonenzymatic scavenger of reactive oxygen and nitrogen species (Bedard and Krause, 2007). The plant parts studied contain bioactive constituents with antioxidant properties that mitigate oxidative stress associated with obesity, including phenolics, carotenoids, flavonoids, anthocyanins, and others (Sayed Ahmed, 2016; Elhassaneen *et al.*, 2016a and Mashal, 2016). Similar results have been observed in studies involving plants like tomatoes, eggplants, pomegranates, onions, and other sources of antioxidants (Elmaadawy *et al.*, 2016; Elhassaneen *et al.*, 2019; El-Gamal, 2020 and Elhassaneen *et al.*, 2020a). Obesity was also associated with a decreased GSH/GSSG ratio, with a statistically significant reduction (9.71) compared to normal controls (12.63). The administration of 10% CLP, SLP, and their combination improved this ratio significantly. Increased oxidative stress, often due to elevated ROS production, reduces the GSH/GSSG ratio either directly or indirectly by depleting NADPH required for GSH-Rd activity (Elhassaneen & Abd El-Moaty, 2003 and Bedard & Krause, 2007). Plant interventions rich in antioxidants, such as those used in this study, help restore redox balance by enhancing the GSH/GSSG ratio and mitigating oxidative stress associated with obesity.

Table 4. Effect of dietary intervention with selected plant parts from agricultural remnants on glutathione fractions level of obese rats*

Value	Normal control	Model control	Agricultural remnants (10%, w/w)		
			CLP	SLP	Mix
Reduced glutathione (GSH, µmol /L)					
Mean	8.61 [a]	5.23 [c]	7.15 [b]	6.76 [b]	7.43 [b]
SD	0.99	0.91	0.71	0.55	0.49
% of Change	0.00	-39.25	36.76	29.25	42.07
Oxidized glutathione (GSSH, µmol /L)					
Mean	0.682 [a]	0.538 [c]	0.602 [ab]	0.581 [b]	0.582 [b]
SD	0.061	0.055	0.062	0.029	0.053
% of Change	0.00	-21.05	11.82	7.88	8.11
GSH/GSSH, ratio					
Mean	12.63 [a]	9.71 [b]	11.88 [a]	11.64 [a]	12.77 [a]
SD	0.59	0.67	0.55	0.42	0.81

* Means with different superscript letters in the same row are significantly different ($p \leq 0.05$). The significance of the experimental groups is shown in Table 1.

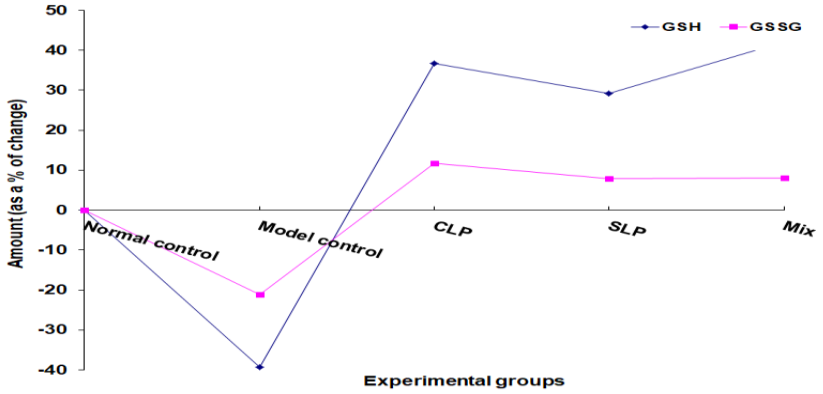

Fig. 4. Effect of dietary intervention with selected plant parts from agricultural remnants on glutathione fractions level (as a % of change) of obese rats. Each data point represents the mean value of six rats. The significance of the experimental groups is shown in Table 1

Effect of dietary intervention with selected plant parts from agricultural remnants on oxidative stress/lipid oxidation parameters of obese rats

Clinical studies have demonstrated a strong link between oxidative stress and obesity by measuring biomarkers that reflect the end products of fat oxidation processes mediated by free radicals (Elhassaneen & Salem, 2014 and Sayed Ahmed, 2016). Key indicators of lipid peroxidation, such as thiobarbituric acid-reactive substances (TBARS)—especially malondialdehyde (MDA)—lipid hydroperoxides, and conjugated dienes, are notably elevated in the plasma of obese individuals (Vincent & Taylor, 2006 and Elhassaneen & Salem, 2014). Obesity-related hyperglycemia, a hallmark of type II diabetes, further exacerbates oxidative stress (DCCTRG, 1993 and Almutairiu, 2020). Additionally, increased circulating lipids trigger reactive oxygen species (ROS) production, which accelerates lipid oxidation and protein carbonylation (Jensen *et al.*, 1989). Table (5) and Fig. (5) reveal that obesity significantly raised blood ROS and MDA concentrations by 55.60% and 39.63%, respectively, compared to the normal control group. Dietary interventions with 10% CLP, SLP, or their mixture (Mix) led to significant reductions in MDA (-21.80%, -18.61%, and -22.93%) and ROS (-20.84%, -14.91%, and -24.04%) levels. The reduction in oxidant levels was dose-dependent. These findings align with previous research indicating that plant parts containing bioactive compounds, similar to those in CLP and SLP, can mitigate oxidative stress associated with obesity (Elbasouny *et al.*, 2019; Elhassaneen *et al.*, 2019; Almutairiu, 2020; El-Gamal, 2020; Alqallaf, 2021; Essa, 2021; Mehram et al., 2021b; Shalaby & Elhassaneen, 2021 and Elhassaneen *et al.*, 2020c; 2022a, b; 2023a,b). Clinical evidence has established a

relationship between obesity and oxidative stress through biomarkers like ROS and MDA, which are used to assess oxidative stress levels (Elhassaneen & Salem, 2014 and Sayed Ahmed, 2016). Elevated MDA levels, a byproduct of ROS, are linked to the peroxidation of polyunsaturated fatty acids and the formation of lipid hydroperoxides and conjugated dienes (Di Giulio, 1991). Research consistently shows higher MDA concentrations in obese individuals, reflecting increased oxidative stress (Vincent and Taylor, 2006; Elhassaneen & Salem, 2014 and Elhassaneen *et al.*, 2023a). Metabolic disturbances associated with obesity, such as hyperglycemia and elevated circulating lipids, further contribute to oxidative stress (Jensen *et al.*, 1989; Bouloumie *et al.*, 1999 and Elhassaneen *et al.*, 2023b). The phytochemicals in CLP and SLP are suggested to reduce oxidative stress through several mechanisms, including enhancing antioxidant enzyme activity (e.g., superoxide dismutase and catalase), scavenging free radicals, and inhibiting lipid peroxidation (Elhassaneen *et al.*, 2023a).

Effect of dietary intervention with selected plant parts from agricultural remnants on inflammatory parameters of obese rats

The effect of dietary intervention with selected plant parts from agricultural remnants inflammatory parameters of obese rats was shown in Table (6) and Fig. (6). Such data indicated that obesity-induced a significant increase ($p \leq 0.05$) in TNF-α (242.54%), IL-6 (185.55%) and NO (33.25%) compared to normal control group. Dietary intervention with CLP, SLP and their mixture on the diet by 10% induced a significant decrease in liver TNF-α, IL-6 and NO levels by the ratio of -28.11, -26.35 and -31.85%, -17.28, -19.10 and -24.71%, and -11.73, -11.03 and -18.18% compared to model control group, respectively. Thus, the combination had the greatest effect on manipulating inflammatory levels in obesity-induced illnesses in rats, followed by CLP and SLP.

Table 5. Effect of dietary intervention with selected plant parts from agricultural remnants on oxidative stress/lipid oxidation parameters of obese rats*

Value	Normal control	Model control	Agricultural remnants (10%, w/w)		
			CLP	SLP	Mix
	Malondialdehyde concentration (MDA, nmol/mL)				
Mean	3.81 c	5.32 a	4.16 b	4.33 b	4.10 b
SD	0.54	0.68	0.39	0.32	0.67
% of Change	0.00	39.63	-21.80	-18.61	-22.93
	Reactive oxygen species (ROS, U/mL)				
Mean	55.56 d	86.45 a	68.43 bc	73.56 b	65.67 c
SD	2.98	4.11	3.07	2.97	44.12
% of Change	0.00	55.60	-20.84	-14.91	-24.04

* Means with different superscript letters in the same row are significantly different ($p \leq 0.05$). The significance of the experimental groups is shown in Table 1.

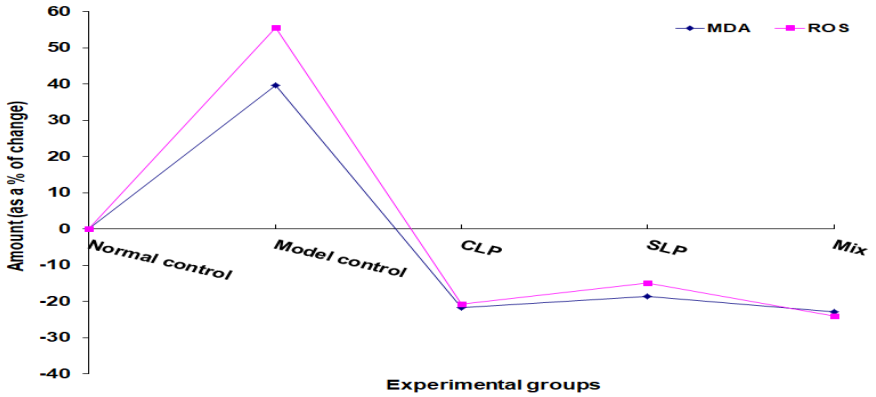

Fig. 5. Effect of dietary intervention with selected plant parts from agricultural remnants on oxidative stress/lipid oxidation parameters (as a % of change) of obese rats. Each data point represents the mean value of six rats. The significance of the experimental groups is as in Table 1

TNF-α is a pro-inflammatory cytokine that promotes tissue inflammation (Kim *et al.,* 2003). TNF-α increases vascular permeability, boosts leukocyte adherence of vascular endothelial cells, and stimulates interleukin (IL) production by endothelial cells, and other inflammatory mediators, resulting in tissue inflammation and endothelial cell injury. TNF-α triggers neutrophil degranulation, resulting in ROS, proteases, and lipids that cause tissue damage (Gao, 1999 and Elhassaneen *et al.,* 2016a). In inflammatory responses, mononuclear macrophages generate and produce TNF-α through autocrine and paracrine processes, releasing IL-1, IL-6, and IL-8, generating a "cascade effect" and worsening tissue damage (Bentrem and Joehl, 2003). An increase in body mass leads to the infiltration of enlarged fat tissue by immune cells and higher concentrations of inflammatory signaling proteins. The first signs of increased cytokine levels in obesity appeared with the finding of elevated TNF-alpha levels, a cytokine that promotes inflammation, in the fat tissue of overweight mice in the early 1990s (Hotamisligil *et al.,* 1993). TNF-alpha is produced and released by adipose tissue, and its levels correlate with obesity and insulin resistance (Tzanavari *et al.,* 2010). Adipocyte-derived TNF-α regulates adipocyte function (Ruan and Lodish, 2003).

Concerning nitric oxide (NO), it is a diminutive molecule produced from the enzymatic conversion of L-arginine to citrulline, facilitated by nitric oxide synthase (NOS), resulting in highly reactive free radical species, namely nitric oxide (NO) (Manahan, 1989). Subsequently, NO can interact with molecular oxygen and water to yield nitrite (NO_2^-) and nitrate (NO_3^-); it can also bind with hemoglobin to generate iron-nitrosyl complexes and/or NO_3^- in the bloodstream, react with superoxide anions to form NO3-, and engage with the amino and thiol groups of proteins to create nitrosylated derivatives (Manahan, 1989 and Misko *et al.,* 1993). The overproduction of NO has been associated with the development and tissue damage in an increasing array of immunological and inflammatory disorders, such as septic shock, arthritis, graft rejection, diabetes, and obesity (Jacob *et al.,* 1992; Elhassaneen *et al.,* 2014; Aly *et al.,* 2017 and Shah *et al.,* 2019). Adipocytes also produce a lot of NO that is reliant on endothelial NO synthase (eNOS) and inducible NO synthase (iNOS). iNOS expression is higher in white adipose tissue (WAT) from diet-induced or hereditary models of obesity. Similarly, eNOS and iNOS are expressed at greater levels in WAT from obese individuals than in lean controls.

The study found that plant-part-treated groups had significantly reduced blood levels of TNF-α, IL-6, and NO compared to the obese group ($P \leq 0.05$). This research, in conjunction with additional findings, indicates that components derived from plants may mitigate the onset of obesity-related immune complications by decreasing vascular permeability and the excretion of inflammatory cells, inflammatory mediators, and the infiltration of inflammatory cells, alleviating edema, and suppressing the synthesis of IL-1, IL-6, and IL-8 (Coskun, 2005 and Elhassaneen *et al.,* 2016c). Talero *et al.* (2015) demonstrated that bioactive chemicals in brown algae (CLP and SLP) may prevent radiation esophagitis by decreasing the synthesis and release of inflammatory response factors like TNF-α.

Table 6. Effect of dietary intervention with selected plant parts from agricultural remnants on inflammatory parameters of obese rats*

Value	Normal control	Model control	Agricultural remnants (10%, w/w)		
			CLP	SLP	Mix
		Tumor necrosis factor-alpha (TNF-α, pg/mL)			
Mean	26.14 ^{c}	89.54^{a}	64.37 ^{b}	65.95^{b}	61.02 ^{b}
SD	2.67	3.99	1.88	3.15	2.84
% of Change	0.00	242.54	-28.11	-26.35	-31.85
		Interleukin 6 (IL-6, pg/mL)			
Mean	14.67 ^{c}	41.89 ^{a}	34.65 ^{b}	33.89 ^{b}	31.54 ^{b}
SD	0.09	0.16	0.18	0.10	0.08
% of Change	0.00	185.55	-17.28	-19.10	-24.71
		Nitric oxide (NO, mM/L)			
Mean	44.78 ^{d}	59.67 ^{a}	52.67 ^{b}	53.09 ^{b}	48.82 ^{c}
SD	1.25	2.40	3.76	2.79	1.95
% of Change	0.00	33.25	-11.73	-11.03	-18.18

* Means with different superscript letters in the same row are significantly different ($p \leq 0.05$). The significance of the experimental groups is shown in Table 1.

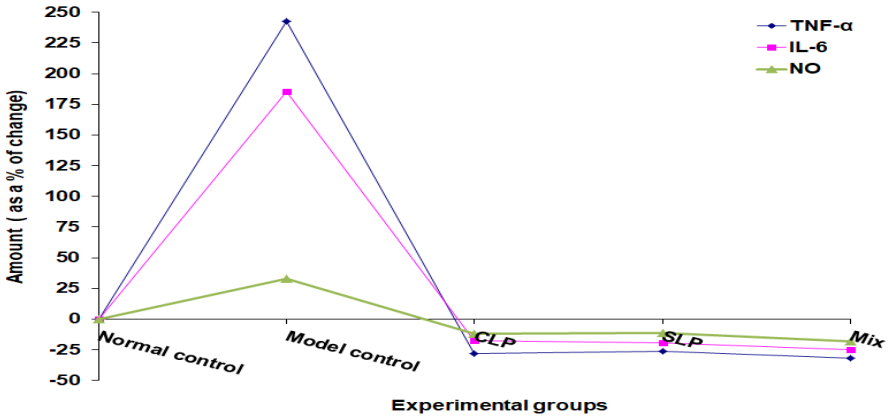

Fig. 6. Effect of dietary intervention with selected plant parts from agricultural remnants on inflammatory parameters (as a % of change) of obese rats. Each data point represents the mean value of six rats. The significance of the experimental groups is shown in Table 1

Table 7. Correlation between oxidative stress, antioxidant and inflammation parameters in obese rat's feeding intervention with CLP, SLP and their mixture

Parameters	r^2*	Parameters	r^2
MDA/GSH	- 0.9187**	Free insulin / TNF-α	0.8631**
MDA/GSSG	- 0.6061^{NS}	Free insulin / IL-6	0.8476**
MDA/Free insulin	0.8019*	Free insulin / NO	0.7952*
MDA/Blood glucose	0.7941*	Blood glucose/ TNF-α	0.8214*
ROS/GSH	- 0.9003**	Blood glucose/ IL-6	0.8183*
ROS/GSSG	- 0.6362*	Blood glucose/ NO	0.8005*
ROS/ Free insulin	0.8592**	NO/ TNF-α	0.7853
ROS/ Blood glucose	0.8042*	NO/ IL-6	0.7698
MDA/ROS	0.9498**	NO/ROS	0.9294**

* $P \leq 0.05$, ** $P \leq 0.01$

Correlation studies

The correlational study revealed significant changes in oxidative stress, antioxidant, and inflammatory markers between obese rats fed CLP, SLP, and a combination of the two Table (7). The findings revealed a substantial negative correlation ($p \leq 0.01$) between MDA concentration and GSH ($r^2 = - 0.9187$), and ROS concentration and GSH ($r^2 = - 0.9003$) in serum. Also, positive significant ($p \leq 0.01$) connection between MDA concentration and ROS ($r^2 = - 0.9498$) in serum. These relationships validate that without alterations in the antioxidant metrics in obese rats, it would be challenging to detect elevated levels of MDA and ROS. In a comparable investigation, Elhassaneen *et al.* (2016a) indicated that significant disparities were observed between plasma MDA and both GSH fractions, as well as antioxidant enzymes in obese rats consuming powdered plant materials enriched with bioactive compounds, similar to those present in CLP and SLP. On the other side, there was a strong positive significant ($p \leq 0.01$) relationship between serum-free insulin/ blood glucose concentration and inflammatory factors (TNF-α, IL-6 and NO). Such data confirmed the presence of insulin resistance associated with the increase of inflammatory parameters. With this context, Tzanavari *et al.* (2010), reported obesity causes macrophage infiltration of enlarged adipose tissue as well as higher levels of pro-inflammatory cytokines. In the early 1990s, increased production of TNF-alpha, a pro-inflammatory cytokine, was discovered in the adipose tissue of obese mice, providing the first indication of increased cytokine release. TNF-alpha is expressed in and released by adipose tissue, and its levels correlate with obesity and insulin resistance. Also, in models of animals, Hotamisligil (2017) found that TNF-α overexpression in adipose tissue contributes to insulin resistance and obesity. Furthermore, multiple investigations have consistently demonstrated elevated inflammation in the adipose tissue of obese animals and humans, (Hotamisligil *et al.*, 1993).

Histopathological examination

Adipose tissue

The impact of dietary interventions utilizing specific plant components derived from agricultural by-products on the histopathological assessment of adipose tissue in obese rats is depicted in Fig. (7). Microscopic evaluation of adipose tissue from group 1 revealed typical unilocular adipocytes, characterized by their polygonal form and signet ring morphology (Photo1). Conversely, adipose tissue from group 2 exhibited histopathological changes, including enlarged unilocular adipocytes, vascular congestion, and infiltration of inflammatory cells (Photo 2). In comparison, tissue samples from group 3 presented histologically normal unilocular adipocytes (Photo 3). Similarly, adipose tissue from group 4 displayed a limited number of enlarged unilocular adipocytes (Photo 4). Additionally, the majority of the sections analyzed from group 5 showed clear histological normality in the unilocular adipocytes (Photo 5). In a similar research, Elhassaneen *et al.* (2022b) discovered that adipose tissue from rats fed a high-fat diet had histological changes characterized by large-size unilocular adipocytes and inflammatory cell infiltration.

Meanwhile, feeding intervention with milk thistle on adipose tissue leads to exhibit apparent histologically normal unilocular adipocytes. Also, Alsaggar *et al.* (2020) showed that fat accumulation in main fat white adipose tissue and adipocyte growth were both inhibited by milk thistle bioactive compounds such found in C LP and SLP. Data from the present study with the other indicated that selected plant parts from agricultural remnants contain several bioactive constituents including phenolics, carotenoids, anthocyanins, flavonoids, lutein and chlorophyll. Such active constituents have the poverty to decrease the oxidative stress and subsequent cytotoxicity, thus protecting intact adipocyte tissue or cells that have not yet sustained irreversible damage (Ehassaneen and Mahran, 2024). Furthermore, many authors showed that CLP and SLP bioactive constituents act as antioxidant and scavenger activities against free radicals as well as inhibition of the lipid peroxidation linked to the progression of cellular injury through increasing the intracellular glutathione content, regulation of membrane permeability/integrity and enhancement of membrane stability in the face of toxicants damage (Elhassaneen *et al.,* 2023a and 2024c).

Liver

The effect of dietary intervention with selected plant parts from agricultural remnants on the histopathological examination of liver tissue of obese rats was illustrated in Fig. (8). Microscopically, the liver of rats in group 1 showed the typical histological architecture of the hepatic lobule (Photo 1). In contrast, the liver of rats in group 2 demonstrated Kupffer cell activation and localized hepatocellular necrosis accompanied by mononuclear inflammatory cell infiltration (Photo 2). Meanwhile, the liver of rats in group 3 revealed minor hepatic sinusoidal congestion (Photo 3). furthermore, the livers of rats in group 4 showed minor congestion of the hepatic sinusoids and slight vacuolization of certain hepatocytes (Photo 4). Furthermore, the liver of rats in group 5 showed minor vacuolization of certain hepatocytes (Photo 5). In a similar study, Elhassaneen *et al.* (2023a) demonstrated that histopathological analysis of rat livers revealed no changes in the control group, whereas the obesity-treated group exhibited focal necrosis and a proliferation of diffuse Kupffer cells interspersed among the hepatocytes. Notable improvements were observed in the protective cohorts, as the obesity rats displayed alterations in the hepatic sinusoids accompanied by infiltration of inflammatory cells and diffuse Kupffer cell proliferation amidst the degenerated hepatocytes, attributed to the treatment with milk thistle (contain the same bioactive compounds found in C LP and SLP). In general oxidative stress induced by obesity has been regarded as a co-pathological mechanism that initiates both the onset and progression of liver damage (Sánchez-Valle *et al*., 2012). Thus, the liver sustains damage due to oxidative stress, primarily affecting its parenchymal cells. Also, Kupffer cells, endothelial cells, and hepatic stellate cells portray an elevated risk of free radicals tied to oxidative stress. Amid oxidative stress, several cytokines, consisting of TNF-α, can be synthesized within Kupffer cells, perhaps heightening inflammation and apoptosis. For hepatic stellate cells, lipid peroxidation induced by oxidative stress promotes cellular proliferation and collagen production (Cichoż-Lach and Michalak, 2014).

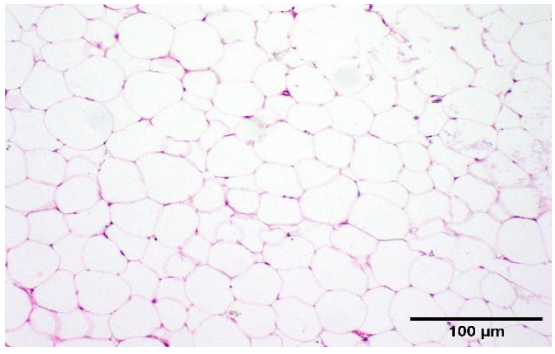

Photo 1. Normal control group

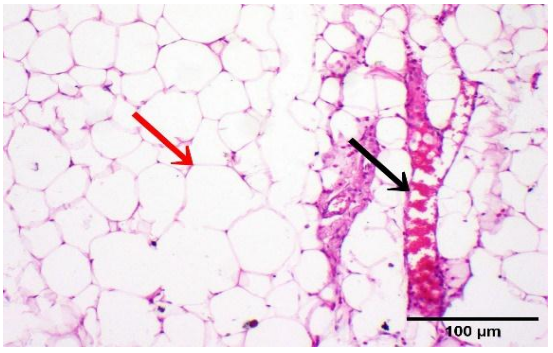

Photo 2. Model control group

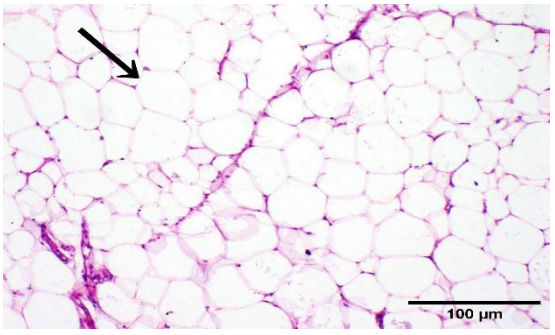

Photo 3. CLP intervention group

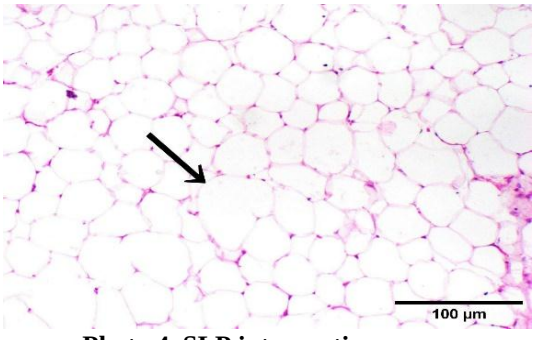

Photo 4. SLP intervention group

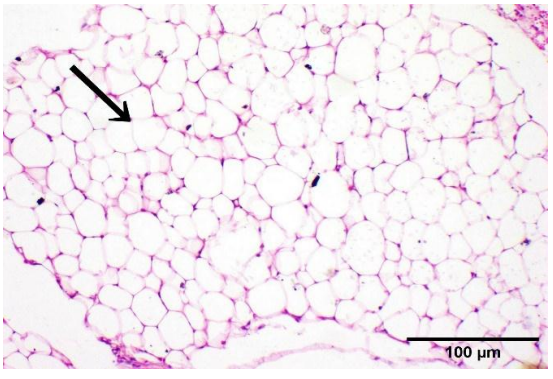

Photo 5. Mix intervention group

Fig. 7. Effect of dietary intervention with selected plant parts from agricultural remnants on the histopathological examination of adipose tissue of obese rats

Photo 1. The photomicrograph depicting adipose tissue from a rat in group 1 displayed typical unilocular adipocytes, characterized by a polygonal shape and a signet ring morphology. Photo 2. The photomicrograph of adipose tissue from rats in group 2 revealed significant histopathological changes, including enlarged unilocular adipocytes, vascular congestion, and infiltration of inflammatory cells. Photo 3. The photomicrograph of adipose tissue from a rat in group 3 indicated histologically normal unilocular adipocytes. Photo 4. The photomicrograph of adipose tissue from a rat in group 4 presented a few enlarged unilocular adipocytes. Photo 5. The photomicrograph of adipose tissue from a rat in group 6 displayed histologically normal unilocular adipocytes (H & E, scale bar 100 µm, X 100). Normal control refers to healthy rats without intervention; Model control pertains to diet-induced obesity (DIO) rats without intervention; CLP signifies cauliflower leaf powder; SLP denotes strawberry leaf powder; and Mix represents an equal mixture of both CLP and SLP.

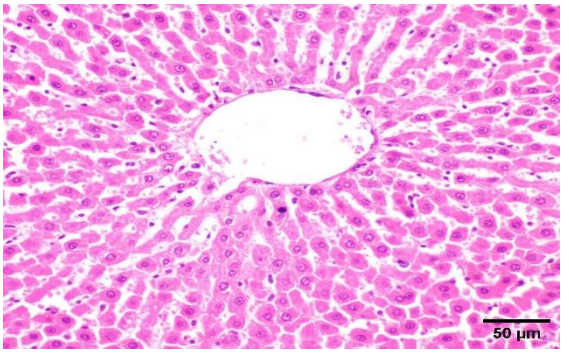

Photo 1. Normal control group

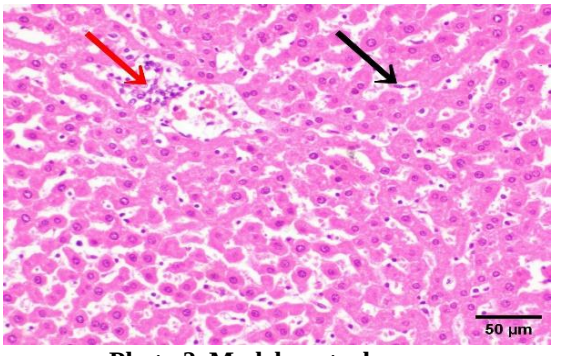

Photo 2. Model control group

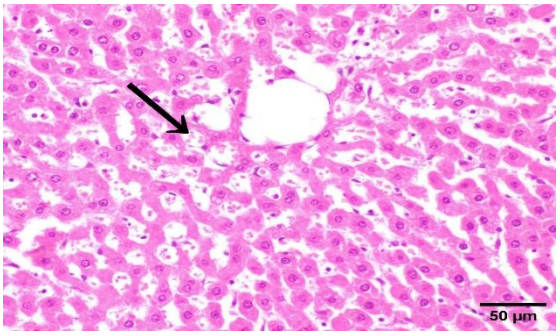

Photo 3. CLP intervention group

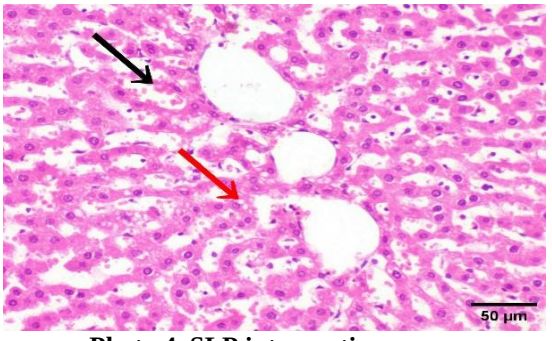

Photo 4. SLP intervention group

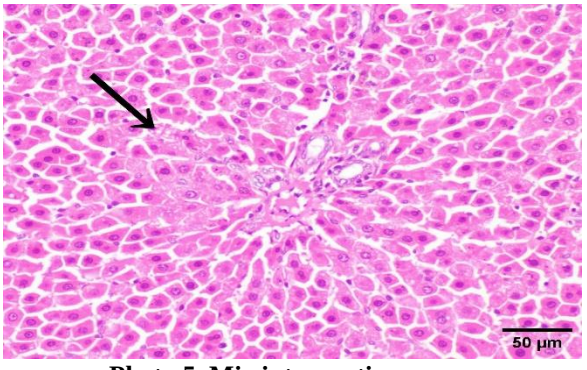

Photo 5. Mix intervention group

Fig. 8. Effect of dietary intervention with selected plant parts from agricultural remnants on the histopathological examination of liver tissue of obese rats

Photo 1. The photomicrograph depicting the liver of a rat from group 1 illustrates the preserved histological structure of the hepatic lobule. Photo 2. The photomicrograph of the liver from a rat in group 2 reveals the activation of Kupffer cells (indicated by the black arrow) alongside focal hepatocellular necrosis accompanied by infiltration of mononuclear inflammatory cells (indicated by the red arrow). Photo 3. The photomicrograph of the liver from a rat in group 4 demonstrates mild congestion of the hepatic sinusoids (indicated by the arrow). Photo 4. The photomicrograph of the liver from a rat in group 4 shows mild congestion of hepatic sinusoids (denoted by the black arrow) and slight vacuolization of certain hepatocytes (denoted by the red arrow). Photo 5. The photomicrograph of the liver from a rat in group 5 indicates slight vacuolization of some hepatocytes (indicated by the arrow) (H & E, scale bar 50 µm, X 200). Normal control refers to healthy rats without any intervention; Model control pertains to diet-induced obesity (DIO) rats without intervention; CLP represents cauliflower leaves powder; SLP stands for strawberry leaves powder; and Mix denotes an equal parts mixture of CLP and SLP.

CONCLUSION

Agricultural residues such as CLP and SLP were useful in preventing complications of obesity. These results validated our hypothesis that these plant parts include multiple types of phytochemicals together with other substances that can prevent or decrease hepatotoxicity by liver serum enzyme-lowering action, lower the serum glucose and insulin level, elevate the serum antioxidant (GSH and GSSG), improve the inflammatory factors (TNF-α, IL-6 and NO) and decreasing the rate of ROS and MDA formation in serum, in clear evidence of suppressing lipid peroxidation and oxidative stress. In addition, favorably controlled obesity-related histological alterations in adipose and hepatic tissues of obese rats were studied. As a result, we advocate including a 10% concentration of these plant components powder into our everyday foods, beverages, and nutritional supplements.

ETHICAL CONSIDERATIONS

The ethics of this study have been reviewed and approved by the Scientific Res. Ethics Committee, Faculty of Home Eco., (Menoufia Uni., Shebin El-Kom, Egy.). (Approval # 18- SREC- 05-2023).

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الملخص العربي

دراسة تأثير التدخل الغذائي بأوراق الفراولة والقرنبيط على الإجهاد التأكسدي والمقاييس الالتهابية والمقاومة للأنسولين والتغيرات النسيجية في الفئران السمينة المستحثة بالنظام الغذائي

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تم تصميم الدراسة الحالية لمعرفة التأثير المحتمل للتدخل الغذائي لمسحوق أوراق الفراولة (SLP) والقرنبيط (CLP) على الإجهاد التأكسدي والالتهابات ومقاومة الأنسولين والتغيرات النسيجية في الجرذان السمينة الناجمة عن النظام الغذائي. تم تقسيم ستة وثلاثين فأرًا إلى مجموعتين رئيسيتين، المجموعة الأولى (المجموعة ١، ٦ فئران) لا تزال تتغذى على النظام الغذائي الأساسي (BD) والمجموعة الرئيسية الأخرى (٣٠ فأرًا) تم تغذيتها على السمنة الناجمة عن النظام الغذائي (DIO) لمدة ٨ أسابيع. والتي قسمت إلى أربع مجموعات فرعية على النحو التالي: المجموعة (٢) التي تغذت على DIO كمجموعة ضابطة إيجابية؛ المجموعات (٣، ٤، ٥)، غذيت على BD المحتوي على ١٠% مسحوق القرنبيط (CLP)، مسحوق أوراق الفراولة (SLP) ومزيج (CLP + SLP بأجزاء متساوية) على التوالي. وفي نهاية التجربة (٨ أسابيع) سجلت فئران المجموعة الطبيعية ٠,٩٥% و١٣,٩٤ جرام/يوم/فأر و٠,٠٧٩ لـ BW و FI و PER، بينما ارتفعت هذه القيم بمعدلات ٥٨,٤٩ و٣٠,٢٧ و٢٣,٥٩. % في المجموعة الضابطة الموجبة (المصابة بالسمنة). أدى التدخل باستخدام CLP و SLP و Mix بمستوى ١٠% من وزن الوجبة في تغذية الجرذان لمدة ٨ أسابيع إلى انخفاض ملحوظ ($p<0,05$) في BW و FI و FER للفئران السمينة. أيضًا، كان CLP و SLP فعالين في الحماية من مضاعفات السمنة بما في ذلك خفض مستوى الجلوكوز والأنسولين في الدم، ومنع تسمم الكبد من خلال خفض نشاط إنزيمات مصل الكبد، وزيادة مضادات الأكسدة في المصل (GSH و GSSG)، وتحسين العوامل الالتهابية (TNF-α، IL-6 ، NO) وانخفاض معدل تكوين ROS و MDA في السيرم، في دليل واضح على قمع اكسدة الدهون والإجهاد التأكسدي. علاوة على ذلك، تم دراسة التغيرات النسيجية المرضية المرتبطة بالسمنة في الأنسجة الدهنية والكبدية لدى الفئران السمينة. تشير النتائج التي توصلنا إليها إلى فوائد التدخلات الغذائية، والمكملات لأجزاء النبات، في الحد من المضاعفات المرتبطة بمرض السمنة بما في ذلك الإجهاد التأكسدي والالتهابات ومشاكل مقاومة الأنسولين.

الكلمات المفتاحية: وزن الجسم، وظائف الكبد، الجلوكوز، الجلوتاثيون، المالونالدهيد، أنواع الأكسجين النشط، عامل النخر الورمى-الفا، انترلوكين-٦، أكسيد النتريك.