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Anti-obesity Influence of Psyllium (*Plantago ovate*) and Chia (*Salvia hispanica* L.) Seeds on Rats Fed a High-Fat Diet

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ABSTRACT

This study has been proposed to study the effect of psyllium and chia seeds on obese rats. The chemical composition, phenolic compounds**,** amino acids, and fatty acids of psyllium and chia seed powders were determined. Thirty male albino rats were fed a standard diet for 7 days as an adaptation period, and then 24 rats were divided into two groups. The first group of six rats was fed a basal diet for another 10 weeks and was considered the negative control group (G1). The second group was divided into four subgroups of six rats each. The first of the four subgroups was fed a high-fat diet (HFD) and was considered a positive control (G2). Other subgroups were fed on different diets for 10 weeks as they were fed on the HFD supplement with psyllium and chia powder (G3, G4, and G5).The results of the biological experiment showed that adding psyllium and chia powder (5%) to the basal diet for obese rats, led to improved liver and kidney functions, an increase in HDL-cholesterol, and a decrease in weight, blood glucose, TC, TG, LDL-cholesterol, and v-LDL cholesterol compared to the positive control group (G2) . Through the results of this study, it was recommended the possibility of using psyllium and chia seeds be explored to improve and reduce the symptoms caused by obesity.

1. Introduction

Obesity is a chronic metabolic disease characterized by an excess of fat stores in the body. It is a gateway to bad health and has grown to be a significant cause of disability and death given that it affects not just adults but also children and adolescents internationally (Aktar et al., 2017). In addition to high-income nations, low and middle-income nations also struggle with the issue of obesity, especially in metropolitan areas. Since 2000, there has been a nearly 24% increase in the proportion of under-5-year-old overweight children in Africa. Furthermore, predictions state that 39 million kids under the age of five will be overweight or obese by the year 2020 (WHO, 2021). Obesity is a significant risk factor for type 2 diabetes patients, metabolic syndrome, cardiovascular disease (primarily heart disease and stroke), a cause of death as well as some cancers (including endometrial, breast, ovarian, prostate, liver, gallbladder, kidney and colon), as well as musculoskeletal disorders. Obesity is a serious metabolic disease in which the body's extra body fat has built up to a point where it may have serious negative health effects and cause further health problems. An imbalance between energy intake and expenditure is the root cause of obesity. Although there is currently no pharmaceutical medication that can reduce obesity with little negative effect, consuming a diet rich as well as some cancers (including endometrial, breast, ovarian, prostate, liver, gallbladder in fibre provides benefits for many of the previous diseases (Jane et al., 2019).

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A cluster of cardio metabolic diseases, like obesity, hypertension, dyslipidemia, glucose intolerance, and insulin resistance, can result from excessive intake of a high-fat diet and foods that are calorie-dense, highly processed, and easily absorbed (Alissa and Ferns, 2014). Chronic disorders like diabetes and cardiovascular diseases are made more likely by them. A growing number of people are interested in discovering novel treatment strategies, such as functional meals, for preventing and managing chronic illnesses and other health conditions (Creus et al., 2016). The bioactive substances found in typical functional foods, such as dietary fibre, polyunsaturated fatty acids, phytochemicals, and antioxidants, may help lower the risk of developing chronic diseases (Gazem and Chandrashekariah, 2016).

Psyllium (*Plantago ovata*) is a member of the family Plantaginaceae. The plant's husk and seeds have significant therapeutic and economic value. Psyllium seeds are used in traditional medicine for a variety of ailments (Tewari et al., 2014). Since 1500 BC, the Chinese have utilized psyllium seeds to treat bladder issues, high blood pressure, diarrhoea, haemorrhoids, and constipation. Additionally, it was applied topically to soothe skin irritants like poison ivy reactions and bites and stings from insects. Psyllium seeds were the first used by North Americans and Europeans for their effects on lowering cholesterol and blood sugar (Ashwini et al., 2015). Psyllium (*Plantago ovata*) is a rich source of vitamin C, natural antioxidants, PUFAs (ω-3 and ω-6 fatty acids), essential and sulfur-rich amino acids as recommended by the FAO for human health, phenolics and flavonoids which can be used as nutrient supplements. Moreover, these compounds have several pharmaceutical applications as anti-cancer agents and natural plant ROS scavengers (Patel et al., 2016).

Chia seeds dissolve in water to form a gel that is good at storing both water and oil while also having strong viscosity and emulsion activity. Fatty acids, dietary fibre, protein, minerals, and antioxidants are all present in good amounts in chia seeds. Using chia seed oil in food is a new application (Sukhneet et al., 2016). Chia seeds contain significant amounts of phenolic chemicals, which have been shown by science to have antioxidant-related properties. One of the richest sources of omega-3 is chia, which is also anti-inflammatory and necessary for good cholesterol levels, immune system function, and brain development. Chia seeds are a better option for treating obesity than natural remedies and other pharmaceuticals. As a result, they are frequently used to treat obesity. It has been shown that chia seeds increase HDL-cholesterol while decreasing total cholesterol levels (Bhutani et al., 2007).

Chia seeds are a good source of both omega-3 fatty acids (linolenic acid), which are necessary for the emulsification and absorption of the fat-soluble vitamins A, D, E, K, and dietary fibre, which lessens the feeling of hunger. Chia oil induced enhanced glucose metabolism, and a healthier phenotype. (Silva, et al., 2020). Chia seeds may improve immunity and may alter the blood clotting process, as well as aid in the treatment of a number of no communicable diseases. Chia seeds may increase food's nutritional value and shield against a variety of ailments if they are added to it remedies for the treatment of obesity are being investigated. This could be a great alternate approach for producing future effective, secure anti-obesity medications (Souza et al., 2020). The present study deals with the dietary fibre, antioxidant and anti-obesity activity of psyllium and chia powder which in turn helps out with the improvement of anti-obesity treatments with no side effects in the future.

2. MATERIALS AND METHODS

Materials:

Psyllium and chia seeds were purchased from the local market in Kafr-elsheikh, Egypt. All chemicals and solvents used in this study were of analytical grade and purchased from Sigma Company, USA.

Animals: A total of thirty adult male albino rats, weighted at (180±5g) were used in the current experiment in the animal house of the Food Technology Research Institute, Agriculture Research Centre, Giza, Egypt, following Agriculture Research Center, animal patronage commission assizes, which are in line with international care and use recommendations.

Methods

Preparation of raw materials

Psyllium and chia seeds were cleaned from dust by air pressure, then milled using a moulinex mill machine (Al Araby for Electronic Manufacture Company, Egypt), kept in polyethylene bags and stored in freezers until analysis and other uses.

Chemical analysis

Psyllium and chia seeds were analyzed for crude protein, ash, crude ether extract and crude fiber according to the methods outlined by the (AOAC, 2012). Available carbohydrates were calculated by difference.

- Total carbohydrates% = 100 – (protein + ash + ether extract)
- Available carbohydrates % = 100 – (protein + ash + ether extract + crude fibers)
- Calorie values were calculated agreeing to the Atwater system (FAO, 2002).
- Calorie value (kcal/100) = (% carbohydrate × 4) + (% protein×4) + (% fat× 9).

Determination of soluble and insoluble dietary fibers

Soluble and insoluble fiber were determined according to the method described by (ASP et al., 1983).

Determination of amino acids

Amino acids composition of psyllium and chia seeds were determined using HPLC according (AOAC, 2012).

Computed protein efficiency ratio (C-PER)

C-PER was calculated as according to the reported method outlined by (Alsmeyer et al., 1974) using the equation:

C−PER = -0.468+0.454 (Leucine) - 0.105(Tyrosine)

Computed Biological value

Biological value (BV) was calculated as described by (Farag et al., 1996). Computed Biological value

(BV) = 49.9 + 10.53 C-PER

where: C-PER = computed protein efficiency ratio.

Determination of fatty acids composition

Fatty acids composition of psyllium and chia powder were determined using gas chromatography according to the methods outlined by (ISO 2015).

Rats feeding

Thirty rats (180 ± 5 g) (6 mice per cage) were housed in wire cages under normal laboratory conditions with constant controlled environments, a temperature 25 ± 3 °C and a 12/12 h light/dark cycle. Every day the rats were observed for their external appearance, shape, color and distribution of hair and physical activity. The diets were introduced to rats in special food cups to avoid loss of food and contamination. Also, rats were provided with water by a metallic tube projecting through wire cages from inverted bottles supported on one side of the cage. Food and water provided were checked daily. Treatments and animal maintenance were in accordance with the guidelines of the experimental animal house of Food Technology Research Institute (FTRI), Animal care and use committee, which follow the International Animal care and use Guidelines. The male albino rats were fed a standard diet for 7 days as an adaptation period. Then the rats were divided into two groups. The first group of six rats was fed a basal diet for another 10 weeks and was considered the negative control group (-). The second group was divided into four subgroups of six rats each . The first of the four subgroups was continued to feed on HFD (casein 20%, mineral mixture 3.5%, choline chloride 0.2%, vitamin mixture 1.0%, DL-methionine 0.3%, cellulose 5.0%, corn starch 15%, sucrose 15% and beef tallow 40%) according to (Assinewe et al., 2003) who considered a positive control group (+). Other subgroups were fed on different diets for 10 weeks as follows:

G1: Negative control (-ve): normal rats fed on a basal diet.

G2: Positive control (+ve): fed on the HFD.

G3: Fed on the HFD substituted with 5% psyllium seeds.

G4: Fed on the HFD substituted with 5% chia seeds.

G5: Fed on the HFD was substituted with 2.5% psyllium seeds and 2.5% chia seeds.

Blood sampling:

After rats were induced with obesity and at the end of the experimental period, blood samples were taken from the lateral tail vein of rats after 12 h of fasting. Using micro capillary glass tubes, blood was collected into a dry, clean centrifuge tube and left to clot in a water bath (37°C) for half an hour according to the method described by (Malhotra, 2003). The blood was centrifuged for 10 minutes at 3000 rpm to separate the serum part for glucose determination and the remnant was carefully transferred into clear, tight-fitting plastic tubes and kept frozen at (-18°C) until biochemical and hematological parameters were measured.

Determined body weight gain (BWG):

$$Body\,weight\,gain\,(B.W.G) = \frac{Final\,weight - Intial\,weight}{Intial\,weight} \times 100$$

The body weight gain was calculated according to (Abdel Azim, 2007) as follows:

Biochemical analysis:

Serum glucose was estimated according to the method of (Trinder, 1969). Total cholesterol , low density lipoprotein (LDL-C), high density lipoprotein (HDL-C), triglyceride (TG) were estimated by the method of (Wieland and Seidal, 1983). Serum alanine aminotransferase (ALT), serum aspartate aminotransferase (AST) were estimated according to the methods of (Henry, 1964 and Reitman et al., 1957). Albumin, urea, creatinine, uric acid and bilirubin were determined according to the method described by (Trinder, 1969 and Jaffě, 1986).

Statistical evaluation:

The average and standard deviation of the experimental data were calculated (n = 3). Using the SPSS 26 software, the statistical comparison was based on the Tukey method with a 95% confidence level according to (McClave and Benson, 1991).

3. Results and Discussions

The chemical composition of psyllium and chia seed powders

The chemical composition of psyllium and chia seed powder was presented in Table 1. Psyllium powder comprises15.82% protein, 5.56% fat, 4.03% ash, 26.00% crude fiber and 74.59% total carbohydrates. These results were similar with (El-Hadidy, 2020). The table also shows the chemical composition of chia seed powder comprised 19.78% protein, 30.06% fat, 4.82% ash, 31.88% crude fiber and 45.34% total carbohydrates. These results were in harmony with those of (Valdivia-Lopez and Tecante, 2015). On the other hand, the results in the same table showed that psyllium and chia seed powder can be considered rich sources for crude fiber , crude protein and fat.

Table 1. Chemical composition of psyllium and chia seed powder (g/100g on dry weight basis)

Raw materials	Psyllium seeds powder	Chia seeds powder
Crude protein %	15.82^{b}±1.22	19.78^{a}±0.015
Crude ether extract %	5.56^{b}±0.72	30.06^{a}±0.038
Ash %	4.03^{b}±0.82	4.82^{a}±0.025
Total carbohydrates %	74.59^{a}±3.32	45.34^{b}±2.32
Available carbohydrates %	47.52a±2.62	13.46^{b}±0.52
Crude fiber %	26.00^{b}±1.23	31.88^{a}±1.62
Soluble fiber %	6.50^{a}±0.62	2.40^{b}±0.02
Insoluble fiber %	19.50^{b}±0.92	29.48^{a}±1.72
Caloric value (kcal/100g)	303.40^{b}±3.78	403.50^{a}±2.50

- a, b, different superscript letters in the same rows are significantly different at LSD at ($p \leq 0.05$).
-Each value is an average of three determinations ± standard deviation.

Amino acid composition of psyllium and chia seed powders (g/100g):

The amino acid composition of psyllium powder was shown in Table 2. The results cleared that psyllium seed protein was considered a rich source of amino acids like leucine (8.20%), lysine (6.76%), tyrosine (6.47%), valine (5.45%), isoleucine (5.01)% and threonine (4.24%) as essential amino acids. On the contrary. Non-essential amino acids include aspartic acid (14.11%), proline

(8.20%), glutamic (7.62 %), arginine (6.45%), and glycine (4.61%) . These values of amino acids were in accordance with those obtained by (El-Hadidy, 2020), and glycine (4.61%). These values of amino acids were in accordance with those obtained by (El -Hadidy, 2020). Amino acid composition of chia seeds is shown in Table 2.The results cleared up the fact that chia seed protein was considered a poor source of amino acids like histidine (2.85%), tyrosine (3.03%), methionine (3.08%), threonine (3.82%) and phenylalanine (4.15%) which are considered essential amino acids. On the contrary, isoleucine, lysine and valine were predominant essential amino acids, representing 4.35, 4.85 and 5.10 % respectively. Nonessential amino acids included glutamic and arginine, which are basic amino acids at 18.65 and 11.33%, respectively, followed by aspartic, proline and alanine 8.93, 6.35, and 5.64 % respectively. These values of amino acids were in agreement with the results of (Abou raya et al., 2019). The study found that chia contains 10 necessary amino acids at cognizable levels. Protein-rich foods have a senior-level impact on weight loss due to the body's removal of fat. Excellent essential-non -essential amino acid balance from chia seed (Sandoval-Oliveros and Paredes-Lopez 2013).

Table 2. Amino acid composition of psyllium and chia seed powders (g. /100g protein)

Amino acids (g/100g protein)	Psyllium seeds powder	Chia seeds powder	FAO/WHO/UNU (1991) pattern
	Essential amino acids (EAA)		
Isoleucine	5.01	4.35	1.30
Lysine	6.76	4.85	1.60
Valine	5.45	5.10	1.30
Methionine	2.57	3.08	1.70
Tryptophan	1.13	1.05	-
Phenylalanine	4.30	4.15	1.90
Tyrosine	6.47	3.03	-
Threonine	4.24	3.82	0.90
Leucine	8.20	5.00	1.90
Histadine	3.51	2.85	1.60
Total EAA	47.64	37.28	12.20
	Non-essential amino acids (Non-EAA)		
Arginine	6.45	11.33	
Alanine	3.87	5.64	
Aspartic acid	14.11	8.93	
Glutamic acid	7.62	18.65	
Glycine	4.61	5.10	
Serine	4.26	5.53	
Proline	8.20	6.35	
Total NEAA	49.12	61.48	
C – PER*	2.58	1.48	
Biological value (B V) **	77.02	65.52	

Fatty acid composition of psyllium and chia seed powders

The results in Table 3. show the fatty acid composition of psyllium and chia powder. It has been observed that linoleic acid and oleic acid are the predominant fatty acids in psyllium seed oil. The oil of psyllium seed contains a high amounts of 12.05**%** palmitic acid (C16:0) and 3.83**%** stearic acid (C18:0); the results are in agreement with those of (El-Hadidy, 2020). From the same table comes the fatty acid composition of chia seed oil. It was observed that linoleic acid and linolenic acid are the predominant fatty acids in chia seed oil. Oil from chia seeds contains high amounts of 7.16**%**

palmitic acid (C16:0), 3.52**%** stearic acid (C18:0) and 10.84**%** oleic acid (C18:1) These results agree with those of **(**Abou raya et al., 2019).

Table 3. Fatty acids composition (g/100g oil) of psyllium and chia seed powders.

Fatty acid (g/100 g oil)	Psyllium powder	Chia powder
Saturated FA		
Myristic C14:0	00.04	00.02
Palmitic C16:0	12.05	07.16
Margaric C17:0	00.10	00.07
Stearic C18:0	03.83	03.52
Arachidic C20:0	00.42	00.32
Total SFA	16.44	11.59
Unsaturated FA		
Palmitoleic acid (C16:1)	00.16	00.08
Oleic acid (C18:1 – ω-9)	38.10	10.84
Linoleic acid (C18:2 – ω-6)	39.65	59.36
Linolenic acid (C18:3 – ω-3	03.18	16.63
Total USFA	81.09	86.91
Total FA	97.53	98.50

Biological Evaluations

Effects of feeding growth parameters

Data in Table 4. showed the effects of feeding with psyllium and chia seed powder on initial weight, final weight and body weight gain in normal and obese rats fed on HFD. These results illustrated that the initial weight ranged from (179.97 to 186.67) and it showed no significant ($p>0.05$) differences between all groups in the primary period of the experiment. Moreover, after inducing obesity, the results indicated a significant difference ($p\leq0.05$) among all experimental groups (G3, G4 and G5) compared to the positive control in the final weight and body weight gain. From the same table, it could be observed that rats fed HFD substituted with psyllium and chia seed powder significantly decreased ($p\leq0.05$) their final weight and body weight gain compared to rats fed the positive control. These findings are in accordance with those observed by **Pai and Prabhu (2019),** who reported that eating fibre increases satiety and thus reduces excess food intake and enhances weight loss.

Table 4. Effect of feeding on psyllium and chia seed on initial and final weight and bodyweight gain in rats.

Groups	Diets	Initial weight (g) (M±SD)	Final weight (g) (M±SD)	Body weight gain	
				g	%
G1	Negative control diet (BD)	179.97^{a}±4.51	213.33^{c}±3.54	33.36^{c}±1.42	18.54^{c}±1.75
G2	Positive control diet (HF)	183.33^{a}±2.54	241.67^{a}±2.56	58.33^{a}±1.62	31.84^{a}±1.53
G3	HF+ psyllium seeds 5%	184.33^{a}±3.51	228.33^{b}±3.52	44.00^{b}±2.11	23.85^{b}±1.56
G4	HF+chia seeds 5%	186.00^{a}±2.88	215.00^{c}±2.77	29.33^{c}±2.04	15.59^{cd}±1.30
G5	HF+2.5% psyllium and 2.5% chia seeds	186.67^{a}±3.55	213.33^{c}±4.15	26.00^{c}±1.75	14.27^{d}±1.46

* Each value was an average of six determinations ± standard deviation
* Values followed by the same letter in columns are not significantly different at ($p\leq0.05$).

Effect of psyllium , chia seeds and their mixture on glucose level

Data tabulated in Table 5. illustrates the effects of feeding psyllium, chia powder and their mixtures in different concentrations on glucose levels. The highest value was recorded in the positive control group because of the high fat diet which resulted in a significant increase ($p \leq 0.05$) in serum glucose level when compared to control group. The results showed that the level of blood glucose in the groups (G3, G4, and G5) of rats that fed on a basal diet supplemented with psyllium , chia seeds and their mixture significantly decreased ($p \leq 0.05$) compared to the positive control HFD (G2). It was also noted that the mixture of the tested seeds (2.5% psyllium and 2.5% chia seed powder) led to a greater reduction in blood glucose levels compared with psyllium and chia powder at (5%). These findings agreed with (Alamri, 2019), who concluded that chia powder has a helpful role in improving blood glucose levels in diabetic rats via increasing glucose tolerance and insulin sensitivity in obese rats.

Table 5. Effects of psyllium and chia seeds on blood glucose levels in rats fed a high-fat diet.

Groups	Glucose(mg/dl) M±SD			
	After adaptation	After 4 week	After 6 week	After 10 week
G1	87.67[a]±2.24	92.00[c]±2.65	92.33[d]±2.66	93.69[d] ±2.55
G2	88.67[a]±1.37	102.00[a]±1.65	117.00[a]±3.60	137.00[a]±2.50
G3	88.66[a]±1.77	97.67[b]±2.50	102.67[b]±2.78	111.67[b]±2.48
G4	87.00[a]±2.21	91.67[c]±2.63	96.63[c]±2.20	101.76[c] ±2.35
G5	89.00[a]±0 .89	90.33[c]±2.06	95.33[c]±2.73	99.00[c]±2.44

* Each value was an average of six determinations ± standard deviation
* Values followed by the same letter in columns are not significantly different at (p≤0.05).

Effect of psyllium and chia seed powder on some serum lipids parameters of rats

At the end of the experiment, a blood sample was taken from the rats for analysis of serum total cholesterol (TC), low lipoprotein cholesterol (LDL), very low lipoprotein cholesterol (vLDL-C), high- density lipoprotein cholesterol (HDL-C) and triglycerides and the results are shown in Table 6. The obtained results indicated a significant decreas (p ≤ 0.05) TC, triglycerides, LDL-c cholesterol and vLDL-C in the groups G3, G4 and G5 of rats that were fed a basal diet supplemented with psyllium , chia powder, or their mixture compared to the positive control group (G2), while HDL-C cholesterol significantly increased (p ≤ 0.05) compared to the positive control group (G2). This result was in agreement with (Kulczynski et al. 2019), who reported that chia seeds have a beneficial effect on improving lipid profiles, this effect may be due to its high content of α-linolenic acid (ALA), which is associated with beneficial changes in plasma lipids.

Table 6 . Effect of feeding rats on psyllium and chia powder on serum lipids parameter .

Groups	T. cholesterol mg/dl (M±SD)	Triglycerides mg/dl (M±SD)	HDL-C mg/dl (M±SD)	LDL-C mg/dl (M±SD)	vLDL-C mg/dl (M±SD)
G1	101.00[e]±3.00	132.66[c]±2.34	57.67[a]±1.82	16.67[e]±2.35	26.33[c]±1.51
G2	274.33[a]±2.41	202.67[a]±4.53	39.33[c]±1.52	194.43[a]±2.51	40.35[a]±1.35
G3	167.33[b]±2.56	160.00[b]±2.54	47.66[b]±2.21	87.66[b]±2.40	32.00[b]±1.36
G4	151.66[c]±2.51	155.00[b]±2.57	53.33[ab]±2.04	67.33[c]±2.35	31.00[b]±1.12
G5	142.67[d]±2.32	136.66[c]±3.15	59.00[a]±1.90	56.33[d]±1.97	27.33[c]±1.23

* Each value was an average of six determinations ± standard deviation
* Values followed by the same letter in columns are not significantly different at (p≤0.05).

Effect of psyllium and chia seed powders on kidney function of rats

Table 7 shows the effects of feeding with psyllium and chia seeds on kidney functions of urea, uric acid and creatinine in plasma. The obtained results illustrated that the urea, uric acid and creatinine increased significantly (p≤0.05) of positive control (G2) compared with the normal control (G1). While there is a significant decrease significant (p≤0.05) in urea, uric acid and creatinine in the groups feeding on the basal diet supplemented with psyllium and chia seeds compared with the positive control (G2), these results agree with Ebadollahi-Natanzi and Arabrahmatipour (2020).

Table 7. Effects of feeding on psyllium and chia seeds on kidney functions (urea, uric acid and creatinine) in rats.

Groups	Urea mg/dl (M±SD)	Uric acid mg/dl (M±SD)	Creatinine mg/dl (M±SD)
G1	38.33[e] ±1.48	2.78[e] ±0.13	0.88[e] ±0.06
G2	72.00[a] ±2.15	6.40[a] ±0.31	2.88[a] ±0.27
G3	65.33[b] ±1.58	5.61[b] ±0.25	2.36[b] ±0.17
G4	54.67[c] ±1.58	4.53[c] ±0.21	2.01[c] ±0.14
G5	45.00[d] ±1.55	3.67[d] ±0.32	1. 56[d] ±0.08

* Each value was an average of six determinations ± standard deviation
* Values followed by the same letter in columns are not significantly different at ($p \leq 0.05$).

Effect of psyllium and chia seeds powder on liver function of rats

Table 9. Effects of feeding with psyllium and chia seed powder on liver functions , Albumin and Bilirubin were increased significantly ($p \leq 0.05$) while total protein decreased significantly ($p \leq 0.05$) for the positive control rats (G2) compared with normal control rats (G1). The rats feeding on a basal diet supplemented with psyllium and chia seed powder showed significant decreases ($p \leq 0.05$) for liver functions while total protein increased compared to the positive control (G2).The results showed that the rats fed their mixture of psyllium and chia seeds showed the greatest improvement in liver function. The G5 results, supported by those of (El-Sherif et al., 2021) and (Fernández-Martínez et al., 2019), concluded that consumption of chia seed powder may improve the health state of non-alcoholic fatty liver disease (NAFLD) and could prevent hepatic cirrhosis or hepatocellular carcinoma (HCC).

Table 8. Effects of feeding different psyllium and chia powders on liver enzymes in diabetic rats.

Group	GOT (AST) IU/L	GPT (ALT) IU/L	Albumin (Unit)	Total protein (g/dl)	Bilirubin (mg/dl)
G1	22.33[d] ±1.18	31.25[e] ±1.76	3.93[d] ±0.15	6.73[a] ±0.34	0.29[e]±0.04
G2	45.67[a] ±2.24	49.66[a]±1.68	7.33[a] ±0.53	4.30[e] ±0.39	0.65[a]±0.06
G3	38.34[b] ±2.01	44.67[b] ±1.85	5.20[b] ±0.46	5.27[d] ±1.66	0.55[b]±0.05
G4	35.15[b] ±1.46	39.23[c] ±1.68	4.77[c] ±0.43	5.63[c]±0.36	0.48[c]±0.04
G5	28.12[c]±1.52	35.33[d] ±1.58	4.03[d] ±0.34	6.07[b] ±0.46	0.36[d]±0.08

* Each value was an average of six determinations ± standard deviation
* Values followed by the same letter in columns are not significantly different at ($p \leq 0.05$).

Discussion

The current study's objective was to determine changes in biological and biochemical parameters to examine the hypolipidemic effects of psyllium and chia powder added to diets in experimental groups that were fed basal diets, or HFD. The findings of the present investigation demonstrated that rats fed HFD showed an increase in blood sugar and cholesterol levels. The rats' blood glucose and cholesterol levels decreased after feeding on psyllium and chia seeds.

In this study, rats were fed a high-fat diet (HFD), which makes rats obese. Use tallow to increase the fat content of a high-fat diet. Elevation of fat (especially beef tallow) in the diet is an important factor in the development of obesity, hyperglycemia, hyperinsulinemia, and hepatic steatosis, which are closely related to human obesity. One of the main causes of obesity is the excessive intake of fatty acids, especially saturated and monounsaturated fatty acids, which are considered a major factor in the development of many diseases such as obesity, heart diseases, pressure and diabetes, and these acids are found in abundance in animal fats (Chinchu et al., 2020).

According to (Karhunen et al., 2010). Diets with psyllium fibre enhance blood sugar, insulin, and cholesterol levels much more than diets without dietary fibre. The cholesterol and glucose-reducing action of psyllium is proposed to be due to the formation of a viscous gel in an aqueous solution. This gel might prevent glucose from reaching the small intestine's absorptive epithelium, which would dampen postprandial glucose peaks. Furthermore, soluble fibre may postpone stomach emptying, decreasing the absorption of carbohydrates. Additional mechanism: psyllium seeds. By sequestering the carbohydrates consumed with the diet and delaying their absorption by digestive enzymes, psyllium seeds may also play a role in the postprandial effect. Also, the inhibition of liver gluconeogenesis may be the cause of the hypoglycemic effects of psyllium seeds (Pal et al., 2014).

Also, a new way that psyllium aids in weight loss may be through increasing adipose tissue's energy expenditure by promoting lipolysis and thermogenesis and activating the adrenal gland's release of adrenaline. Hormone-sensitive lipase (HSL), a crucial enzyme in the control of lipid storage, is activated as a result of this rise in serum adrenaline levels. The ability of HDL-C to act as acceptor particles for macrophage cholesterol efflux, avoid endothelial dysfunction, and maintain endothelial integrity also helps to prevent atherosclerosis (Linsel-Nitschke and Tall, 2005).

Additionally, three main theories have frequently been put forth to explain how soluble dietary fibre, such as psyllium, lowers cholesterol (Cornfine et al., 2010), first, viscous soluble fibre slows gastric emptying, which reduces the transfer and mixing of digestive enzymes and raises the resistance of the unstirred water layer lining the mucosa to intestinal absorption, delaying the digestion of macronutrients (Lairon, 2007). Second, increased faecal bile salt excretion may occur as a result of soluble fibre in the small intestine physically preventing bile salt reabsorption into the enterohepatic circulation. In the event that the liver's bile salt reserves are depleted, cholesterol may be rapidly catabolized in hepatocytes via activation of cholesterol 7-alpha-monooxygenase in order to refill the bile salt pool. Moreover, there was an increase in LDL-C surface membrane receptor synthesis, which improved LDL-C uptake from the bloodstream and lowered cholesterol levels (Ellegard and Andersson, 2007). The third is that fibre physically interferes with the intraluminal creation of micelles, reducing hepatic cholesterol synthesis that is controlled by fermentation products like propionate and decreasing cholesterol absorption and bile acid reabsorption (Anderson et al., 2000).

(Poudyal et al., 2012) demonstrated diets containing chia seed for obese rats over the course of eight weeks and noted a decrease in hepatic steatosis in the animals. This outcome may be attributable to chia seeds' capacity to cause lipid redistribution in the body, which reduces fat buildup in the liver and visceral tissue and has a hepatoprotective impact.

4. Conclusion

This study demonstrated that a meal supplemented with psyllium and chia powder had considerable antioxidant benefits in addition to having hypoglycemic and hypolipidemic effects. As a result, it was shown that psyllium and chia powder may be useful in the treatment of hyperglycemia and hyperlipidemia by lowering glucose and lipid profiles while reducing the risk of cardiovascular diseases.

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