Chapter 13

THE ROLE OF MEDICINAL PLANTS IN CORRECTING METABOLISM DURING AN UNHEALTHY DIET

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INTRODUCTION

Obesity has become one of the most pressing social problems in most economically developed countries. Even moderate obesity increases the risk of cardiovascular disease, diabetes and dyslipidemia (a component of the metabolic syndrome). According to the World Health Organization, in 2019, coronary heart disease, stroke and cirrhosis of the liver were the third, fourth and tenth leading causes of death, respectively. In upper-middle-income countries, coronary heart disease and stroke were the first and second leading causes of death in 2019, according to the same organization. One of the reasons for the development of these diseases is the increased calorie intake and high fat content in the daily diet[1]. Metabolic diseases, such as dyslipidemia and diabetes mellitus, are multifactorial and characterized by a combination of genetic predisposition and environmental factors such as diet and lifestyle. Obesity, which occurs as a result of metabolic changes at the organ and tissue level, leads to an imbalance between energy intake and energy use which in turn leads to increased lipid accumulation in adipose tissue. And adipose tissue itself is an important site for the synthesis of hormones, including leptin and adiponectin, as well as chemokines. Excess adipose tissue, caused by obesity, becomes dysfunctional and inflamed. Over time, these metabolic abnormalities can lead to vascular complications, which can result in vital organ dysfunction with a fatal outcome or a significant reduction in quality of life[2]. Some progress has been made in treating and preventing obesity, and several approaches have been proposed,

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including non-medical, medical and surgical procedures. Among the medical methods, synthetic drugs that normalize the hormonal background, suppress appetite, inhibit digestion and more are widely used. There are currently two main drugs on the market to treat obesity: orlistat, which slows down the absorption of fat in the intestines by inhibiting pancreatic lipase, and sibutramine, an anorectic that suppresses appetite. Of course, both these drugs have side effects, including headache, dry mouth, insomnia and increased blood pressure. Orlistat has been reported to cause gastrointestinal complications, and sibutramine has been associated with an increased cardiovascular risk[3]. Semaglutide, a GLP-1 analogue, is marketed for the treatment of type 2 diabetes and cardiovascular risk reduction in adults at doses up to 1 mg weekly. It has also been shown to cause weight loss in people with type 2 diabetes and obese adults in trials Sodhi (2023) and Wilding et al. (2021)[4].

An alternative to synthetic drugs is the use of medicinal plants, which often work similarly but are less toxic, relatively inexpensive and have no environmental impact[5]. Medicinal plants are used in traditional and folk medicine and in veterinary practice for treatment and prevention of aggravation of chronic diseases, diseases of the cardiovascular and nervous system, respiratory and digestive organs, liver, bile ducts, kidneys, urinary tract, for regulation of metabolism, for strengthening immunity, etc. Biologically active substances (alkaloids, glycosides, tannins, essential oils, etc.) contained in various parts of plants have a therapeutic effect on the body. For example, silymarin, extracted from the dried seeds of *Sylibum marianum*, is a well-known remedy with many scientific publications confirming the preventive and therapeutic effects of silymarin on various components of the metabolic syndrome. It has been shown to have protective effects, such as reducing insulin resistance, regulating blood pressure and lipid profile, as well as antioxidant and cytoprotective effects[6]. Herbal weight loss products are particularly attractive to consumers because of the general perception that if they are natural, they must be safe and effective. However, this is not

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always the case. The risks associated with many over-the-counter anti-obesity products are not properly controlled, and in many cases these supplements have been linked to serious health complications. One example is *Ephedra sinica*, which has been used as an appetite suppressant but has been banned by the Food and Drug Administration (FDA) due to a lack of toxicity studies[7]. Medicinal plants can exert their weight loss effects through five main mechanisms: appetite control, stimulation of thermogenesis and lipid metabolism, inhibition of pancreatic lipase activity, prevention of adipogenesis and stimulation of lipolysis. Well-known natural appetite suppressing medicinal plants include *Panax ginseng*, *Garcinia cambogia*, *Camellia sinensis*, *Hoodia gordonii*, *Hoodia pilifera*, *Phaseolus vulgaris*, *Robinia pseudoacacia*, *Pinus koraiensis*, *Ephedra* species, *Citrus aurantium*, *Hypericum perforatum*. Their main active ingredients in appetite suppressing action are saponins, steroidal glycosides, hydroxycitric acid (HCA), lectins, epigallocatechin gallate (EGCG), pine nut fatty acids, ephedrine, synephrine and others[8].

An important goal in the treatment of obesity is to inhibit the digestion and absorption of dietary carbohydrates and fats. Carbohydrate digestion is prevented by amylase inhibitors, also known as starch blockers. Some medicinal plants or herbal supplements based on them promote weight loss by preventing the breakdown of complex carbohydrates (amylase inhibitors) or by providing resistant or inaccessible starches in the large intestine. Developing fat digestion and absorption inhibitors is considered an important strategy to reduce energy intake by inhibiting pancreatic lipase[9]. The highest inhibitory activity against pancreatic lipase is shown by *Aleurites moluccana* (100%), *Cynometra cauliflora* (100%), *Orixa japonica* (80%), *Mangifera indica* (75%), *Justicia gendarussa* (61. 1%), *Rosa damascena* and *Levisticum officinale* (> 50%), *Myrtus communis*, *Nigella sativa*, *Pistacia vera*, *Pimpinella anisum*, *Trigonella foenum-graecum* and *Urtica urens* (25-50%) and others[10].

Herbal treatments have been suggested to have an anti-obesity effect by regulating the number and size of adipocytes, the expression of signals

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involved in energy balance, and the modulation of specific adipokines. *Garcinia cambogia*, *Capsicum annuum*, *Camellia sinensis*, *Panax ginseng*, *Silybum marianum*, *Allium sativum*, *Rosmarinus officinalis*, *Curcuma longa*, *Humulus lupulus* are the best-known natural inhibitors of adipocyte differentiation. The main active ingredients that have an antiadipogenic effect are hydroxycitric acid (HCA), capsaicin, tocotrienol, epigallocatechin gallate, ginsenosides, silibinin, ajoene, carnosic acid, curcumin, xanthohumol[11]. Phytochemicals such as resveratrol (a polyphenolic compound found naturally in peanuts, grapes, red wine and some berries) and epigallocatechin gallate (the most abundant catechin in tea) increase energy expenditure and thermogenesis. And various plant extracts and phytochemicals have been shown to reduce obesity by activating thermogenesis. Long-term studies have confirmed the benefits of fiber in the prevention and treatment of obesity, as high-fiber diets provide greater satiety than low-fiber diets. Fibers such as pectin, gum, mucilage, cellulose, hemicellulose, lignin and soluble fiber are found in many whole plant foods, including medicinal plants[12].

Despite the large amount of accumulated knowledge on the role of medicinal plants in the control and prevention of metabolic disorders, there is an urgent need to test the efficacy and safety of treatments based on them in clinical trials. Therefore, the objective of this study was to determine the general effect of a number of medicinal plants on the physiological activity and metabolic processes in model animals against the background of excessive fat content in the diet.

1. The problem's prerequisites emergence and the problem's formulation

In order to determine the corrective effect of medicinal plants on metabolic processes in the body, an experimental study was conducted on model animals.

Experimental design

Ethics. The selection of animals for the experiment, the research protocols and the withdrawal of animals from the experiment were approved by the local ethics committee of the Dnipro State Agrarian and Economic University (Dnipro, Ukraine). Maintenance, nutrition, care and withdrawal of animals from the experiment were carried out in accordance with the principles set forth in the "European Convention for the Protection of Vertebrate Animals used for Experimental or other Scientific Purposes" (Strasbourg, France,

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[12] Park T., Kim Y. Phytochemicals as potential agents for prevention and treatment of obesity and metabolic diseases. Anti-Obesity Drug Discovery and Development. 2011. P. 150–185.

March 18, 1986, ETS No. 123) and the Law of Ukraine "On Protection of Animals from Cruel Treatment" (Kyiv, February 21, 2006, No. 3447-IV).

Animals and diets. The experiment was conducted using 1.5-month-old outbred male laboratory rats with an average weight of 150 ± 10 g. The animals were kept in polycarbonate cages with four animals per cage in an indoor environment (temperature 20-22 °C, relative humidity 50-65%, light regime 12 hours of light and 12 hours of darkness). A control group and 14 experimental groups of seven animals each (n = 7) were formed. The control group of rats received a balanced diet consisting of a cereal mixture (75%) (corn, sunflower seeds, wheat, barley), root vegetables (8%), meat and bone meal (2%), and a mineral and vitamin complex (2%). Granules were made from the grinded components using a granulator. In addition, root vegetables in the appropriate amount and in fresh form were given on a daily basis. The high-fat diet for the experimental groups was prepared by adding 15% sunflower oil to the formulated balanced diet and then extruding it into pellets. In addition to the high-fat diet, the experimental groups received a dietary supplement comprising 5% of the dry and crushed components of medicinal plants, including inflorescences, flowers, leaves, young shoots, seeds, roots, and fruits. The raw materials of medicinal plants in a dry and finely ground state were added to the mixture of crushed grains with the premix, mixed thoroughly, and vegetable oil was added. Following this, pellets were produced at a rate of 4.200 g for each group over the entire period of the experiment.

Medicinal plants. Medicinal raw materials were administered in the official dosage form or were collected, dried, ground, and then added to the mixture of dry ingredients used to prepare pellets in a total amount of 4 kg per group of animals. Plants were collected from the Oles Honchar Dnipro National University Botanical Garden, Dnipro, Ukraine (48.4355°N, 35.0431°E). A total of 15 groups were formed, including one control group and 14 research groups. The characteristics of the groups are shown in Table 1.

Table 1

Characteristics of animal groups, medicinal plants and raw materials used in the study

Group number	Diet type	Medicinal plant	Medicinal raw materials
1	balanced	–	–
2	high-fat	–	–
3	high-fat diet	Golden root *Rhodiola rosea*	root
4	high-fat diet	Pomegranate *Punica granatum*	fruit peel
5	high-fat diet	Purple coneflower *Echinacea purpurea*	seeds

Continuation of table 1

Group number	Diet type	Medicinal plant	Medicinal raw materials
6	high-fat diet	Milk thistle *Sylibum marianum*	seeds
7	high-fat diet	Oregano *Origanum vulgare*	herb (young shoots and leaves)
8	high-fat diet	Baikal skullcap *Scutellaria baicalensis*	roots
9	high-fat diet	Elecampane *Inula helenium*	roots
10	high-fat diet	Blue chamomile *Matricaria chamomilla*	inflorescence
11	high-fat diet	Narrow-leaved lavender *Lavandula angustifolia*	inflorescence
12	high-fat diet	Lemon balm *Melissa officinalis*	herb (young shoots and leaves)
13	high-fat diet	Chaste tree *Vitex angus-castus*	herb (young shoots and leaves)
14	high-fat diet	Common sage *Salvia officinalis*	herb (young shoots and leaves)
15	high-fat diet	Clary sage *Salvia sclarea*	herb (young shoots and leaves)

Characteristics of the medicinal plants used in the experiment

Golden root (*Rhodiola rosea* L.) – is a well-known medicinal plant belonging to the genus *Rhodiola* of the family *Crassulaceae*. It is widely used as a tonic, antidepressant, anti-stress or functional food ingredient in many countries worldwide[13]. The plant's rhizome (underground stem) is mainly used for medicinal purposes, from which about 140 compounds have been isolated[14]. The main biologically active substance of *Rhodiola* is salidroside, which has numerous pharmacological effects (antidepressant, anticancer, antioxidant, antihyperlipidemic, antidiabetic, anti-inflammatory, immunomodulatory, etc.)[15]. The therapeutic effect of salidroside in the treatment of cardiovascular diseases is based on its antioxidant activity[16]. This compound has a neuroprotective effect that has been studied in

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experimental models in vitro and in vivo in ischaemic stroke[17]. A number of studies have shown that salidroside has neuroprotective activities, including anti-Alzheimer's disease, anti-Parkinson's disease, anti-Huntington's disease, anti-stroke, anti-depressive effects, and anti-traumatic brain injury; it is also useful for improving cognitive function, treating addiction, and preventing epilepsy[18]. *Rhodiola rosea* and salidroside in experiment showed good results in alleviating the symptoms of pulmonary hypertension in the exacerbation stage[19]. Salidroside has antiproliferative activity against breast, ovarian, cervical, colorectal, lung, liver, stomach, bladder, kidney, and skin cancer, as well as glioma and fibrosarcoma[20]. Beneficial effects in psychiatric, behavioural and metabolic disorders have been reported with Rhodiola extracts and salidroside. A review by Hung et al (2011)[21] showed that *Rhodiola rosea* may have beneficial effects on physical and mental performance as well as on certain mental disorders. This medicinal plant was chosen for this trial as there are recommendations for its use as an adaptogen[22] and as an immunomodulator[23].

Pomegranate (*Punica granatum L.*) is an ancient and useful plant of the Lythraceae family, now distributed almost worldwide and cultivated for food in many countries[24]. The phytochemical composition of the fruit is rich in compounds (flavonoid, ellagitannin, proanthocyanidin, mineral salts, vitamins, lipids, organic acids) with significant biological and nutritional value[25]. Pomegranate (*Punica granatum L.*) arils, peel, membranes and seed by-products

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are a rich source of phytochemicals (ascorbic acid, anthocyanins, gallic acid, ellagic acid, punicalagin, quercetin, etc.) with high antioxidant activity and thus have health benefits[26]. Pomegranate peel contains significant amounts of phenolic compounds such as hydrolysable tannins (punicalin, punicalagin, ellagic and gallic acid), flavonoids (anthocyanins and catechins), which are responsible for its biological activity[27]. Punicalin is an important antioxidant that is abundant in pomegranate peel. Pomegranate polyphenols not only have a strong antioxidant capacity, but also inhibit the growth of pathogenic bacteria (such as *Vibrio cholera, Pseudomonas aeruginosa and Staphylococcus aureus, Bacillus cereus, Escherichia coli*) and fungi (such as *Aspergillus ophraseus* and *Penicillium citrinum*)[28]. Due to the high content of polyphenols (ellagic acid, punicalagin), pomegranate peel is also effective against many pathogenic and opportunistic fungi[29]. Some studies have shown anti-cestode, anti-nematode and anti-protozoal activity[30]. In several studies, the fruit peel of P. granatum has been used in the treatment of cryptosoridiosis, indicating the absence of side effects[31]. In a review by Guerrero-Solano et al. (2020), different parts of pomegranate were found to have an antinociceptive effect, which may be due to the presence of polyphenols, flavonoids or fatty acids. Pomegranate components (e.g., tannins, flavonoids, phytoestrogens, anthocyanins, alkaloids, etc.) have beneficial effects on the cardiovascular system, improve parameters such as oxidative stress and enzymatic antioxidant system, reduce the formation of reactive oxygen species, and act in an anti-inflammatory manner[32]. Due to its antioxidant activity, the use of pomegranate is promising in the treatment of chronic diseases[33]. Pomegranate-derived compounds reduce oxidative stress and platelet aggregation, reduce lipid

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uptake by macrophages, benefit endothelial cell function and are involved in regulating blood pressure[34]. The angiotensive effect of *Punica granatum* is associated with angiotensin-converting enzyme inhibition, as demonstrated in in vitro studies in laboratory animals and humans[35]. Pomegranate has shown antiproliferative, antimetastatic and anti-invasive effects on various cancer cell lines *in vitro, in vivo* and in clinical trials[36]. Given that many publications indicate the ability of pomegranate fruit to influence lipid metabolism[37] and even recommend using the plant to treat obesity[38], we chose this medicinal plant for our study.

Purple coneflower (*Echinacea purpurea (L.)* Moench) is a well-known medicinal plant with a long history of medicinal use, particularly for infections[39]. It contains many active compounds, but the main active component of coneflower is a mixture of oxycinnamic acids: cichoric acid, ferulic acid, coumaric acid and caffeic acid. The plant contains polysaccharides (heteroxylans, arabinorhamnogalactans), essential oils (0.15-0.50%), flavonoids, tannins, saponins, polyamines, echinacin (amide of polyunsaturated acid), echinolone (unsaturated ketoalcohol), echinacoside (glycoside containing caffeic acid and pyrocatechin), organic acids, resins, phytosterols and other components. The plant is rich in macro (potassium, calcium) and trace minerals (selenium, cobalt, silver, molybdenum, zinc, manganese, etc.)[40]. It is used to treat depression, mental and physical exhaustion, sore throat, tonsillitis, visceral inflammation, acute infections,

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wounds, ulcers and burns[41]. Echinacea polysaccharides have been used as antioxidant agents[42]. This plant is considered to be an immune response enhancer and its main indications are the prevention and treatment of the common cold, influenza, and infections of the upper respiratory tract or lower urinary tract[43]. *Echinacea purpurea* activates the immune system by stimulating T-cell production, lymphocyte activity, phagocytosis, cellular respiration and suppressing hyaluronidase enzyme secretion. Described immunomodulatory mechanisms include macrophage activation, polymorphonuclear leukocyte and natural killer cell activation, and the ability to alter T and B lymphocyte numbers and their activity[44]. *In vitro* studies have shown that chicoric acid, the major constituent of *Echinacea purpurea*, inhibits the proliferation of human colon cancer cells in a dose– and time-dependent manner. In mice with leukaemia, it exerts a suppressive effect on leukaemia cells via IFN-γ activity[45]. There have been no long-term studies of the effect of echinacea on relative organ mass in animals, and studies of its effect on blood biochemical and cytological parameters are fragmentary. There are no comprehensive evaluations of the effect of any echinacea preparations on mammals under conditions of excessive caloric intake or high-fat diet.

Milk thistle (*Silybum marianum* (L.) Gaertn.) – is a medicinal plant cultivated for its medicinal properties and as a melliferous plant. For a long time, milk thistle was not considered as a raw material for producing pharmacological preparations, but it was found that the fruits contain a group of flavonolignans, the components of which are silibin, silidianin and silicristin. The chemical composition of the fruit includes proteins, saponins, fatty oil (up to 25%), alkaloids, vitamin K, macro– and trace elements, tyramine, histamine, resins, mucilage. The main active compounds in milk thistle are flavonoids and flavonolignans under the common name of silymarin. Silymarin is found throughout the plant, but its maximum level is concentrated in the seeds. Silymarin acts as an antioxidant by reducing free radical formation and lipid peroxidation, has antifibrotic effects and may act as a toxin blocker by inhibiting the binding of toxins to hepatocyte cell

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membrane receptors. Silymarin has been used to treat alcoholic liver disease, acute and chronic viral hepatitis, and toxin-induced liver failure[46]. Neha et al. (2014)[47] evaluated the association between obesity caused by high-fat diet and dementia and found that silymarin may play an important role in improving cognitive status in post-obesity dementia by exerting anti-inflammatory and antioxidant effects. In diabetes mellitus, silymarin reduces plasma glucose levels by reducing insulin resistance and restoring pancreatic islet beta-cell function[48]. In diabetes and hypertension, silymarin prevents the urinary excretion of albumin, thereby reducing kidney damage[49]. The clinical efficacy of silymarin in combination with berberine has been demonstrated in patients with type II diabetes mellitus with severe hyperlipidemia. Their use can improve fasting blood glucose levels, total cholesterol, LDL, triglycerides and hepatic transaminases[50]. Scientists have developed hepatoprotectors ('Carsil', 'Silibor', 'Legalon', 'Hepabene', 'Hepasil') based on milk thistle fruits, which have antioxidant and immunomodulatory properties, including a mild choleretic effect. Produced formulations contain a variety of flavonoids and flavonolignans and are used in the treatment of liver diseases (hepatitis, cirrhosis, toxic lesions), spleen, gallstones, jaundice, chronic cough and other diseases. Most of the effects of milk thistle seeds are related to hypoglycemic and hypolipidemic action. This is why this plant was selected for inclusion in our experiment.

Oregano (*Origanum vulgare L.*) is a perennial herbaceous plant of the Lamiaceae family that is cultivated in many countries. The oregano herb (*Herba Origani vulgaris*) is used as a raw material for medicinal purposes and is harvested during mass flowering. The medicinal properties of oregano are due to its biochemical composition. The plant raw material contains ascorbic acid, carotenoids, a number of flavonoids, tannins, organic acids, but especially valuable is its essential oil, which contains such aromatic and biologically active substances as phenols, terpenoids, saponins, alkaloids,

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coumarins, anthocyanins. The high content of carvacrol and thymol gives it strong antibacterial properties, more effective than many modern antibiotics. *Origanum vulgare* is widely used in traditional medicine for the treatment of many conditions such as allergies, hypertension, respiratory infections, diabetes, stomach pain and intestinal antispasmodic[51]. *Origanum vulgare* is used medicinally as an antifungal agent, diuretic, anti-inflammatory, laxative, gastric stimulant, analgesic, expectorant, cough suppressant, disinfectant, anticonvulsant, anticancer[52] and as an alternative antimalarial. Pezzani et al. (2017)[53] review the biological activities of *Origanum vulgare* and its main bioactive phytochemicals, considering both preclinical (*in vitro* and *in vivo*) and human studies with a focus on anticancer, anti-inflammatory, antioxidant and antimicrobial activities. The essential oil obtained from the plant contains thymol 44-50%, carvacrol, bi– and tricyclic sesquiterpenes 12.5%, and geranyl acetate 2.6-5.0%[54]. *Origanum vulgare* has been described as one of the sources of plant tannins, which probably accounts for the widespread use of its essential oil in the treatment of skin diseases[55]. The antiplatelet activity of *Origanum vulgare* is associated with the presence of caffeic acid, salvigenin and umbelliferone, and it is known that plants rich in polyphenols are used to prevent thrombosis. In addition to antimicrobial activity, oregano essential oils also have antidiabetic and anticancer activities[56]. Studies by Mahmoudian-Sani et al. (2017)[57] found that *Origanum vulgare* can stimulate the function of Treg cells, which play an important role in maintaining self-tolerance and preventing autoimmune diseases. The multiple effects of *Origanum vulgare's* active compounds contributed to the selection of this plant in our experiment.

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Baikal skullcap *(Scutellaria baicalensis)* is a perennial species of the Lamiaceae family distributed in China, Korea, Mongolia, and the Russian Far East and Siberia[58]. Phytochemistry and pharmacology of Scutellaria plants, especially *Scutellaria baicalensis*, *Scutellaria barbata* and *Scutellaria lateriflora* species, have been of interest to many researchers in recent decades. The root of *Scutellaria baicalensis*, which contains several important bioactive compounds: wogonin, scutellarein, baicalein and baicalin, has long been used in traditional Chinese medicine[59]. The roots of *Scutellaria baicalensis* have been used for the prevention and treatment of type 2 diabetes, atherosclerosis, high blood pressure, hyperlipidemia, dysentery and respiratory diseases[60]. *In vitro* and *in vivo* studies have supported the value of bioactive compounds from the genus Scutellaria for central nervous system disorders such as Alzheimer's disease, cerebral ischemia, depression and anxiety[61]. The main bioactive flavonoids in *Scutellaria baicalensis* are baicalein and baicalin. Due to its anti-inflammatory and immunomodulatory effects, baicalin has been successfully used in the treatment of cerebrovascular and neurological diseases, as supported by numerous in vivo and *in vitro* studies[62]. Pharmacological mechanisms have shown that baicalin and baicalein have multiple biological activities, including antioxidant, anti-apoptotic, anti-inflammatory and anti-excitotoxicity effects, mitochondrial protection, promotion of neuronal protective factor expression and adult neurogenesis effects, and many more. Baicalein exhibits potent antioxidant and anti-inflammatory effects, has anticonvulsant, anxiolytic and mild sedative properties, and significantly improves cognitive and mental function in animal models of brain ageing and neurodegeneration[63]. The anti-inflammatory, anticancer and antiviral effects

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of baicalein are related to its regulatory effect on the immune system[64]. Baicalin ameliorates chronic inflammation, immune dysregulation, impaired lipid metabolism, apoptosis and oxidative stress, thus playing an important role in preventing the onset and progression of cardiovascular diseases (atherosclerosis, hypertension, myocardial infarction and heart failure)[65]. Accumulated data show that *Scutellaria baicalensis* has potent anticancer activity. A review by Li-Weber (2009)[66] summarized the results obtained over the last 20 years and highlighted the main molecular mechanisms of action. Baicalein has a complex anticancer potential, ranging from anti-inflammatory to anti-angiogenic/anti-metastatic effects. Park et al (2019)[67] attributed the alleviation of cancer cachexia symptoms by *Scutellaria baicalensis* administration to its anti-inflammatory effects, regulation of the neuroendocrine pathway, and modulation of the ubiquitin proteasome system or protein synthesis. Zhang et al. (2018)[68] attributed the anti-tumor effect of *Scutellaria baicalensis* to the mechanism of inhibition of angiogenesis through inhibition of cytokines (vascular endothelial growth factor) that initiate it. Extracts and major flavonoids of *Scutellaria baicalensis* have shown anti-cancer effects on several cancer cell lines in in vitro and in vivo experiments. Despite numerous reports on the pharmacological effects of baicalin and baicalein, some reports suggest that the baicalin form is unlikely to be absorbed in the gut and should be pre-hydrolyzed to baicalein for absorption. It is more likely that the pharmacokinetic properties of baicalin and baicalein are influenced by the gut microbiome[69]. Baicalein is a well-studied drug derived from the roots of the plant *Scutellaria baicalensis*. Its popularity is attributed to its antioxidant, antiviral, anti-inflammatory, anti-allergic and anti-thrombotic properties, which allows its use in the treatment of cardiovascular diseases. Experimental and clinical data prove that vagonin exhibits diverse biological activities such as anticancer, anti-inflammatory, used for the treatment of bacterial and viral diseases. Vagonin has been shown

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to inhibit tumor cell growth, induce apoptosis and inhibit angiogenesis[70]. The diversity and pronounced biological activity of the flavonoids of *Scutellaria baicalensis* indicate that this plant deserves further research for the development of new drugs[71]. Therefore, we selected this plant for the experiment.

Elecampane *(Inula helenium L.)* is a perennial plant of the Asteraceae family. The rhizomes and root contain inulin (up to 44.0%) – a polymer of fructose – and other polysaccharides, bitter substances, essential oil (up to 4.5%), saponins, resins, gum, mucilage and small amounts of alkaloids. The root contains helenin ($C_{15}H_{20}O_2$), a stearoptene, which can be prepared in white acicular crystals, insoluble in water but freely soluble in alcohol. The essential oil contains alantolactone (proazulene, helenin), resins, mucilage, dihydroalantolactone, friedelin, stigmasterne, phytomelan, pectins, wax, gum and vitamin E[72]. The plant has expectorant and anti-inflammatory effects, reduces intestinal peristalsis, and decreases gastric juice secretion. Tavares & Seca (2019)[73], in their study of *Inula L.*, identified the most promising secondary metabolites for the treatment of oxidative stress-related human diseases. β-Caryophyllene is the most promising, as it showed the highest antioxidant activity, even when compared to ascorbic acid. Alantolactone and related terpenoids are considered to be the major bioactive compounds in elecampane. Studies have been carried out with alantolactone from *Inula helenium* rhizomes, which have shown activity against tumor cells[74]. Alantolactone has also been shown to have anti-inflammatory properties by enhancing the phagocytic activity of macrophages[75]. In folk medicine, preparations of this plant are reported to have diuretic and anthelmintic effects. The essential oil of *Inula helenium* roots has bactericidal and

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fungicidal properties[76]. Folk medicine uses rhizome tinctures and extracts for malaria, edema, urolithiasis, gastritis with hypochlorhydria, migraine, pertussis, bronchial asthma, as a styptic, diuretic, anti-inflammatory for skin diseases[77]. The presence of many pharmacological effects allowed us to hypothesize metabolic effects of this plant and include elecampane in our experiment.

Chamomile *(Matricaria chamomilla L.)* is widespread in Europe, Asia and North America, growing widely in fields, gardens, wastelands and settlements, and is cultivated in many countries as a valuable medicinal plant[78]. Chamomile is known as a valuable medicinal plant used in both traditional medicine and the official pharmacopoeia of 26 countries[79]. Chamomile contains a number of phytochemicals: flavonoids and other phenolic compounds, essential oil, polysaccharides, amino acids, fatty acids and mineral elements[80]. Chamomile inflorescences are more commonly used in medicine. Dried inflorescences contain derivatives of apigenin, luteolin and quercetin, coumarins (herniarin and umbelliferone), free organic acids (caprylic acid, anthemic acid, isovaleric acid, salicylic acid), phytosterols, bitters, gums and the glycosides apigenin and herniarin. Chamomile is used to make infusions and extracts, as well as extracted essential oil, the most valuable part of which is azulene chamazulene, but also contains other sesquiterpenoids (up to 50%) – farnesene, bisabolol, bisabolol oxides A and B, monoterpene myrcene and others. In addition, more than 120 chemical components have been identified as secondary metabolites in chamomile flowers[81]. At the same time, the content of individual substances depends on many factors, including climatic conditions, soil and fertilizers used during cultivation[82]. Due to the diverse composition of active compounds, chamomile preparations have numerous pharmacological effects. Chamazulene has anti-inflammatory, anti-allergic, sedative and local

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anesthetic effects, enhances regenerative processes, activates the function of immune organs. Apigenin and herniarin have a moderate antispasmodic effect, so chamomile preparations are actively used to relieve pain and relax smooth muscles in gastrointestinal disorders. Herniarin also has diaphoretic properties. The antispasmodic effect of chamomile preparations has found application in gynecology: they are used in menstrual disorders, dysmenorrhea, endocervicitis, vulvitis, vaginitis, nipple fissures in breastfeeding mothers[83]. The cholesterol-lowering and anti-diabetic effects of chamomile have been demonstrated in animal studies[84]. The active constituents of chamomile also influence the hormonal status, so chamomile preparations are mainly used in endocrinology to normalize the functions of endocrine organs and metabolic processes. Zand et al. (2001)[85] showed a weak estrogenic and progestogenic effect of chamomile extract in high concentrations. Chamomile preparations have pronounced effects on the nervous system. Chamomile essential oil has been shown to increase reflex activity, excite the medulla oblongata, increase heart rate, increase respiration, dilate cerebral vessels, but at high doses it causes decreased muscle tone and central nervous system depression[86]. Chamomile preparations are often used externally, mainly as an anti-inflammatory agent, but infusion of chamomile flowers has styptic, antiseptic, slightly astringent, analgesic, sedative, anticonvulsant, diaphoretic, choleretic effects. In dentistry, chamomile preparations are used to treat periodontitis, gingivitis and stomatitis and in dermatology to treat seborrhea, hyperkeratosis and eczema[87]. Animal studies suggest that chamomile has antispasmodic, anxiolytic, anti-inflammatory and some antimutagenic and cholesterol-lowering effects[88]. Therefore, chamomile is recommended for the treatment

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of certain pathological changes in hypertension, which is why we chose this medicinal plant for the current study.

Narrow-leaved lavender *(Lavandula angustifolia)* is a perennial plant used in many areas of life. The experimental pharmacology of *Lavandula angustifolia* includes anticonvulsant, sedative, anti-inflammatory, antimicrobial, antispasmodic effects, the ability to relax the central nervous system, and in clinical pharmacology its analgesic effect and effect on the cardiovascular system are being considered[89]. In folk medicine, *Lavandula angustifolia* is used to treat migraine, neurasthenia, stress[90], cardiovascular diseases[91] and some diseases of the urinary system[92]. *Lavandula angustifolia* preparations have also been shown to be effective in the treatment of skin diseases, rheumatism and injuries[93]. There are many reports on the positive effect of *Lavandula angustifolia* on the state of the nervous system (mood, behavior and perception), which is used in the treatment of various nervous disorders such as epilepsy, stress, dementia, Alzheimer's disease[94]. A number of scientific studies have been devoted to the investigation of the pharmacological effects of *Lavandula angustifolia* essential oil[95]. A systematic meta-analysis of randomized controlled trials on the efficacy of *Lavandula angustifolia* essential oil showed that its inhalation can significantly reduce anxiety, but no significant effect on the reduction of systolic blood pressure was found[96]. The compounds in *Lavandula angustifolia* essential oil have immunomodulatory properties, increasing the

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phagocytic activity of macrophages against bacteria[97]. Researchers suggest that the antimicrobial effect of *Lavandula angustifolia* essential oil is associated with the concomitant acceleration of phagocytosis and activation of the inhibition of intracellular replication of bacteria grown in human monocytes pretreated with essential oil and then infected with *S. aureus*. This stimulation was associated with the expression of genes involved in the production of reactive oxygen species. Therefore, the authors concluded that *Lavandula angustifolia* essential oil enhances innate immunity by stimulating phagocytosis while attenuating the inflammatory response, thereby supporting and balancing the overall immune response[98]. By studying the levels of IgA in the saliva of pregnant women, researchers have found that aromatherapy massage with *Lavandula angustifolia* essential oil can significantly improve immune function. A statistically significant increase in the number of leukocytes and lymphocytes in the peripheral blood of people with breast cancer was found during a 30-minute aromatherapy massage twice a week for one month using essential oils including *Lavandula angustifolia*[99]. The essential oil of *Lavandula angustifolia* has a marked analgesic effect, in particular its inhalation reduces the severity of pain in the postoperative period after inguinal hernia repair, palatine tonsil removal in children, caesarean section in laboring women and during childbirth in women, in cancer and during hemodialysis[100]. Because of the wide range of pharmacological effects of both the plant itself and the drugs derived from it, we chose this medicinal plant for our study.

Lemon balm *(Melissa officinalis L.)* is a well-known medicinal plant that has long been used in folk medicine in various countries. The leaves and stems of lemon balm are used as medicinal raw materials, containing up to 1% essential oil, rich in citral, citronellal, myrcene, geraniol, cineole and aldehydes. The plant contains many biologically active compounds such as terpenes (monoterpenes, sesquiterpenes and triterpenes) and phenolic

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compounds (phenolic acids, flavonoids and tannins)[101]. A brief description of the botanical characteristics, traditional uses, phytochemistry, pharmacological activity, pharmacokinetics and toxicity of *Melissa officinalis*, as well as unresolved issues and future research opportunities for this plant can be found in the review by Shakeri et al. (2016)[102]. Lemon balm has a wide range of pharmacological effects. For example, the scientific literature describes its sedative, antispasmodic, hypotensive, analgesic, antimicrobial, antihistamine, mild laxative and diaphoretic effects. Lemon balm aqueous-alcohol extract is recommended as an alternative or complementary medicine in the treatment of diabetes mellitus, as it has been shown to be active in preventing damage to β-cells of the pancreatic islets[103]. Lemon balm essential oil has been shown to have a hypoglycemic effect and a beneficial effect on non-alcoholic fatty liver disease caused by a high-fat diet. It has also been shown that the compound ALS-L1023, an angiogenesis inhibitor isolated from *Melissa officinalis*, when administered to obese mice, reduces weight gain, the amount of adipose tissue and adipocyte size[104]. Lemon balm in the form of a 10% aqueous tincture has been shown to protect liver tissue and normalize blood glucose levels in rats fed an unbalanced diet (cafeteria diet)[105].

Chaste tree *(Vitex agnus-castus L.)* is an arboreal shrub of the Lamiaceae family; leaves, flowers, fruits, branches, and rarely bark are medicinal raw materials[106]. All parts of the plant contain iridoid glycosides (agnuside, aucubin), flavonoids (casticin, vitexin, isovitexin, orientin, isoorientin), p-hydroxybenzoic acid, alkaloids, tannins, essential oil. The essential oil of the leaves contains 1,8-cineol, trans-beta-farnesene, alpha-pinene, trans-beta-caryophyllene and terpinen-4-ol. The leaves contain mainly 1,8-cineol (22.0%), trans-beta-farnesene (9.4%), alpha-pinene (9.4%), trans-beta-caryophyllene (8.2%), terpinen-4-ol (7.8%), limonene (4.8%), alpha-

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terpineol (3.8%), sclarene (3.3%), alpha-terpinyl acetate (3.1%), p-cymene (3.0%). 1,8-cineol and alpha-pinene also showed very high antimicrobial activity[107]. The fruits and herb of Chaste tree are included in the European Pharmacopoeia and the pharmacopoeias of several European countries. They are used in cases of insufficient lactation, menstrual disorders, and as a diuretic and an irritant. *Vitex agnus-castus* extract had the highest cytotoxic activity of 57 medicinal plants tested in the experiment[108]; the authors also indicate that the particularly high cytotoxicity is not due to the low concentration of antioxidants in it, but is manifested through other signaling pathways. An extract from the ripe fruit of *Vitex agnus-castus* may be a promising anticancer candidate[109]. Vitex induced a dose– and time-dependent decrease in cell viability associated with induction of apoptosis and G(2)/M cell cycle arrest. Vitex-based preparations are used in gynecology for premenstrual syndrome accompanied by edema, scanty or absent menstruation, anovulatory cycles, cycle irregularities after the use of contraceptives, infertility associated with hyperprolactinemia, breast pain[110]. The plant is also used in the production of drugs such as Cyclodynon, Mastodynon, Prefemine, Biocyclin and others. According to Safarabadi et al (2018)[111], *L. officinalis* and *V. agnus-castus* are among the most important analgesic plants. Despite the relatively detailed study of the chemical composition of Chaste tree, its effects on metabolic processes are poorly understood. Therefore, this medicinal plant was included in our experiment.

Common sage *(Salvia officinalis)* is a well-known medicinal plant cultivated in several European countries. The leaves or flowering tops of sage are the raw material. The value of sage as a medicinal plant is its essential oil, which consists of D-α-pinene, cineol (about 15%), α– and β-thujone, D-borneol, and D-camphor. The leaves also contain alkaloids, flavonoids, tannins, oleanolic and ursolic acid, and the fruit contains 19-25% fatty oil, mainly linoleic acid glycerides. *Salvia officinalis* was used as a reference

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plant with well-documented antioxidant activity[112]. A correlation between the radical scavenging capacities of the extracts and the total phenolic compound content was observed. The extract of Salvia officinalis has the strongest antioxidant capacity among the five species of the genus Salvia that were studied[113].

Clary sage *(Salvia sclarea L.)* is an equally well-known medicinal plant used for essential oil production[114]. The essential oil of *Salvia sclarea L*. has been known since ancient Greece and its main components are linalyl acetate (19.8–31.1%), linalool (18.5–30.4%), geranyl acetate (4.5–12.1%), and a-terpineol (5.1–7.6%)[115]. Karayel & Akcura (2019)[116] found that the volatile oil components of *Salvia sclarea* and *Salvia officinalis* are comparatively richer in terpenes, and the amount of volatile oil varies according to ecological factors. While the seed oil of *Salvia officinalis* can be classified as an oleic-linoleic oil, the predominant fatty acid in *Salvia sclarea* was – linolenic acid (about 54%). Among the tocols, the major isomers in both seeds and oils were – tocopherol, followed by – tocopherol[117]. The acetone extract of *Salvia sclarea* contains nine diterpenes: sclareol, manool, salvipisone, ferruginol, microstegiol, candidissiol and 7-oxoroyleanone, 2,3-dehydrosalvipisone and 7-oxoferruginol-18-al. In addition, two sesquiterpenes, caryophyllene oxide and spathulenol, alpha-amyrin, beta-sitosterol, and the flavonoids apigenin, luteolin, 4'-methylapigenin, 6-hydroxyluteolin-6,7,3',4'-tetramethyl ether, 6-hydroxypigenin-7,4'-dimethyl ether were found in the plant[118]. The results confirmed that the activity of sclareol could reduce tumor growth in vivo against breast cancer. The antiviral activity of sclareol also has significant potential. Filoviruses are

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known to cause severe hemorrhagic fevers in humans. Ebola virus (EBOV) is the most infectious filovirus. Sclareol and sclareolide showed inhibitory effects on the entry of all tested filoviruses, indicating their broad-spectrum activities against filoviruses[119]. Modern clinical studies confirmed the efficacy of *Salvia sclarea* oil as an anti-stress, antidepressant, and analgesic in primary dysmenorrhea. The antioxidant, antimicrobial, cytotoxic, and anti-inflammatory effects of clary sage have been confirmed. Salvia sclarea essential oil has pronounced antifungal activity. 2,3-Dehydrosalvipisone, sclareol, manool, 7-oxoroyleanone, spathulenol, and caryophyllene oxide were found to be active against S. aureus, the first and third compounds against Candida albicans, and the last compound against Proteus mirabilis[120]. Aromatic plant species of the genus Salvia are important medicinal plants highly recommended for their therapeutic properties: antiseptic, antispasmodic, antimicrobial, antirheumatic, antidiabetic, and carminative[121]. Species of the genus Salvia possess significant antioxidant and antiproliferative activities against tumor cells. The results strengthen the evidence that the genus Salvia could be considered a natural resource of potential antitumor agents[122]. The antioxidant properties of sage are mainly attributed to the high content of phenolic compounds. The *Salvia sclarea* diterpenoids aethiopinone and salvipisone may be useful in the treatment of human cancers, especially in the case of drug resistance[123]. Therefore, we selected these two species of Salvia plants for the present experiment.

During the experiment, the amount of food and water consumed by the rats in each group and the total amount were determined. Animals were weighed at the beginning of the experiment, periodic control weighs were performed, and the weight of each animal was determined at the end of the experiment. Total weight gain and daily live weight gain were calculated.

Blood was collected from the rats during euthanasia. After anesthesia, blood was collected directly from the heart. A test tube was used to collect whole blood (1-1.5 mL) to obtain serum for further biochemical assays.

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Blood serum was obtained by allowing the blood to stand for some time and then centrifuging it on a CM-3M.01 MICROmed centrifuge (200×g, 5 min; MICROmed, Shenzhen, China). All assays of blood biochemical parameters were performed using a Miura 200 automated analyzer (I.S.E. Srl, Rome, Italy). We also followed the manufacturer's instructions for the use of commercial reagent toolkits from High Technology Inc. (North Attleborough, MA, USA), PZ Cormay S.A. (Lublin, Poland), and Spinreact S.A. (Girona, Spain).

To evaluate protein and mineral metabolism in the obtained blood serum, we determined total protein and its individual fraction, urea, creatinine, total bilirubin, total calcium, inorganic phosphorus, C-reactive protein. Total protein (g/L) was measured using the Biuret reagent (Cormay Diagnostics, Warsaw, Poland), whose copper ions react with protein in alkaline solution, forming a colored complex. The concentration of albumins (g/L) was measured using bromocresol green (Cormay Diagnostics, Warsaw, Poland). Globulins (g/L) were estimated by subtracting the concentration of albumins from the total protein concentration. Enzymatic method gave total bilirubin concentration (μmol/L). We used urease enzyme, which forms a colored complex by reacting with cholesterol in blood. The color intensity of the reaction was measured spectrophotometrically at λ=490-520 nm, and the absorbance was proportional to the concentration of cholesterol in blood serum. Urea (mmol/L) was determined enzymatically. In urease-catalyzed reactions, urea interacts with NADH, the absorbance of which was measured spectrophotometrically at λ=340 nm. Simultaneously, blood urea nitrogen (mg/100 g) was determined. Creatinine (μmol/L) was determined kinetically based on the Jaffe reaction with picric acid. Creatinine in blood serum reacts with picric acid in acidic solution to form a yellow-red colored complex. The absorbance at λ=505 nm of the formed complex is proportional to the creatinine concentration in the sample. Total calcium (mmol/L) and inorganic phosphorus (mmol/L) were determined by spectrophotometric method at λ=635 nm. Calcium in the sample reacted with arsenazo III (Cormay Diagnostics, Warsaw, Poland) to form a colored complex, and phosphorus reacted with ammonium molybdenum. The Ca/P ratio indicator is the ratio of total calcium to inorganic phosphorus. Quantification of C-reactive protein (mmol/L) was performed in relation to the turbidity of the solution after latex agglutination with specific antibodies. Carbohydrate metabolism was identified by the concentration of glucose (mmol/L). It was determined by the glucose oxidase method with the consecutive use of glucose oxidase and peroxidase, resulting in the formation of a colored complex, measured by the spectrophotometric method at λ=505 nm. Lipid metabolism was evaluated by the following parameters: cholesterol, blood triglycerides, high-density lipoprotein (HDL) cholesterol (mmol/L) and low-density lipoprotein (LDL) cholesterol, and plasma atherogenic index. Cholesterol (mmol/L) was identified by cholesterol oxidase, which reacts with cholesterol to form a colored complex. Its color intensity, measured spectrophotometrically at λ=490-520 nm, is proportional to the concentration of cholesterol in the examined material. Blood triglycerides (mmol/L) were quantified enzymatically using glycerol kinase and glycerol phosphate oxidase, which form a colored complex as a result of a side reaction in the presence of ATP. The spectrophotometric method was used at λ=365-405 nm and the absorbance of the complex was proportional to the triglyceride content of the sample. HDL cholesterol (mmol/L) and LDL cholesterol (mmol/L) were determined using selective detergents and after identifying the color intensity of the quinine reagent formed using a spectrophotometer at λ=600 nm. We also calculated the atherogenic index of plasma. Changes in enzymatic activity in blood plasma were monitored in relation to activities in aspartate aminotransferase (AST, U/L) and alanine aminotransferase (ALT, U/L). The kinetic method based on the Warburg test was used. The activities of AST and ALT were determined according to the rates of NADH (nicotinamide adenine dinucleotide), and the absorbance was measured spectrophotometrically at λ=340 nm. Alkaline phosphatase activity (U/L) was determined enzymatically according to the rates of formation of 4-nitrophenol, the absorbance of which was quantified at λ=405 nm. The rates of 4-nitrophenol formation are directly proportional to the activity of alkaline phosphatase. The activity of γ-glutamyltransferase (U/L) was determined kinetically according to the degradation of L-γ-glutamyl-3-carboxy-4-nitroanilide with the formation of 5-amino-2-nitrobenzoate. The rates of its formation were determined spectrophotometrically; the absorbance at λ=365-405 nm is directly proportional to the activity of γ-glutamyltransferase[124].

The data were analyzed using Statistica 8.0 program (StatSoft Inc., USA). The tables demonstrate the results as x ± SD (x ± standard deviation). Differences between the values of the control and experimental groups were determined using the Tukey test, where the differences were considered significant at $P < 0.05$.

2. The effect of some medicinal plants on the body weight of rats and on some of their internal organs in the context of a high-fat diet

In the experiment, rats fed a complete balanced diet for 30 days had an average daily body weight gain of 525 ± 144 µg/day, equivalent to 10.2 ± 4.7 %/day. In comparison, rats fed a high-fat diet for the same period had a 33.3% higher average daily body-weight gain, corresponding to 700 ± 271 µg/day

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(Table 2). The intensity of weight gain in animals varied when medicinal plants were added to a high-fat diet. For example, when rats consumed *Salvia sclarea*, *Origanum vulgare*, *Silybum marianum* seeds and *Inula helenium* roots as part of a high-fat diet, the increase in body weight was significantly slower than in animals on a high-fat diet alone and lower than in animals in the control group. Supplementing the diet with *Salvia sclarea* resulted in the greatest slowing of weight gain: 72.3% compared to animals receiving the high-fat diet alone and 63.4% compared to the control group. With the addition of *Origanum vulgare*, the average daily weight gain of the rats was 70.7% and 60.9% lower, respectively. *Silybum marianum* seeds slowed the weight gain of rats by 55.7% compared to the high-fat diet group and by 40.9% compared to the control group. The addition of *Inula helenium* roots to the high-fat diet also helped to reduce the average daily weight gain of the rats by 53.6% and 38.1% respectively.

Table 2

Changes in body weight of rats treated with medicinal plants as part of a high-fat diet (x ± SD, n = 8, duration of experiment – 30 days)

Group of animals	Parameter	
	Change in body weight, μg/day	Change in body weight, %/day
Control	525 ± 144	10.2 ±4.7
High-fat diet	700 ± 271	13.6 ± 5.9
Rhodiola rosea	1276 ± 319*	25.7 ± 9.1**
Punica granatum	1533 ± 189***	24.0 ± 3.5***
Echinacea purpurea	1394 ± 340***	18.1 ± 3.7
Sylibum marianum	310 ± 155***	5.3 ± 2.6***
Origanum vulgare	205 ± 181***	3.7 ± 3.2***
Scutellaria baicalensis	1417 ± 326***	26.3 ± 7.4**
Inula helenium	325 ± 208**	5.3 ± 3.5
Matricaria chamomilla	1505 ± 198***	22.9 ± 2.9*
Lavandula angustifolia	1943 ± 496***	35.7 ± 8.0***
Melissa officinalis	2024 ± 393***	36.7 ± 7.9***
Vitex angus-castus	1171 ± 417	18.8 ± 6.5
Salvia officinalis	1771 ± 373*	29.3 ± 5.8*
Salvia sclarea	194 ± 127*	3.3 ± 2.1*

*Note: * – P < 0.05, ** – P < 0.01, *** – P < 0.001 probability of differences compared to the control within one line of the table according to the results of comparison using ANOVA with Bonferroni correction.*

All the other medicinal plants in the study caused an increase in the intensity of body weight gain in rats, both in comparison with the group on a high-fat diet alone and in comparison with the group on a complete diet. The greatest weight gain was observed when *Melissa officinalis* was added to the diet. In this group, the average daily weight gain was 189.1% higher than in the high-fat diet group and 285.5% higher than in the control group. Supplementation with *Lavandula angustifolia* inflorescences increased body-weight gain by 177.5% and 270.1%, *Salvia officinalis* by 153.0% and 237.3%, *Punica granatum* fruit peels by 119.0% and 192.0%, *Matricaria chamomilla* inflorescences by 115. 0% and 186.7%, *Scutellaria baicalensis* root – 102.4% and 169.9%, *Echinacea purpurea* seeds – 99.1% and 165.5%, *Rhodiola rosea root* – 82.3% and 143.0%, *Vitex angus-castus* herb – 67.3% and 123.0%.

Thus, the intensity of weight gain in rats fed a high-fat diet for 30 days was greater than in the control group (complete balanced diet). The addition of medicinal plants to the high-fat diet caused multidirectional changes in the dynamics of the animals' body weight. *Melissa officinalis* herb, *Lavandula angustifolia* inflorescences, *Salvia officinalis* herb, *Punica granatum* fruit peels, *Matricaria chamomilla* inflorescences, *Scutellaria baicalensis* roots, *Echinacea purpurea* seeds, *Rhodiola rosea* root, *Vitex angus-castus* herb increased weight gain in rats, while *Salvia sclarea* herb, *Origanum vulgare* herb, *Silybum marianum* seeds and *Inula helenium* root slowed weight gain.

Despite numerous studies demonstrating the anti-obesity activity of pomegranate (*Punica granatum*) and naming this plant as one of the seven most important plants in the fight against obesity[125], in our experiment the addition of *Punica granatum* fruit peels to a high-fat diet resulted in an increase in body weight gain. Cerdá et al (2003)[126] showed that pomegranate leaf extract reduces hunger and consequently body weight and suppresses the onset of obesity and hyperlipidaemia. This was explained by the presence of tannins in pomegranate that interact with proteins. The anti-obesity effects of pomegranate on energy intake are similar to those of orlistat, a clinically proven drug that inhibits pancreatic lipase, reducing the absorption of dietary fat in the blood and increasing fat excretion in the feces. In addition, pomegranate-derived compounds (ellagic acid and tannic acid) reduce hyperlipidaemia by reducing pancreatic lipase activity in vitro and increasing faecal fat excretion. Several studies in animal models have shown that pomegranate extract also has an effect similar to that of sibutramine, a drug used to reduce appetite[127].

In our study, a decrease in body weight was observed in rats when *Inula helenium* root was consumed. This is probably due to the bitter and fiery

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burning taste that is characteristic of *Inula helenium* root[128], which may have caused a decrease in the appetite of the animals. *Inula helenium* contains sesquiterpene lactones, which may have both anti-inflammatory and local irritant effects, depending on the dose[129]. At the same time, the use of ethanolic extract of elecampane (*Inula helenium* L.) root at doses ranging from 0 to 1000 mg/kg of diet caused a linear increase in weight gain in broiler chickens by boosting the digestibility of feed dry matter, but feed intake remained unchanged[130].

The decrease in average daily feed intake when some medicinal plants are added to the diet may be due to their high essential oil content and consequently unpleasant taste. However, preliminary taste studies in rats showed that the maximum dose ingested by the animals when added to neutral gelatine was 200 mg/kg of pure essential oil of *Origanum vulgare* [131]. In the same study, it was found that different doses (50, 100 and 200 mg/kg per day) of this essential oil did not result in significant differences in final body weight, body-weight gain or total food intake between groups.

The decrease in body weight in rats fed a high-fat diet supplemented with *Origanum vulgare* leaves can be explained by the inhibitory effect of this medicinal plant on pancreatic lipase, as reported in studies by Marrelli et al. (2013)[132] and Seyedan et al. (2015)[133]. *Silybum marianum* seeds in a high-fat diet have improved body weight gain in animals due to silibinin, which is an inhibitor of adipogenesis and adipogenic factors[134].

Organ weight is often used as a sensitive indicator to assess toxic effects of various substances, including drugs[135]. An increase in total body weight on

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[135] Lieshchova M. A., Brygadyrenko V. V. Effect of *Bidens tripartita* leaf supplementation on the organism of rats fed a hypercaloric diet high in fat and fructose. Regulatory Mechanisms in Biosystems. 2024. Vol. 15(3). P. 648-655.

a high-fat diet is accompanied by an increase in the absolute weight of internal organs, while the relative weight may not always increase. Another important indicator is the mass coefficient, the percentage of organ weight to body weight, an integral indicator used in toxicology to assess the state of internal organs. In our research, we have studied the effect of medicinal plants on the growth and weight gain of rats fed a high-fat diet, while determining the absolute weight of the organs.

The most important organ where most metabolic processes take place is the liver. It is the largest gland in the body and is responsible for the synthesis of cholesterol and its esters, lipids and phospholipids, lipoproteins and regulation of lipid metabolism; synthesis of bile acids and bilirubin, production and secretion of bile; replenishment and storage of rapidly mobilised energy reserves in the form of glycogen and regulation of carbohydrate metabolism; synthesis of many blood plasma proteins – albumin, alpha– and beta-globulins, transport proteins for various hormones and vitamins, blood clotting proteins and anticoagulant systems, and many other processes. In rats fed a complete diet for 30 days, the absolute weight of the liver was 6.61 ± 1.00 g. In animals fed a high fat diet for the same period, the weight of the liver was 9.8% higher and amounted to 7.26 ± 0.39 g (Fig. 1).

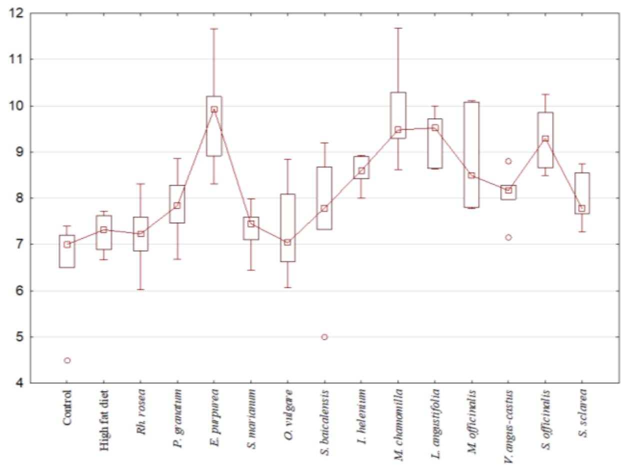

Fig. 1. Absolute liver weight of rats fed standard diet and high-fat diet supplemented with medicinal plants, g (x ± SD, n = 7, duration of experiment – 30 days)

Lieshchova M. A., Brygadyrenko V. V. The effect on the organism of rats of adding *Helichrysum arenarium* inflorescences to a hypercaloric diet, high in sugar and fat. Biosystems Diversity. 2023. Vol. 31(3). P. 350–357.

The addition of medicinal plants to the diet caused an increase in the absolute weight of the liver compared to the control group and especially compared to the high-fat diet group. The greatest increase in liver weight was observed in rats fed *Echinacea purpurea* seeds in the high-fat diet at 48.6% compared with the control group and 35.3% compared with animals fed a high-fat diet. Significant differences in this indicator were also observed in animals fed *Matricaria chamomilla* inflorescence (liver weight was 48.1% and 34.8% higher, respectively), *Lavandula angustifolia* inflorescence (liver weight was 41.6% and 28.9% higher, respectively) and *Salvia officinalis* (liver weight was 40.5% and 28.0% higher, respectively). A significant increase in liver weight in rats compared with the control group was observed after consumption of *Melissa officinalis* (by 31.8%), *Inula helenium* root (by 29.8%), *Vitex angus-castus* (by 22.5%), *Salvia sclarea* (by 20.0%), *Punica granatum* fruit peel (by 18.6%) and *Scutellaria baicalensis* root (by 15.6%). When other medicinal plants were added to the high-fat diet, the absolute weight of the liver was slightly higher than in the control group, but not significantly different from the liver weight of rats fed a high-fat diet alone. Thus, the absolute liver weight of rats fed the high-fat diet was higher than that of the control group. The addition of *Echinacea purpurea* seeds, *Matricaria chamomilla* and *Lavandula angustifolia* inflorescences and *Salvia officinalis* herb to the high-fat diet resulted in an increase in this indicator above that of the control and high-fat diet groups.

Alterations in metabolic processes may be manifested by damage to the cardiovascular system and reflected in damaged myocardium. In rats fed a high-fat diet, the absolute heart weight after 30 days was 0.60 ± 0.12 g. In animals fed a high-fat diet after the same period, the absolute organ weight did not change (0.63 ± 0.05 g). When the medicinal plants were added to the high-fat diet, most of the heart weights were higher than in the control group (Fig. 2).

The greatest increase in absolute heart weight was in rats that received *Echinacea purpurea* seeds (45.0%), *Matricaria chamomilla* inflorescences (40.0%), *Salvia officinalis* (35.0%), *Lavandula angustifolia* inflorescences (31.7%) and *Vitex angus-castus* (28.3%) in addition to the high-fat diet. Thus, the high-fat diet given to the rats during the 30-day experiment did not cause an increase in absolute heart weight, and the supplementation of the diet with *Echinacea purpurea* seeds, *Matricaria chamomilla* inflorescence, *Salvia officinalis*, *Lavandula angustifolia* inflorescence and *Vitex angus-castus* herb caused an increase in this indicator above that of the control group.

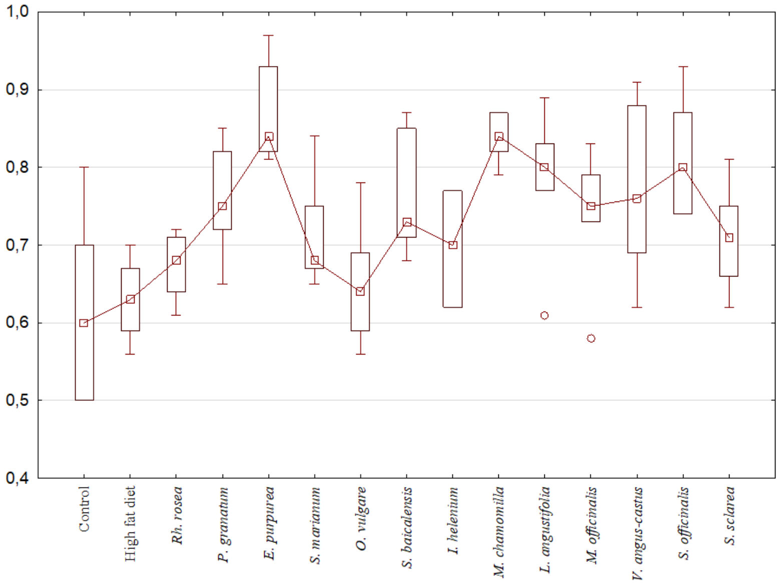

Fig. 2. Absolute heart weight of rats fed standard diet and high-fat diet supplemented with medicinal plants, g (x ± SD, n = 7, duration of experiment – 30 days)

It is known that the lung, in addition to its barrier function, performs respiratory and metabolic functions that are closely related to lipid metabolism. In our experiment, the absolute weight of the lungs on day 30 of the experiment was 1.73 ± 0.17 g and 1.74 ± 0.34 g in rats fed the complete diet and the high-fat diet, respectively (Fig. 3).

This indicator was not affected by the supplementation of *Inula helenium* root to the high-fat diet. The addition of other medicinal plants to the high-fat diet resulted in an increase in the absolute weight of the rats' lungs. The highest increase in absolute lung weight was observed when *Matricaria chamomilla* inflorescences (28.9%), *Echinacea purpurea* seeds (27.2%), *Scutellaria baicalensis* root (23.1%) and *Vitex angus-castus* herb (22.0%) were added to the high-fat diet. Lung weight increased moderately (by 15.0-13.3%) in rats fed *Salvia sclarea*, *Punica granatum* fruit peel and *Melissa officinalis*. *Silybum marianum* seeds, *Rhodiola rosea* root and *Origanum vulgare* herb had the least effect on this indicator. Thus, the high-fat diet administered to rats for 30 days did not cause any changes in the absolute weight of the lungs. All of the animals that received the additional medicinal plants, with the exception of *Inula helenium* roots, had an increase in absolute lung weight compared to the control animals.

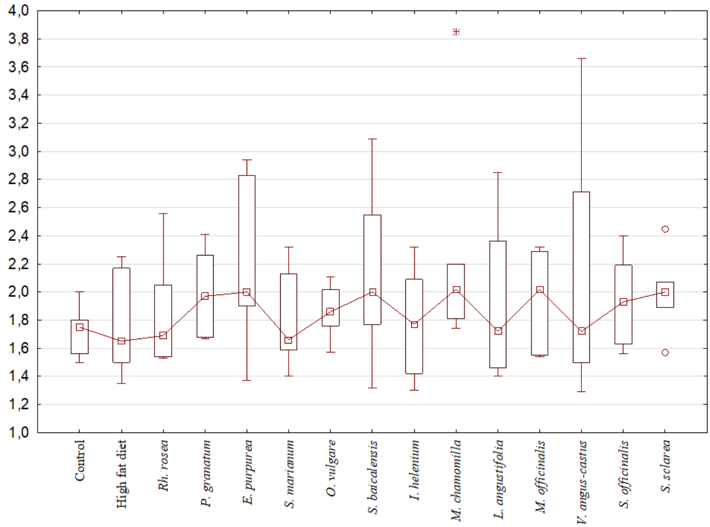

Fig. 3. Absolute lungs weight of rats fed standard diet and high-fat diet supplemented with medicinal plants, g (x ± SD, n = 7, duration of experiment – 30 days)

The kidneys are organs that are responsible for the acid-base balance of the blood plasma and the maintenance of the water-salt balance. The protective functions of the kidneys include the elimination of nitrogen metabolism products, excess organic (and inorganic) compounds and toxins (including those from drugs). The absolute weight of the kidneys of rats fed a complete diet on day 30 of the experiment was 0.69 ± 0.07 g. In animals fed a high-fat diet, the absolute weight of the kidneys decreased to 0.65 ± 0.07 g (Fig. 4). Adding *Salvia sclarea*, *Rhodiola rosea* and *Inula helenium* roots to the diet reduced the absolute kidney weight of the rats by 8.7% and 7.2% respectively compared to the control group. Supplementing the high-fat diet with *Echinacea purpurea* seeds, *Matricaria chamomilla* inflorescences and *Punica granatum* fruit peels increased the absolute weight of the kidneys by 17.4%, 14.5% and 10.1%, respectively, compared to the control group. The other studied medicinal plants used in the high-fat diet had no effect on the mass parameters of the animals' kidneys. Thus, the high-fat diet consumed by the experimental animals for 30 days did not affect the absolute weight of the rats' kidneys, and the addition of medicinal plants had a multidirectional effect on this indicator. For example, the consumption of *Echinacea purpurea* seeds, *Matricaria chamomilla* inflorescences and *Punica granatum* peels led to an increase in the absolute weight of the kidneys, while the herb *Salvia sclarea*, *Rhodiola rosea* and *Inula helenium* roots led to a decrease.

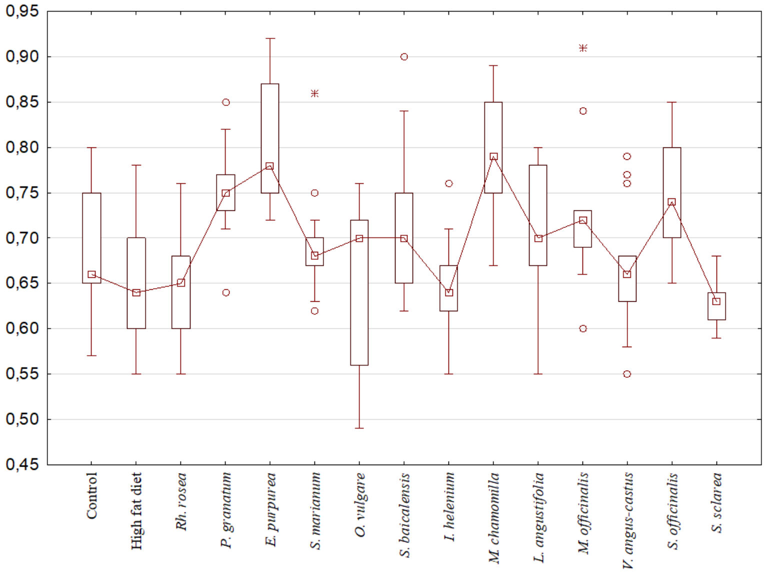

Fig. 4. Absolute kidneys weight of rats fed standard diet and high-fat diet supplemented with medicinal plants, g (x ± SD, n = 7, duration of experiment – 30 days)

The spleen is an important organ of lymphoid haematopoiesis and immune defence, where red blood cells and platelets that have completed their life cycle are eliminated, blood and iron are deposited, lymphocytes proliferate and differentiate antigenically and form antibodies, and biologically active substances are produced that suppress erythropoiesis in the red bone marrow. The absolute weight of the spleen in rats fed a complete diet for 30 days was 0.75 ± 0.06 g (Fig. 5). Consumption of the high-fat diet caused a slight decrease in the absolute weight of the rats' spleens to 0.66 ± 0.06 g compared with the control group. The supplementation of the high-fat diet with medicinal plants had a different effect on the weight of the spleen. For example, the addition of *Rhodiola rosea* root reduced the absolute weight of the spleen below that of both the control group and the high-fat diet group. *Salvia sclarea, Salvia officinalis, Origanum vulgare, Inula helenium root* and *Silybum marianum* seeds caused a slight reduction in the absolute weight of the spleen compared with the control group, but this was greater than in animals fed a high-fat diet alone.

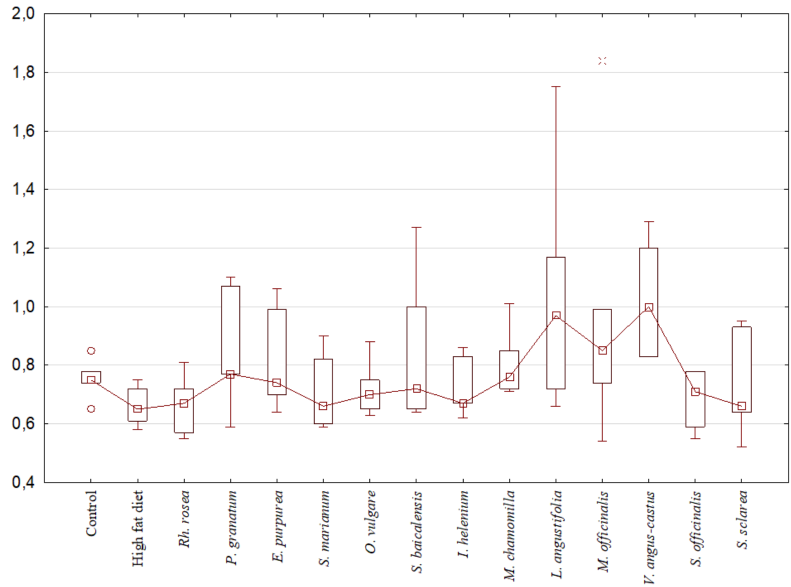

Fig. 5. Absolute spleen weight of rats fed standard diet and high-fat diet supplemented with medicinal plants, g (x ± SD, n = 7, duration of experiment – 30 days)

Compared with the control group, the other medicinal plants contributed to the increase in this indicator. *Vitex angus-castus* herb and *Lavandula angustifolia* inflorescences (37.3%), *Melissa officinalis* herb (25.3%), *Punica granatum* fruit peels (14.7%) and *Inula helenium* root (10.7%) showed the greatest increase in absolute spleen weight. The lowest levels were found in *Echinacea purpurea* seeds by 6.7%) and *Matricaria chamomilla* inflorescences (by 5.3%). Thus, the high-fat diet administered to rats for 30 days of the experiment caused a decrease in the absolute weight of the spleen compared to the group of animals on a complete diet. Medicinal plants had a multidirectional effect on spleen weight. *Vitex angus-castus* herb, *Lavandula angustifolia* inflorescences, *Melissa officinalis* herb, *Punica granatum* fruit peels, *Inula helenium* root, *Echinacea purpurea* seeds, *Matricaria chamomilla* inflorescences caused an increase in absolute spleen weight and *Rhodiola rosea* root, *Salvia sclarea* herb, *Salvia officinalis* herb, *Origanum vulgare* herb, *Inula helenium* root and *Silybum marianum* seeds caused a decrease.

Brain mass parameters are important indicators for assessing the toxic effects of various substances on the nervous system and the body as a whole. An increase in these parameters may indicate the development of acute oedema, haemorrhagic infiltration and other pathological processes[136]. In rats that consumed a complete diet during the study (30 days), the absolute weight of the brain was 1.63 ± 0.16 g, and in the group of animals that received a high-fat diet – 1.54 ± 0.11 g (Fig. 6).

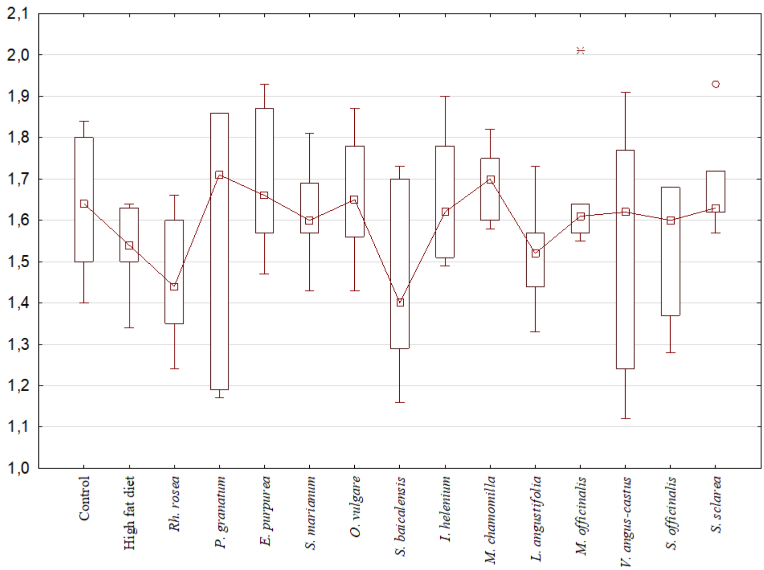

Fig. 6. Absolute brain weight of rats fed standard diet and high-fat diet supplemented with medicinal plants, g (x ± SD, n = 7, duration of experiment – 30 days)

The addition of medicinal herbs to the high-fat diet had no significant effect on the absolute weight of the brain, which may be an indication of the absence of their toxic effects. With the addition of *Rhodiola rosea* root, *Scutellaria baicalensis* root, and *Lavandula angustifolia* inflorescences, the absolute weight of the brain was reduced compared to animals in the control group and those fed a high-fat diet. *Punica granatum* peels and *Matricaria chamomilla* inflorescences, on the other hand, contributed to an increase in the absolute brain weight of the rats. Thus, neither the high-fat diet nor the addition of medicinal herbs to it had a significant effect on the absolute brain weight of the rats in the 30-day experiment.

[136] Романюк, А. М., Будко, Г. Ю. Особливості масометричних показників та морфологічних змін головного мозку статевозрілих щурів в умовах впливу на організм сульфатів міді, цинку та заліза. Вісник Наукових Досліджень. 2015. № 1.

3. Effect of medicinal plants on blood biochemical parameters in rats fed a high-fat diet

3.1. Effect on protein and mineral metabolism

Total protein is a laboratory indicator of protein concentration in blood serum. Because proteins in the bloodstream are involved in the vital functions of the body, their levels can fluctuate under the influence of many factors, including diet. Analyzing the indicators of protein metabolism, it was found that in rats fed a balanced diet for 30 days, the content of total protein in blood plasma was 65.0 ± 6.95 g/L, which is within the reference values for this species and age group of animals[137]. In the group of rats that consumed a high-fat diet during the same period, the level of total protein in the blood plasma increased by 18.5% (Fig. 7). Despite the increase, this indicator remained within the reference range, but was at the upper limit of normal value. Supplementation of the high-fat diet with medicinal plants caused an increase in the content of total protein in rats of all groups in comparison with the control group. This indicator was only lower (67.6 ± 9.94 g/L) in rats receiving *Matricaria chamomilla* inflorescences in addition to the high fat diet. The total protein level increased most in the blood plasma of rats treated with *Inula helenium* root (41.1%), *Punica granatum* fruit peel (35.8%), *Echinacea purpurea* seeds (34.0%), *Vitex angus-castus* herb (32.9%), *Salvia officinalis* herb (30.1%), *Salvia sclarea* herb (27.7%), *Origanum vulgare* herb (24.5%), *Melissa officinalis* herb (23.0%) and *Silybum marianum* seed (22.9%); the lowest – in rats fed *Lavandula angustifolia* herb (16.9%), *Rhodiola rosea* root (15.4%), *Scutellaria baicalensis* root (12.9%) compared to the control group.

Compared with rats consuming a high-fat diet, the addition of *Rhodiola rosea*, *Scutellaria baicalensis*, *Lavandula angustifolia* and *Matricaria chamomilla* did not cause any significant changes in this indicator. On the other hand, the additional consumption of all the other studied medicinal plants contributed to an increase in the concentration of total protein in the blood plasma of experimental rats.

Thus, consuming a high-fat diet during a 30-day experiment causes an increase in the total protein concentration in the blood plasma of experimental rats, and supplementing the diet with most of the studied medicinal plants enhances this effect, with the exception of *Rhodiola rosea*, *Scutellaria baicalensis*, *Lavandula angustifolia* and *Matricaria chamomilla*.

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[137] Shayakhmetova G. M., Kovalenko V. M., Basovska O. G., Vozna A. V. Clinical biochemical parameters of healthy adult white male rats blood serum (retrospective assessment). Pharmacology and Drug Toxicology. 2019. Vol. 13(6). P. 428–433.

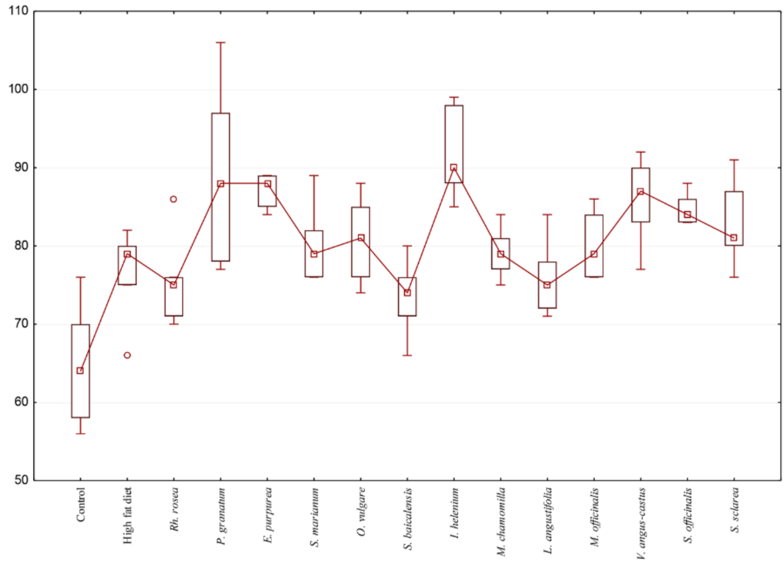

Fig. 7. Total protein concentration in blood plasma of rats fed a standard diet and a high-fat diet supplemented with medicinal plants, g/L (x ± SD, n = 7, duration of experiment – 30 days)

Albumin is the most prevalent protein in blood plasma. Albumin has three main functions: it is essential for maintaining plasma colloidal oncotic pressure, it participates in non-specific transport as a carrier for many non-polar compounds, and it is a source of endogenous amino acids. The blood plasma albumin level of rats fed the complete diet for 30 days was 42.9 ± 3.98 g/L, which is within the reference range for this species and age group of animals (Fig. 8). In the group of rats fed a high-fat diet for the same period, the blood plasma albumin level decreased by 7.7%, which is at the lower limit of the reference range for this species. Both an increase and a decrease in this indicator were observed in experimental animals fed a high-fat diet supplemented with medicinal plants, but the level of albumin in the blood plasma never exceeded the normal reference values.

Thus, supplementing the high-fat diet with *Echinacea purpurea*, *Inula helenium*, *Vitex angus-castus*, *Salvia officinalis*, *Punica granatum* slightly increased albumin in the blood plasma of rats, whereas *Rhodiola rosea*, *Lavandula angustifolia*, *Origanum vulgare* decreased this indicator compared to the control group. At the same time, *Silybum marianum*, *Matricaria chamomilla*, *Lavandula angustifolia*, *Melissa officinalis* and *Salvia sclarea* did not affect albumin level in the blood plasma of rats compared to the control group. Therefore, supplementation of high-fat diet with medicinal plants did not cause significant changes in the albumin levels in the blood plasma of rats during the 30-day experiment.

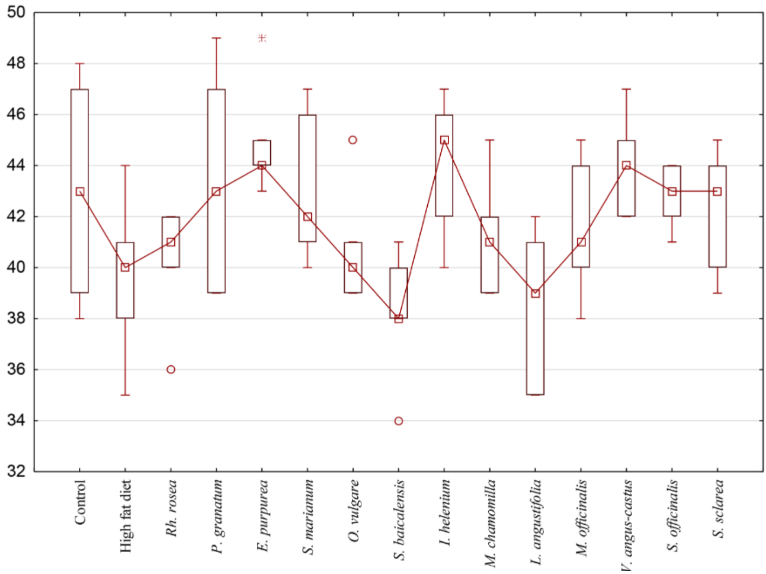

Fig. 8. Blood plasma albumin levels in rats fed standard diet and high-fat diet supplemented with medicinal plants, g/L (x ± SD, n = 7, duration of experiment – 30 days)

Globulins are a group of blood proteins produced by the liver and immune system. Globulins play an important role in liver function, blood clotting and fighting infections. In the control group of rats, which were fed a balanced standard diet for 30 days of the experiment, the level of globulins in the blood was 29.7 ± 3.04 g/L, which is within the reference range. In the experimental groups of rats that consumed a high-fat diet during the same period, the level of globulins increased by 25.9% and reached 37.4 ± 4.24 g/L, which is higher than the reference value. In most cases, this effect was enhanced by the addition of medicinal plants to the high-fat diet. For example, the addition of *Inula helenium* roots to the high-fat diet increased the level of globulins in the blood by 59.3% compared with the control group and by 26.5% compared with rats fed a high-fat diet alone. *Punica granatum* peel in the high-fat diet increased this indicator by 51.5% and 20.3% respectively; *Silybum marianum* seeds by 43.4% and 13.9%; *Vitex angus-castus* herb by 42.8% and 13.4%; *Salvia officinalis* herb by 40.1% and 11.2%; *Echinacea purpurea* seeds and *Salvia sclarea* herb by 36.0% and 8.0%. Blood globulin levels in rats additionally supplemented with *Melissa officinalis* (by 30.3%), *Matricaria chamomilla* inflorescences (by 25.9%), *Lavandula angustifolia* inflorescences (by 25.6%), and *Silybum marianum* seeds (by 24.6%) exceeded the upper reference range limit. Only the supplementation with *Rhodiola rosea* and *Scutellaria baicalensis* roots to the high-fat diet led to a normalization of the globulin levels in the blood compared to rats on the high-fat diet alone (Fig. 9). Thus, consuming a high-fat diet during a 30-day experiment caused plasma globulin levels to increase in experimental rats. A positive effect was only seen when *Rhodiola rosea* and *Scutellaria baicalensis* roots were added to the diet. Most of the medicinal plants studied only caused an increase in blood plasma globulins.

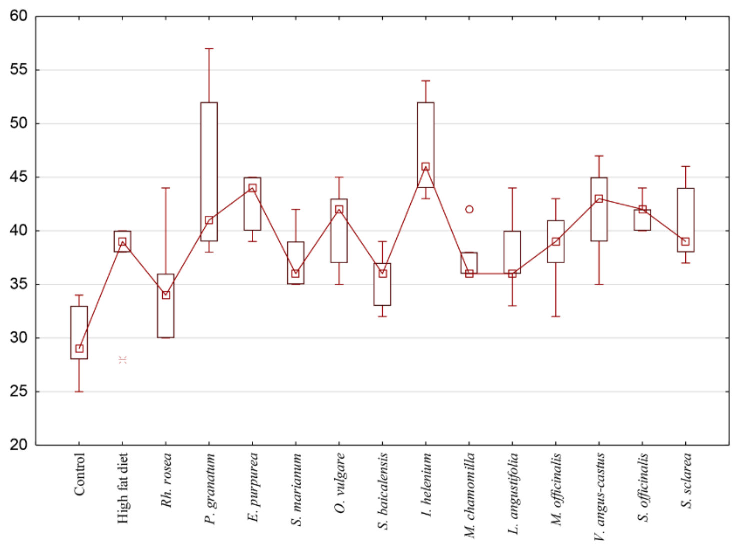

Fig. 9. Blood plasma globulin levels in rats fed standard diet and high-fat diet supplemented with medicinal plants, g/L (x ± SD, n = 7, duration of experiment – 30 days)

Urea is synthesized in the liver as a by-product of the amino acid deamination reaction. Its excretion in the urine is the main pathway for nitrogen elimination. In a 30-day experiment in rats fed a balanced diet, the level of urea in the blood plasma was 6.4 ± 0.84 mmol/L. In the group of rats fed a high-fat diet over the same period, the plasma urea level remained almost unchanged at 6.8 ± 1.10 mmol/L (Fig. 10). In the groups of rats that received medicinal plants in addition to a high-fat diet, the level of urea in the blood plasma was lower than in the control group, with the exception of the animals that ate the fruit peel of *Punica granatum*. Thus, when the rats consumed a high fat diet and *Punica granatum* fruit peels, the level of urea in the blood plasma was 8.6 ± 2.58 mmol/L, which was 34.4% higher than in the control group and 26.5% higher than in the group of animals fed a high-fat diet alone. It should be noted that the blood plasma urea level in this experimental group was above the reference range.

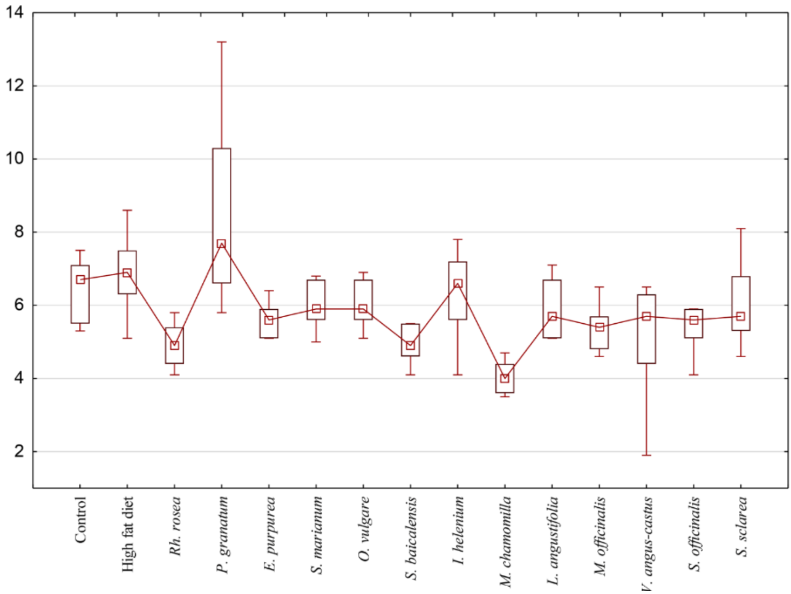

Fig. 10. Blood plasma urea levels in rats fed standard diet and high-fat diet supplemented with medicinal plants, mmol/L (x ± SD, n = 7, duration of experiment – 30 days)

The lowest level (below the reference range) in the experimental groups of animals was observed when the inflorescences of *Matricaria chamomilla*, *Scutellaria baicalensis* root, *Rhodiola rosea* root and *Vitex angus-castus* herb were added to the high-fat diet. Compared with the control group, urea levels were 37.5% lower in rats treated with *Matricaria chamomilla* inflorescences, 23.4% lower with *Scutellaria baicalensis* and *Rhodiola rosea* roots, and 20.3% lower with *Vitex angus-castus* herb. All other herbs included in the high-fat diet contributed to a reduction in blood plasma urea levels, but not below the reference range. For example, compared with the control group, the blood plasma urea levels of the rats decreased slightly after consumption of *Salvia officinalis* and *Melissa officinalis* (by 15.6%), *Echinacea purpurea* seeds (by 12.5%), *Silybum marianum* seeds, *Lavandula angustifolia* inflorescences and *Salvia sclarea* (by 6.25%). Rats treated with *Inula* *helenium* roots and *Origanum vulgare* herb had almost no change in blood plasma urea levels. Therefore, during the 30-day experiment with a high-fat diet, no significant changes were observed in urea level in the blood plasma of the rats. However, the addition of *Punica granatum* fruit peels to the high-fat diet resulted in an increase in this indicator above the reference values and the level of the control group. All the other studied medicinal plants contributed to a decrease in blood plasma urea levels. Furthermore, when the rats consumed *Matricaria chamomilla* inflorescences, *Rhodiola rosea* root, *Scutellaria baicalensis* root and *Vitex angus-castus* herb, the level of urea in the blood plasma was below the minimum reference value.

Bilirubin is a pigment produced in the reticuloendothelial system of the liver and spleen when hemoglobin, myoglobin and cytochromes break down. It is one of the major components of bile and is present in the blood in two fractions: conjugated (bound) and unconjugated (unbound or free) bilirubin, which together make up total blood bilirubin. At the end of the experiment, total blood plasma bilirubin in rats on balanced diet was 2.3 ± 0.87 µmol/L. In the high-fat diet group, this value increased to 6.1 ± 1.81 µmol/L, but did not exceed the reference values (Fig. 11). When the high-fat diet was supplemented with medicinal plants, the total bilirubin level in the blood plasma of rats increased in all experimental groups compared with the control group. The consumption of *Silybum marianum* seeds, *Origanum vulgare* herb, *Salvia sclarea* herb and *Inula helenium* roots resulted in an increase in the level of bilirubin in the blood plasma above that in the control group and in the group fed the high-fat diet. The supplementation of the diet with *Vitex angus-castus*, *Scutellaria baicalensis* root, *Punica granatum* fruit peels, *Echinacea purpurea* seeds, *Melissa officinalis* and *Lavandula angustifolia* inflorescences contributed to an increase in the total bilirubin level in the blood plasma of the rats compared with the control group, but reduced this indicator compared with the group of rats fed only a high-fat diet. Thus, consuming a high-fat diet increases total bilirubin in the blood plasma of rats, but not above the reference values. At the same time, the inclusion of *Silybum marianum* seeds, *Origanum vulgare* herb, *Salvia sclarea* herb and *Inula helenium* root to the high-fat diet promotes an increase in total bilirubin levels in rats' blood plasma above the physiological norm.

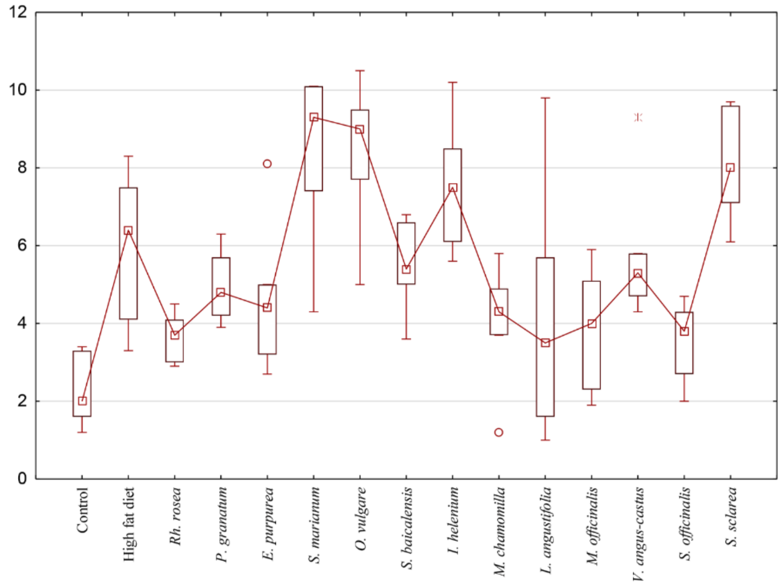

Fig. 11. Blood plasma total bilirubin levels in rats fed standard diet and high-fat diet supplemented with medicinal plants, µmol/L (x ± SD, n = 7, duration of experiment – 30 days)

Creatinine is the end product of creatine (or phosphocreatine) catabolism. The amount produced each day depends on muscle mass. Creatinine is freely filtered by the glomeruli (small amounts are reabsorbed and secreted by the renal tubules). In rats, plasma creatinine levels at the end of the study were 40.8 ± 15.99 µmol/L when fed a standard diet (Fig. 12). Consumption of a high-fat diet for 30 days resulted in a 54.4% increase in this indicator. With the addition of medicinal plants to the high-fat diet, the creatinine level in the blood plasma of the animals increased in all experimental groups, without exception, compared to the control. This was most significantly influenced by the consumption of *Melissa officinalis* (by 83.6%), *Echinacea purpurea* seeds (by 80.4%), *Origanum vulgare* (by 71.8%), *Matricaria chamomilla* inflorescences (by 70.6%) and *Silybum marianum* seeds (by 67.4%). A decrease in creatinine levels in the blood plasma compared to the animals in the high-fat diet group was caused by the consumption of *Punica granatum* peels, *Rhodiola rosea* root and *Lavandula angustifolia* inflorescences.

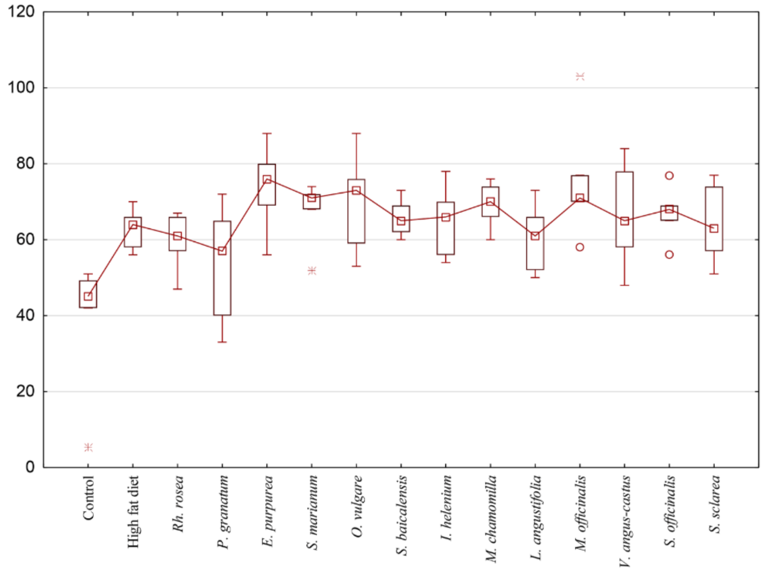

Fig. 12. Blood plasma creatinine levels in rats fed standard diet and high-fat diet supplemented with medicinal plants, µmol/L (x ± SD, n = 7, duration of experiment – 30 days)

And when *Inula helenium* root, *Salvia sclarea*, *Scutellaria baicalensis* root, *Vitex angus-castus* and *Salvia officinalis* were consumed, the creatinine level in the blood plasma of the rats did not change significantly compared to the rats in the high-fat diet group, but was lower than in the control group. For example, plasma creatinine levels did not rise above the reference values when rats were fed a high-fat diet for 30 days. The supplementation of the high-fat diet with medicinal plants mostly increased this effect, and the herb *Melissa officinalis* and the seeds of *Echinacea purpurea* caused an increase in this indicator above the reference range. *Punica granatum* fruit, *Rhodiola rosea* root and *Lavandula angustifolia* inflorescences when consumed with a high-fat diet slightly slowed the increase in plasma creatinine levels.

C-reactive protein (CRP) is an annular (ring-shaped) pentameric protein found in blood plasma whose circulating concentrations increase in response to inflammation. It is an acute-phase protein of hepatic origin that increases the subsequent secretion of interleukin-6 by macrophages and T-cells. Its physiological role is to bind to lysophosphatidylcholine expressed on the surface of dead or dying cells (and some types of bacteria) to activate the complement system via C1q. The level of C-reactive protein in the blood is a marker of acute inflammation in the body. In rats fed a nutritious diet, the level of C-reactive protein was 4.27 ± 1.19 mg/L, whereas in animals fed a high-fat diet for 30 days, the level of C-reactive protein increased by 193% to 12.51 mg/L (Fig. 13). C-reactive protein levels were not reduced to those of the control group of animals when medicinal plants were added to the high-fat diet. However, when *Punica granatum* fruit peel was added to the high-fat diet, C-reactive protein levels increased by 100% compared to animals on the high-fat diet alone. Other medicinal plants have shown the same effect. The roots of *Inula helenium* increased C-reactive protein levels by 65.5%, the herb *Salvia officinalis* by 23.7%, the root of *Rhodiola rosea* by 9.0% and the inflorescences of *Lavandula angustifolia* by 5.7%. A decrease in the level of C-reactive protein compared to that of animals fed a high-fat diet was observed against the background of the addition of *Silybum marianum* seeds to the diet (by 36.4%), *Matricaria chamomilla* inflorescences (by 32.0%), *Salvia sclarea* herb (by 26.1%), *Origanum vulgare* herb (by 20.9%), *Scutellaria baicalensis* roots (by 20.3%) and *Melissa officinalis* herb (by 18.2%). At the same time, *Echinacea purpurea* seeds and *Vitex angus-castus* herb did not cause any changes in the levels of C-reactive protein in the animals' blood. Thus, C-reactive protein levels in the blood of rats increased with the high-fat diet, and the addition of medicinal plants to the diet did not restore this indicator to the level of the control group. At the same time, *Punica granatum* fruit peels, *Inula helenium* roots, *Salvia officinalis* herb, *Rhodiola rosea* root, *Lavandula angustifolia* inflorescences further increased this indicator, while *Silybum marianum* seeds, *Matricaria chamomilla* inflorescences, *Salvia sclarea* herb, *Origanum vulgare* herb, *Scutellaria baicalensis* roots and *Melissa officinalis* herb decreased it.

Total calcium is an important indicator of the level of a natural macronutrient. It plays an important role in bone formation, the musculoskeletal system, the nervous and endocrine systems, and affects blood clotting. In the control group of rats fed a balanced diet for 30 days, total plasma calcium was 2.37 ± 0.14 mmol/L (Fig. 14). In the group of rats fed a high-fat diet, this indicator did not change significantly at the end of the experiment and was at the level of 2.53 ± 0.10 mmol/L. In rats fed a high-fat diet with medicinal plants, the level of total calcium in blood plasma fluctuated within insignificant limits. The highest value was found in the context of the consumption of *Salvia officinalis* (2.69 ± 0.22 mmol/L), *Origanum vulgare* (2.67 ± 0.16 mmol/L) and *Salvia sclarea* (2.64 ± 0.15 mmol/L). It should be noted that neither the high-fat diet nor the supplementation with medicinal plants caused a change in this indicator beyond the physiological values.

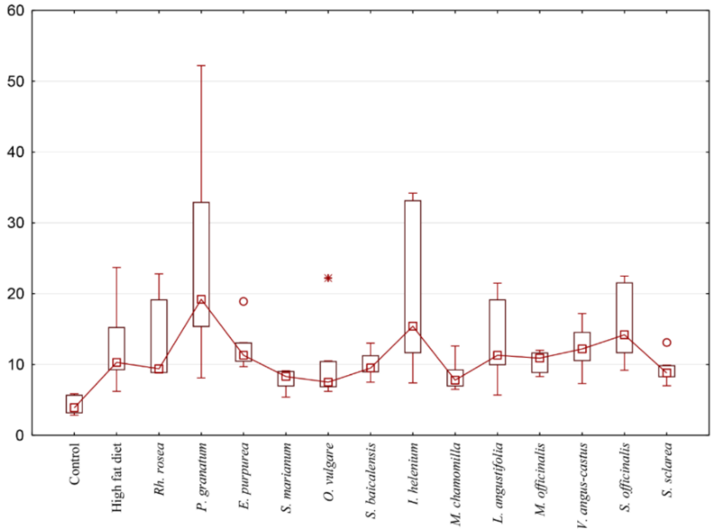

Fig. 13. Blood plasma C-reactive protein levels in rats fed standard diet and high-fat diet supplemented with medicinal plants, mg/L (x ± SD, n = 7, duration of experiment – 30 days)

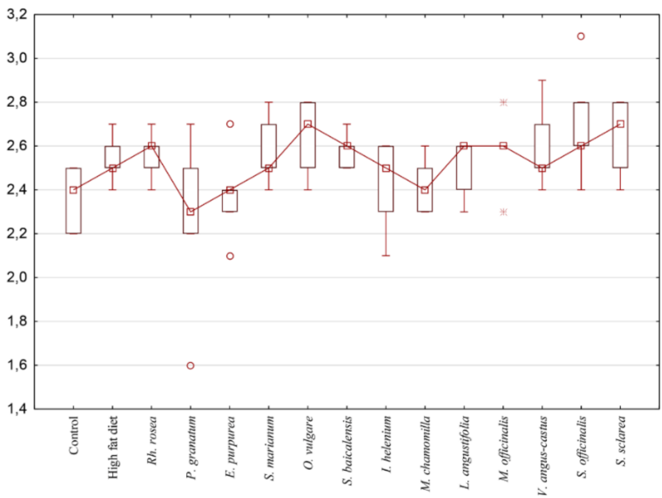

Fig. 14. Blood plasma Total calcium levels in rats fed standard diet and high-fat diet supplemented with medicinal plants, mmol/L (x ± SD, n = 7, duration of experiment – 30 days)

Inorganic phosphorus is one of the most important elements in the animal body and plays an important role in metabolic reactions and energy transfer. It is a key component in the structure of bones, cell membranes and important molecules such as ATP, which contributes significantly to various functions of living organisms. In the blood plasma of rats fed a balanced diet during the 30-day experiment, the level of inorganic phosphorus was 2.39 ± 0.31 mmol/L. In comparison, this value increased by 28.4% to 3.07 ± 0.63 mmol/L in rats fed a high-fat diet (Fig. 15). In comparison with the control group, the addition of medicinal plants to the high-fat diet overwhelmingly contributed to an increase in inorganic phosphorus levels in the blood plasma of rats. The exception was the addition of *Silybum marianum* seeds, which caused a slight decrease in this indicator in the rats compared to the control, and the addition of *Salvia sclarea*, which did not change this indicator at all.

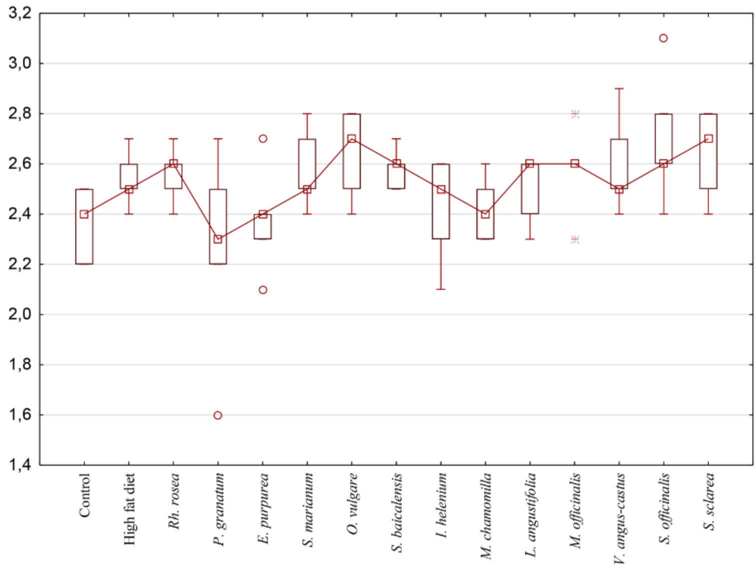

Fig. 15. Blood plasma Inorganic phosphorus levels in rats fed standard diet and high-fat diet supplemented with medicinal plants, mmol/L (x ± SD, n = 7, duration of experiment – 30 days)

Melissa officinalis and *Salvia officinalis* caused a significant increase in plasma inorganic phosphorus compared with both the control and the high-fat diet groups, while the level of inorganic phosphorus was at the upper limit of the physiological norm, and the peel of *Punica granatum* and *Lavandula angustifolia* inflorescences even increased this indicator above the reference range. The inorganic phosphorus content of blood plasma was reduced by the addition of *Silybum marianum* seeds, *Salvia sclarea*, *Origanum vulgare* and *Matricaria chamomilla* inflorescences compared to the group of rats fed a high-fat diet. And the addition of *Scutellaria baicalensis* roots, *Echinacea purpurea* seeds, *Inula helenium* roots, *Vitex angus-castus* herb did not cause any changes in this indicator compared with the group of rats fed only the high-fat diet, but reduced it compared with the control group. However, the high-fat diet consumed by the rats for 30 days had no significant effect on the level of inorganic phosphorus in the blood. The supplementation of *Punica granatum* peels and *Lavandula angustifolia* dried inflorescences to the high-fat diet favours an increase in the level of inorganic phosphorus in the blood above the reference values.

The observed increase in globulin concentration under the influence of *Inula helenium* may be related to the immunostimulative effect of phenolic compounds and alantolactone contained in elecampane roots[138]. A meta-analysis by Sahebkar et al. (2017)[139] found no convincing evidence that pomegranate juice consumption significantly reduced CRP concentrations in five acceptable randomised controlled trials, and the effect of pomegranate juice on plasma CRP levels was independent of duration of consumption.

Sage *Salvia officinalis* powder (doses of 4 and 8 g/kg) as part of the basic diet for broiler chickens had an effect on immune organs and blood biochemical parameters. It was shown that such a diet did not affect the ratio of albumin to globulin, the ratio of granulocytes to lymphocytes in the blood and the concentration of cholesterol, HDL and LDL. At the same time, a high concentration of the powder (8 g/kg) significantly increased the relative mass of the cloacal bursa in chickens and decreased the concentration of total protein and triglycerides in blood serum[140].

3.2. Effects on carbohydrate and lipid metabolism

Glucose is the major source of energy in the body. In the rats of the control group, which were fed a complete balanced diet during the 30 days of the experiment, the blood glucose level was 5.6 ± 1.59 mmol/L (Fig. 16). In rats fed a high-fat diet during the same period, plasma glucose level increased by 32.1% to 7.4 ± 1.12 mmol/L, which is the upper limit of the reference values. Adding medicinal plants to the diet had a multidirectional effect on this

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[138] Lieshchova M., Yefimov V., Brygadyrenko V. Influence of *Inula helenium* rhizomes and *Matricaria chamomilla* inflorescences on the biochemical and physiological parameters in male rats fed a high-fat diet. Roczniki Państwowego Zakładu Higieny. 2023. P. 447–458.

[139] Sahebkar A., Gurban C., Serban A., Andrica F., Serban M. C. Effects of supplementation with pomegranate juice on plasma C-reactive protein concentrations: A systematic review and meta-analysis of randomized controlled trials. Phytomedicine. 2016. Vol. 23(11). P. 1095–1102.

[140] Toghyani M., Akhavan M. I., Aghdam S. H. Effect of sage powder *(Salvia officinalis L.)* on serum biochemistry and immunity of broiler chicks. Reviews on Clinical Pharmacology and Drug Therapy. 2012. Vol. 10(2). P. 107.

parameter. For example, the root of *Scutellaria baicalensis* in the high-fat diet caused a sharp decrease in plasma glucose levels by 23.2% compared with the control group and by 41.9% compared with the high-fat diet group.

The herb *Origanum vulgare* also reduced plasma glucose levels by 10.7% compared with the control group and by 32.4% compared with the high-fat diet group. *Silybum marianum* seeds lowered plasma glucose levels in rats by 32.1% compared with animals fed a high-fat diet, bringing this indicator to the level of the control group. *Punica granatum* fruit peels and *Echinacea purpurea* seeds also decreased plasma glucose levels in rats by 21.6% compared to the high-fat diet group. *Matricaria chamomilla* inflorescences, on the other hand, increased plasma glucose levels above the normal reference value in both the high-fat diet group (by 2.7%) and the control group (by 35.7%). The addition of *Inula helenium* root, *Rhodiola rosea* root, *Lavandula angustifolia* inflorescences, *Vitex angus-castus*, *Melissa officinalis*, *Salvia officinalis*, *Salvia sclarea* to the high-fat diet resulted in higher plasma glucose levels than in the control group, but did not reach the level of rats fed only the high-fat diet.

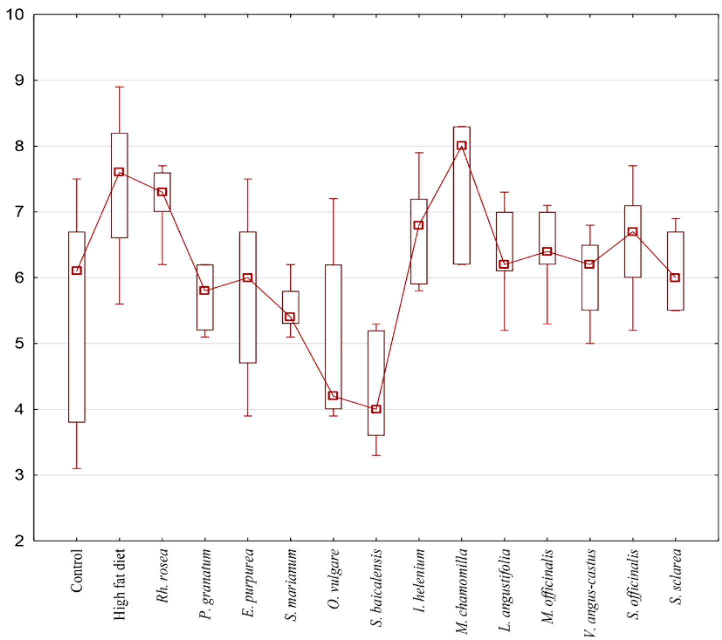

Fig. 16. Blood plasma glucose levels in rats fed standard diet and high-fat diet supplemented with medicinal plants, mmol/L (x ± SD, n = 7, duration of experiment – 30 days)

Furthermore, consuming a high-fat diet for 30 days increased plasma glucose levels in rats. Herbal supplementation of rats with a high-fat diet had the same result, except for *Matricaria chamomilla*, which increased plasma glucose levels above that of rats on a high-fat diet.

It is interesting to note the moderate hypoglycaemic effect of *Echinacea purpurea* and *Sylibum marianum* seeds in experimental rats. Despite the fact that the glucose level in rats of the control group was at the upper limit of the reference range, additional consumption of *Echinacea purpurea* and *Sylibum marianum* seeds lowered the glucose level. The hypoglycaemic effect of silymarin in metabolic syndrome, particularly diabetes mellitus, has been reported in many scientific publications[141].

Many parts of the pomegranate (bark, seeds, flowers, juice) have demonstrated hypoglycaemic effects related to their phenolic compounds, the presumed effects of inhibition of enzymes involved in carbohydrate metabolism, stimulation of insulin release by β-cells and, in general, protection of pancreatic tissue[142]. Notably, *in vivo* studies in rodents with induced hyperglycaemia demonstrated pomegranate's hypoglycaemic effect[143]. Consumption of pomegranate has not been shown to have a significant beneficial effect on the improvement of glucose and insulin metabolism, and even daily supplementation with pomegranate is not recommended as a potential therapeutic strategy in glycaemic management[144].

Rosmarinic acid is particularly abundant in many Lamiaceae, in species commonly used as culinary herbs such as *Ocimum basilicum* L. (basil), *Ocimum tenuiflorum* L. (holy basil), *Melissa officinalis* L. (lemon balm), *Salvia rosmarinus* Spenn. (rosemary), *Origanum majorana* L. (marjoram), *Salvia officinalis* L. (sage), *Thymus vulgaris* L. (thyme) and *Mentha piperita* L. (peppermint)[145]. Rosmarinic acid possesses remarkable pharmacological activities, which has recently led to its exploration as a therapeutic drug in the treatment of diabetes. Previous studies have demonstrated the potent role of rosmarinic acid in controlling blood glucose level and increasing insulin sensitivity in hyperglycaemia. Although rosmarinic acid is readily absorbed

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[141] Lieshchova M. A., Brygadyrenko V. V. Effect of *Echinacea purpurea* and *Silybum marianum* seeds on the body of rats with an excessive fat diet. Biosystems Diversity. 2023. Vol. 31(1). P. 90–99.

[142] Jandari S., Hatami E., Ziaei R., Ghavami A., Yamchi A. M. The effect of pomegranate (*Punica granatum*) supplementation on metabolic status in patients with type 2 diabetes: A systematic review and meta-analysis. Complementary Therapies in Medicine. 2020. Vol. 52. 102478.

[143] Virgen-Carrillo C. A., Moreno A. G. M., Miramontes E. H. V. Potential hypoglycemic effect of pomegranate juice and its mechanism of action: A systematic review. Journal of Medicinal Food. 2020. Vol. 23(1). P. 1–11.

[144] Huang H. H., Liao D., Chen G. Z., Chen H. L., Zhu Y. K. Lack of efficacy of pomegranate supplementation for glucose management, insulin levels and sensitivity: Evidence from a systematic review and meta-analysis. Nutrition Journal. 2017. Vol. 16. P. 67.

[145] Sik B., Kapcsandi V., Szekelyhidi R., Hanczne E. L., Ajtony Z. Recent advances in the analysis of rosmarinic acid from herbs in the Lamiaceae family. Natural Product Communications. 2019. Vol. 14(7). 1934578X19864216.

by the human body, its mechanism after consumption remains unclear[146]. The hypoglycaemic effect of the active components of *Origanum vulgare* in a 90-day experiment was also reported in the study by Horky et al. (2019)[147].

Cholesterol is an essential component of cell membranes, ensuring their permeability and fluidity. Cholesterol is also a precursor of steroid hormones, bile acids and vitamin D. Dietary cholesterol is partially absorbed, and the liver and other tissues synthesise cholesterol. Cholesterol is transported into the plasma by lipoproteins. It is then eliminated unchanged in the bile or converted to bile acids. According to the lipid hypothesis, elevated blood cholesterol levels lead to atherosclerosis, which may increase the risk of heart attack, stroke and peripheral arterial disease. In the control group of rats fed a balanced diet for 30 days, blood plasma cholesterol levels were 1.3 ± 0.38 mmol/L. Consumption of a high-fat diet during the same period did not significantly affect this indicator, which was 1.27 ± 0.15 mmol/L (Fig. 17). The addition of medicinal plants to the high-fat diet had a significant effect on blood plasma cholesterol levels in the presence of *Echinacea purpurea* seeds. The increase was 59.8% compared with the group of rats on the high-fat diet and 56.1% compared with the control group. The addition of *Salvia sclarea* to the high-fat diet also increased blood plasma cholesterol levels by 28.3% in comparison with the high-fat diet group and by 25.4% in comparison with the control group.

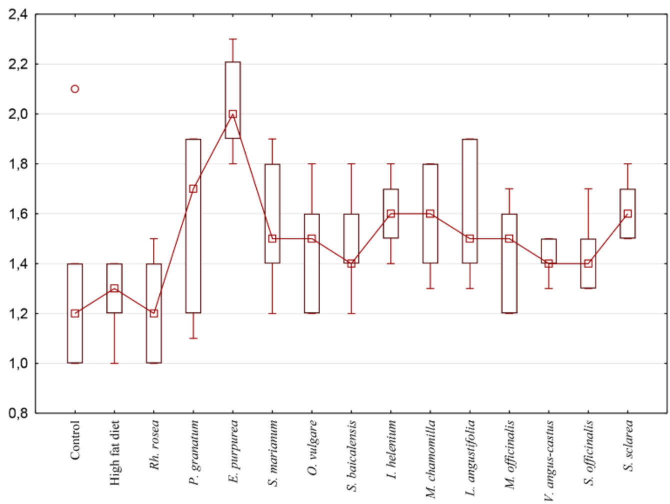

Fig. 17. Blood plasma Cholesterol levels in rats fed standard diet and high-fat diet supplemented with medicinal plants, mmol/L (x ± SD, n = 7, duration of experiment – 30 days)

[146] Ngo Y. L., Lau C. H., Chua L. S. Review on rosmarinic acid extraction, fractionation and its anti-diabetic potential. Food and Chemical Toxicology. 2018. Vol. 121.P. 687–700.

[147] Horky P., Skalickova S., Smerkova K., Skladanka J. Essential oils as a feed additives: Pharmacokinetics and potential toxicity in monogastric animals. Animals. 2019. Vol. 9(6). P. 352.

Thus, the high-fat diet did not cause blood plasma cholesterol levels to rise above physiological levels during the 30-day experiment. The addition of medicinal plants to the high-fat diet also had no significant effect on blood plasma cholesterol levels, with the exception of *Echinacea purpurea* seeds.

Triacylglycerols are esters of glycerol and fatty acids that are ingested with food or synthesised in the liver. Triacylglycerols are transported into the plasma by lipoproteins and are used in adipose tissue, skeletal muscle, etc. The main function of triglycerides is to provide energy for cells. Blood triglyceride levels were 0.84 ± 0.13 mmol/L in rats in the control group fed a balanced standard diet for 30 days (Fig. 18). After 30 days, rats fed the high-fat diet showed a 153.6% rise compared with controls. The addition of the medicinal plants to the high-fat diet reduced this parameter to a level below that of the high-fat diet group, and in some cases even below that of the control group.

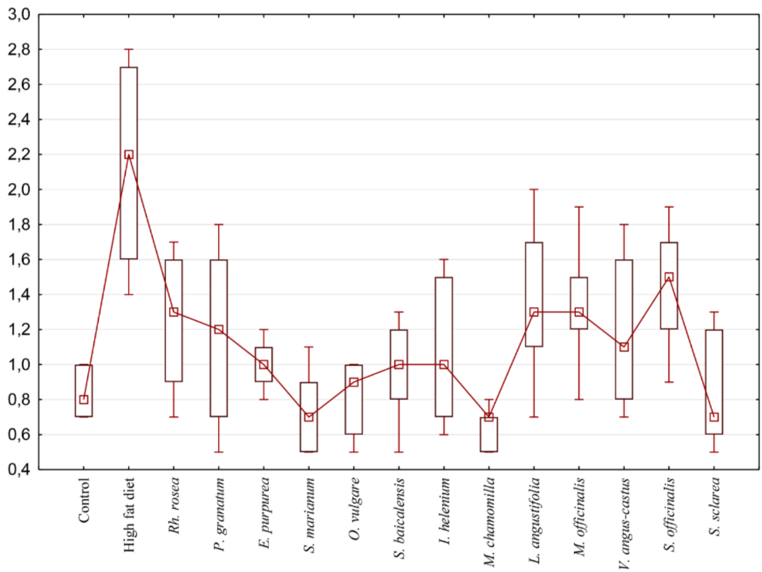

Fig. 18. Blood plasma Blood triglycerides levels in rats fed standard diet and high-fat diet supplemented with medicinal plants, mmol/L (x ± SD, n = 7, duration of experiment – 30 days)

Adding *Matricaria chamomilla* inflorescences to the high-fat diet reduced blood triglyceride levels by 25.0% compared with the control group and by 70.4% compared with the group of rats consuming the high-fat diet alone. *Silybum marianum* seeds had the same effect, reducing blood triglycerides by

13.0% and 65.7% respectively. When *Origanum vulgare* and *Salvia sclarea* were administered in the high-fat diet, blood triglycerides decreased by 62.0% and 61.0%, respectively, compared with the group of animals consuming high-fat diet, bringing this indicator to the level of the control group. Blood triglyceride levels were also reduced in rats fed *Echinacea purpurea* seeds and *Scutellaria baicalensis* root (by 53.5%), *Inula helenium* root (by 51.2%), *Punica granatum* fruit peel (by 46.5%), *Rhodiola rosea* root and *Vitex angus-castus* herb (by 43.7%), *Melissa officinalis* herb (by 37.1%), *Lavandula angustifolia* inflorescences and *Salvia officinalis* herb (by 36.1%). However, despite the reduction, blood triglyceride levels did not reach those of control rats. Thus, the consumption of a high-fat diet caused an increase in blood triglyceride levels, and the additional supplementation of medicinal plants contributed to a decrease in this parameter. In addition, *Echinacea purpurea* seeds, *Scutellaria baicalensis* roots, *Inula helenium* roots, *Rhodiola rosea* roots, *Punica granatum* fruit peels, *Vitex angus-castus* herb, *Melissa officinalis* herb, *Salvia officinalis* herb and *Lavandula angustifolia* inflorescences reduced blood triglyceride levels compared to rats fed a high-fat diet. It was also reduced below the level of the control group by *Matricaria chamomilla* inflorescences and *Silybum marianum* seeds.

High-density lipoprotein (HDL) is one of the five main groups of lipoproteins. Lipoproteins are complex particles made up of several proteins. They carry all the fat molecules (lipids) in the body in water outside the cells. Lipoproteins are divided into five subgroups according to their density and size (an inverse relationship), which is also correlated with their function and the incidence of cardiovascular events. HDL particles carry fat molecules away from the cells, unlike the larger lipoprotein particles, which carry fat molecules into the cells. The lipids that are carried include cholesterol, phospholipids and triglycerides, although the amount of each is variable. An increase in the concentration of HDL particles is associated with a decrease in the build-up of atherosclerosis in the walls of the arteries, which reduces the risk of sudden plaque rupture, cardiovascular disease, stroke and other vascular diseases. HDL particles help prevent and even reverse atherosclerosis by removing fat molecules from the artery walls and reducing macrophage accumulation, and are commonly referred to as "good cholesterol". Higher levels of HDL-C may not necessarily be protective against cardiovascular disease and may even be harmful at extremely high levels, with an increased risk of cardiovascular disease, particularly in patients with high blood pressure. In rats that were fed a complete balanced diet for 30 days, the level of high-density lipoprotein (HDL) cholesterol was 0.61 ± 0.14 mmol/L (Fig. 19).

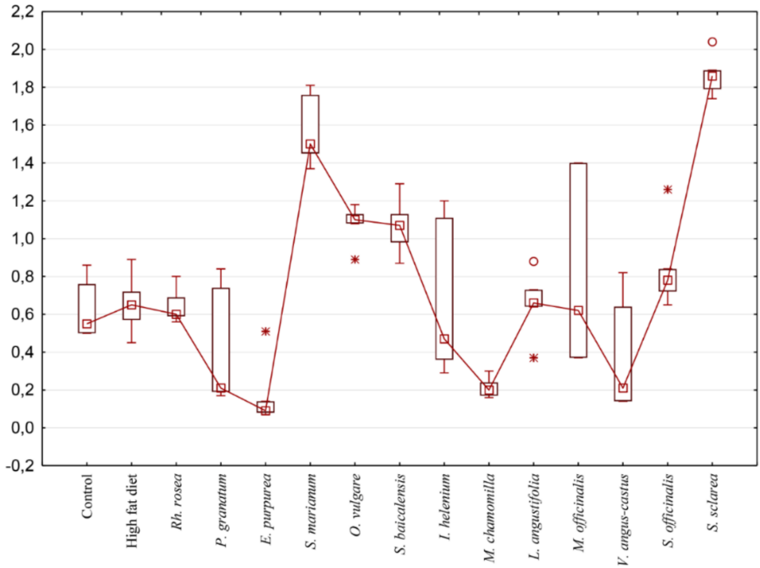

Fig. 19. The level of high-density lipoprotein (HDL) cholesterol in the blood plasma of rats fed standard diet and high-fat diet supplemented with medicinal plants, mmol/L (x ± SD, n = 7, duration of experiment – 30 days)

High-density lipoprotein (HDL) cholesterol levels increased slightly to 0.65 ± 0.14 mmol/L in rats fed a high-fat diet during the same period. Adding medicinal plants to the high-fat diet affected this parameter differently. Thus, the maximum increase in high-density lipoprotein (HDL) cholesterol levels in the blood of rats that consumed *Salvia sclarea* was 186.1% in comparison with the high-fat diet group and 204.9% in comparison with the control group. A significant increase in high-density lipoprotein (HDL) cholesterol levels was seen with *Silybum marianum* seeds by 140% and 155.7%, and *Origanum vulgare* by 66.1% and 77.0% respectively. The herbs *Melissa officinalis* and *Salvia officinalis* also increased this indicator by 27.7% and 36.1%, respectively, compared to the high-fat and control groups of rats. A decrease in the level of high-density lipoprotein (HDL) cholesterol in the blood below the level of the control group was found in rats fed *Echinacea purpurea* seeds (by 73.8%), *Matricaria chamomilla* inflorescences (by 65.6%), *Vitex angus-castus* herb (by 44.3%) and Punica granatum fruit peel (by 39.3%). Blood high-density lipoprotein (HDL) cholesterol levels were not significantly affected by the addition of *Rhodiola rosea* root, *Inula helenium* root, and *Lavandula angustifolia* inflorescences to the high-fat diet.

Consumption of a high-fat diet slightly increased the level of high-density lipoprotein (HDL) cholesterol in the blood of rats, and the supplementation with medicinal plants had a multidirectional effect. Thus, under the influence of *Silybum marianum* seeds, *Origanum vulgare* herb, *Melissa officinalis* herb and *Salvia officinalis* herb, the level of high-density lipoprotein (HDL) cholesterol in the blood of rats increased, while *Echinacea purpurea* seeds, *Matricaria chamomilla* inflorescences, *Vitex angus-castus* herb, *Punica granatum* fruit peel decreased.

Low-density lipoprotein (LDL) is one of the five major groups of lipoproteins that carry all the molecules of fat in the extracellular fluid around the body. Lipoproteins transport lipids (fats) around the body in the extracellular fluid, making fats available to body cells for receptor-mediated endocytosis. Lipoproteins are complex particles composed of multiple proteins. Typically, there are 80-100 proteins per particle (organised by a single apolipoprotein B for LDL and the larger particles). A single LDL particle is about 220-275 angstroms in diameter. It typically carries 3.000 to 6.000 fat molecules per particle and varies in size depending on the number and composition of the fat molecules it contains. The lipids carried include all fat molecules, with cholesterol, phospholipids and triglycerides dominating. The amount of each varies considerably. A good clinical interpretation of blood lipid levels is that high LDL combined with high triglycerides, indicating a high likelihood of the LDL being oxidised, is associated with increased risk of cardiovascular disease[148].

Blood plasma low-density lipoprotein (LDL) cholesterol levels were 0.47 ± 0.15 mmol/L in rats fed a complete balanced diet on day 30 of the experiment. In animals fed a high-fat diet for 30 days, the level of low-density lipoprotein (LDL) cholesterol increased by 10.6% to 0.52 ± 0.31 mmol/L (Fig. 20).

Adding most of the medicinal plants to the high-fat diet contributed to increasing this parameter, both in comparison with the control group and above the level in the high-fat diet group. In the blood of rats treated with *Echinacea purpurea* seeds (212.8%), *Matricaria chamomilla* inflorescences (195.7%), *Lavandula angustifolia* inflorescences (144.7%), and *Vitex angus-castus* herb (102.1%), a large increase in the level of low-density lipoprotein (LDL) cholesterol was found compared with the control. The addition of *Punica granatum* peels, *Rhodiola rosea* root, *Origanum vulgare* herb and *Inula helenium* root to the high-fat diet increased this indicator by 74.5%, 59.6%, 53.2% and 46.8% respectively. The consumption of *Silybum marianum* seeds (by 27.6%) and *Salvia sclarea* (by 25.5%) reduced low-

[148] Carson J. A. S., Lichtenstein A. H., Anderson C. A. M., Appel L. J., Kris-Etherton P. M., Meyer K. A., Petersen K., Polonsky T., Van Horn L. Dietary cholesterol and cardiovascular risk: a science advisory from the American Heart Association. Circulation. 2020. Vol. 141(3)..

density lipoprotein (LDL) cholesterol below the level of the control group. At the same time, *Scutellaria baicalensis* root, *Melissa officinalis* and *Salvia officinalis* had no significant effect on low-density lipoprotein (LDL) cholesterol. In addition, compared with animals in the control group (balanced diet), the high-fat diet for 30 days caused an increase in low-density lipoprotein (LDL) cholesterol levels in the rats' blood. Supplementing the high-fat diet with the herbs *Silybum marianum* and *Salvia sclarea* reduced this parameter. On the other hand, *Echinacea purpurea* seeds, *Matricaria chamomilla* and *Lavandula angustifolia* inflorescences, *Vitex angus-castus* herb, *Punica granatum* fruit peels, *Rhodiola rosea* root, *Origanum vulgare* herb, *Inula helenium* root increased the level of low-density lipoprotein (LDL) cholesterol in the blood of rats.

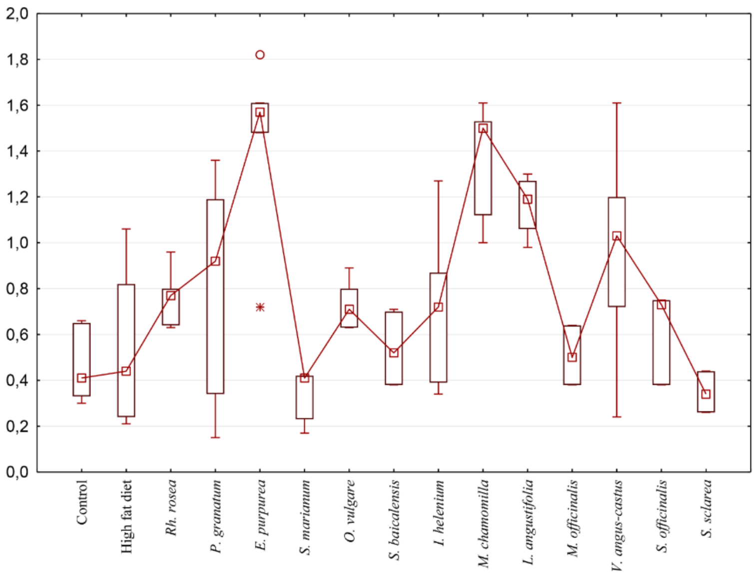

Fig. 20. The level of low-density lipoprotein (LDL) cholesterol in the blood plasma of rats fed sandard diet and high-fat diet supplemented with medicinal plants, mmol/L (x ± SD, n = 7, duration of experiment – 30 days)

In our study, an increase in the concentration of cholesterol in the blood serum was observed under the influence of a number of medicinal plants. What is more important is the increase in the level of cholesterol which is a part of the low-density lipoproteins against the background of a decrease in the content of the high-density lipoproteins cholesterol. The relationship between increasing LDL-C, decreasing HDL-C and the risk of developing cardiovascular disease due to the formation of vascular atherosclerosis has been established[149], which is confirmed by a significant increase in the atherogenicity index in animals of the experimental groups. Reduction of serum LDL-C concentrations is not always prophylactically effective due to high triglyceride concentrations[150]. Therefore, the observed decrease in triglyceride concentration under the influence of some medicinal plants can be considered as a positive factor, since triglycerides and their metabolites may contribute to the development of atherosclerosis by modulating inflammation, oxidative stress and foam cell formation[151].

It is generally accepted that abnormal levels of cholesterol, triglycerides or free fatty acids are signs of impaired lipid metabolism. Hyperlipidaemia and hypercholesterolaemia, and in particular high plasma concentrations of low-density lipoprotein cholesterol (LDL-C), are the primary initiating factors in the development of atherosclerotic lesions. In our study, both the high-fat diet and the addition of *Echinacea purpurea* and *Sylibum marianum* seeds caused significant blood dyslipidaemia in rats. In the group of animals fed a high fat diet (15%) for 30 days, triglycerides and low-density lipoprotein cholesterol (LDL-C) increased above the physiological norm. Adding *Echinacea purpurea* seeds to the diet aggravated the dyslipidaemia by increasing cholesterol and low-density lipoprotein (LDL) cholesterol and decreasing blood triglycerides and high-density lipoprotein (HDL) cholesterol. *Sylibum marianum* seeds had the opposite action, increasing HDL cholesterol, decreasing blood triglycerides, and not changing cholesterol and LDL cholesterol, resulting in a reduction of plasma atherogenic index below that of the control group. This suggests that *Sylibum marianum* can be recommended for the treatment and prevention of diseases associated with impaired lipid metabolism. A study on the effect of long-term use of silymarin in patients with type 2 diabetes mellitus showed an antitriglyceride effect, but no effect on cholesterol levels and blood pressure[152].

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Although there are publications that pomegranate has a beneficial effect on lipid profile[153], other studies show no effect and no significant influence on lipid profile[154]. Studies by Rios et al. (2018)[155] show that it is the ellagic acid in pomegranate fruit that reduces plasma levels of total cholesterol and triglycerides, but this is directly dependent on the dose of the substance. It is also the extract of pomegranate fruit that induces the strongest reduction in plasma levels of total cholesterol and triglycerides when compared to other fruit extracts[156]. Furthermore, pomegranate flower extract has been shown to reduce total cholesterol, triglycerides, LDL-C, VLDL-C and raise HDL-C levels of streptozotocin diabetic rats, thereby improving the course of diabetes[157].

Sclareol is a bioactive hydrophobic diterpene in *Salvia sclarea* essential oil, widely studied for its anti-inflammatory and antioxidant effects. The study showed that sclareol-loaded lipid nanoparticles (L-Sc) improved the metabolic profile of obese mice by reducing adiposity, improving insulin sensitivity and glucose tolerance, and increasing plasma HDL levels in the blood of obese rats. For the treatment of metabolic disorders by reducing adipose tissue, the use of sclareol together with lipid nanocarriers may be promising[158]. *Salvia sclarea* essential oils have shown potential antidiabetic activity and may be used in the future as a complementary or alternative medicine in the management of diabetes and related complications[159].

Agadzhanyan (2015)[160] investigated the hypoglycaemic and hypolipidaemic activity of *Salvia officinalis* leaf extracts on human serum with glucose concentration of 10.0 mmol/l and total cholesterol level of 8.2 mmol/l *in vitro*. The results showed that both aqueous and alcoholic extracts

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of the studied plant reduced glucose concentration and serum cholesterol levels[161]. In studies on diet-induced obese mice, low-dose ethanolic extract of sage was found to have rosiglitazone-like effects, improving insulin sensitivity, inhibiting lipogenesis in adipocytes and reducing inflammation[162].

The study conducted by Ekin et al. (2019)[163] was aimed at determining the the anti-Alzheimer, antidiabetic, antioxidant and antiobesity activities of ethanolic extracts of *Salvia sclarea*. The leaf extract of *Salvia sclarea* showed a remarkable butyrylcholinesterase inhibition (51.76 +/– 1.04%). The highest total antioxidant activity was observed in the Salvia species. The highest iron-reducing antioxidant activities were found in *S. sclarea* flower (1.34 +/– 0.08) and leaf (1.34 +/– 0.08) extracts. The study indicated that *Salvia sclarea* extracts showed valuable inhibitory activity and emerged as a source of possible alpha-glucosidase inhibitors. Clary sage treatment increased NO production and eNOS levels and reduced oxidative stress in rats subjected to immobilisation stress, contributing to the recovery of endothelial dysfunction. Adequate concentrations of clary sage can reverse endothelial dysfunction. These findings suggest that clary sage essential oil may be effective in the prevention and treatment of stress-induced cardiovascular disease[164].

Heshmati et al. (2020)[165] pointed out that the intake of *Melissa officinalis* was associated with a reduction in total cholesterol and a reduction in systolic blood pressure. The intake of *Melissa officinalis* was not associated with statistically significant changes in triglycerides, low-density lipoprotein, diastolic blood pressure, high-sensitivity C-reactive protein levels, fasting plasma glucose, HbA1c, insulin, or high-density lipoprotein levels. There were no serious adverse events reported. The study by Heshmati et al. (2020) suggests that *Melissa officinalis* is a safe dietary supplement with beneficial effects. Numerous studies have shown that *Melissa officinalis* possesses high levels of antioxidant activity through its chemical components, including

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high levels of flavonoids, rosmaric acid, gallic acid, and phenolic content. Many studies have confirmed the antioxidant effects of *Melissa officinalis*; therefore, its effect in the prevention and treatment of oxidative stress-related diseases may be reliable[166]. Moradi et al. (2016)[167] pointed out that more comprehensive studies using more advanced methods are needed to achieve promising anti-HSV agents isolated from bioactive compounds of *Melissa officinalis*.

In the blood of animals consuming *Origanum vulgare*, lipid metabolism was found to be normalised compared to the high-fat diet group. Similar changes in lipid metabolism were observed when *Scutellaria baicalensis* was fed. Blood levels of high-density lipoproteins also increased, while triglycerides decreased[168]. According to Abd Rashed et al (2017)[169], the attenuating effect of essential oils, including *Origanum vulgare*, on obesity can be explained by several possible mechanisms, including antilipase activity, increase in plasma glycerol concentration and suppression of fat accumulation.

3.3. Effect on blood enzyme activity

Blood enzyme activity is an important diagnostic test for the assessment of both general health and the functional activity of individual organs, including the liver. Aspartate aminotransferase (AST) catalyses the formation of glutamic acid from 2-oxoglutarate by transferring an amino group. AST is most abundant in the liver and heart muscle, but is also found in high concentrations in skeletal muscle, kidney and pancreas. In laboratory animals, this indicator varies within a wide range of reference values. In control rats fed a complete balanced diet for 30 days, AST activity was 122.4 ± 16.85 U/L, which is higher than the reference values for this species (Fig. 21). Blood AST activity was 52.2% higher in the group of rats fed a high fat diet. This indicator was also higher in the groups of rats that received medicinal plants in addition to the high-fat diet than in the control group, and in some of them it was even higher than in the rats that received only a high-fat diet. For example, the addition of *Origanum vulgare* to the high-fat diet increased AST activity by 81.7% compared with the control group and by 19.4% compared with rats fed a high-fat diet alone. Adding *Salvia sclarea* to the high-fat diet increased blood AST activity by 73.0% compared with the control group and by 13.6% compared with animals fed the high-fat diet.

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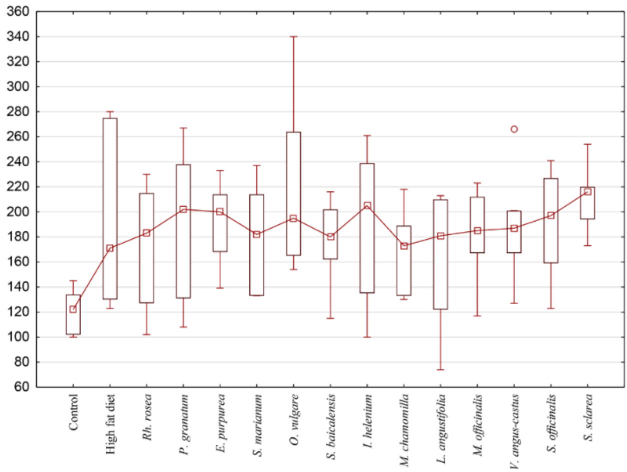

Fig. 21. Aspartate aminotransferase (AST) activity in the blood plasma of rats fed standard diet and high-fat diet supplemented with medicinal plants, U/L (x ± SD, n = 7, duration of experiment – 30 days)

The addition of *Punica granatum* fruit peel to the high-fat diet increased blood AST activity by 55.2% compared with the control group and was almost indistinguishable from the value in animals on the high-fat diet. *Echinacea purpurea* seeds (56.8% increase), *Inula helenium* root (55.8% increase), *Vitex angus-castus* (55.7% increase), *Salvia officinalis* (53.0% increase) and *Melissa officinalis* (48.8% increase) had a similar effect on this parameter compared with the control. Other medicinal plants in the study contributed to a reduction in blood AST activity in relation to this parameter in rats fed a high-fat diet. It should be noted, however, that the AST activity in the blood was still higher in comparison with the control group (high-fat diet). The addition of *Lavandula angustifolia* inflorescences to the high-fat diet reduced blood AST activity by 14.3% compared with the high-fat diet, *Matricaria chamomilla* inflorescences by 8.2%, *Rhodiola rosea* and *Scutellaria baicalensis* roots by 4.6% and Silybum marianum seeds by only 3.7%. Thus, the high-fat diet consumed by the rats for 30 days caused an increase in blood AST activity, both compared with the control group and above the reference values. Adding medicinal plants to the high-fat diet did not normalise this indicator and did not contribute to a significant reduction of AST activity in the blood of the rats compared to the control group. However, the addition of *Lavandula angustifolia* and *Matricaria chamomilla* inflorescences, *Rhodiola rosea* and *Scutellaria baicalensis* roots and *Silybum marianum* seeds to the high-fat diet slightly reduced the activity of AST in the blood of rats compared with rats consuming a high-fat diet.

Alanine aminotransferase (ALT) catalyses the formation of glutamic acid from 2-oxoglutarate by amino group transfer. ALT is normally found in a number of different tissues, but the highest levels are found in the liver and the kidneys. In the control group of rats consuming a complete diet during the 30-day experiment, ALT activity was 51.4 ± 6.94 U/L (Fig. 22). In comparison, rats fed the high-fat diet had a 154.3% increase in this parameter on the 30th day of the experiment. The addition of medicinal plants to the high-fat diet had a different effect on the activity of ALT in the blood of the rats, but the consumption of none of them reduced this indicator to the level of the control group. Thus, when *Punica granatum* fruit peel was added to the high-fat diet, there was a significant increase in blood ALT activity of 64.2% compared with the group of rats on a high-fat diet and of 317. 5% compared to the control group of animals, *Inula helenium* root – by 48.9% and 278.6%, *Vitex angus-castus* herb – by 36.9% and 248.0%, *Echinacea purpurea* seeds – by 32.6% and 237.2%, *Rhodiola rosea* root – by 17.0% and 197.5%. At the same time, compared with animals in the high-fat diet group, the supplementation of *Silybum marianum* seeds in the diet contributed to a 39.1% decrease in ALT activity in the blood of rats. The same effect was observed with the addition of *Salvia sclarea* (17.9% reduction), *Origanum vulgare* (15.6% reduction), *Melissa officinalis* (14.8% reduction), *Matricaria chamomilla* inflorescences (14.0% reduction) and *Scutellaria baicalensis* roots (11.2% reduction). However, when *Salvia officinalis and Lavandula angustifolia* inflorescences were added to the diet, blood ALT activity remained at the level of the high-fat diet group.

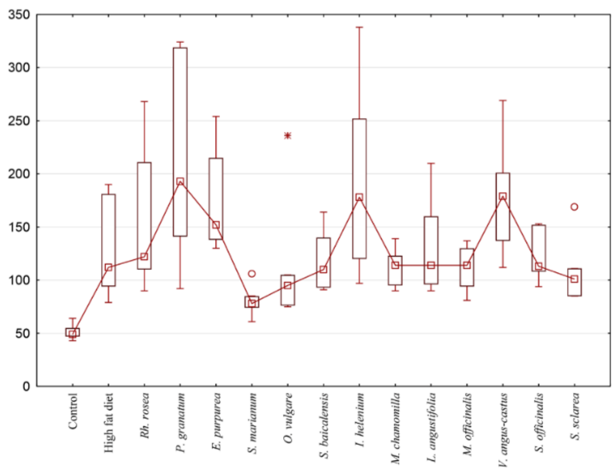

Fig. 22. Alanine aminotransferase (ALT) activity in the blood plasma of rats fed standard diet and high-fat diet supplemented with medicinal plants, U/L (x ± SD, n = 7, duration of experiment – 30 days)

For example, the activity of alanine aminotransferase (ALT) in blood plasma rises sharply when animals were fed a high-fat diet for 30 days. The addition of medicinal plants to a high-fat diet has a different effect on this indicator. Compared with the high-fat diet group, Punica granatum fruit peel, Inulae herba root and Rhodiola rosea root increased blood ALT activity, whereas *Silybum marianum* seed, *Salvia sclarea* herb, *Origanum vulgare* herb, *Melissa officinalis* herb, *Matricaria chamomilla* inflorescences and *Scutellaria baicalensis* root decreased this indicator.

Alkaline phosphatase is the enzyme that catalyses the hydrolysis of organic phosphate monoesters in an alkaline environment. The enzyme is present in almost all body tissues, particularly in cell membranes, and is found in particularly high concentrations in the placenta, intestinal epithelium, renal tubules, osteoblasts and liver. In the control group of rats fed a complete balanced diet, the activity of ALP was 151.1 ± 21.86 U/L, slightly higher than the reference values (Fig. 23). Consumption of a high fat diet for 30 days of the experiment resulted in a decrease in this indicator to a level of 129.0 ± 69.17 U/L, which corresponded to the upper limit of the reference range for this species.

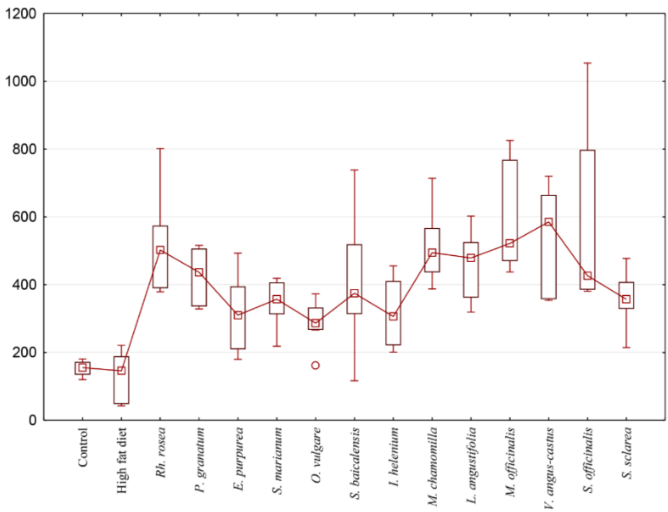

Fig. 23. Alkaline phosphatase activity in the blood plasma of rats fed standard diet and high-fat diet supplemented with medicinal plants, U/L (x ± SD, n = 7, duration of experiment – 30 days)

When medicinal plants were added to the high-fat diet, the alkaline phosphatase activity in the rats' blood plasma increased significantly, both compared to the control group and compared to the animals on the high-fat diet. The greatest increase in alkaline phosphatase activity in the blood plasma of rats was caused by the consumption *of Melissa officinalis*: 297.5% compared with the control group and 365.6% compared with the high-fat diet group. A significant increase in alkaline phosphatase activity in blood plasma was caused by Salvia officinalis – by 271.4% and 335.0%, *Vitex angus-castus* – by 298.6% and 306.2%, *Rhodiola rosea* root – by 240.3% and 298.6%, *Matricaria chamomilla* inflorescences – by 239.0% and 297.0%, compared to the control and the high-fat diet groups, respectively. The same effect, but less intense, was observed with the supplementation of *Lavandula angustifolia* inflorescences to the high-fat diet (increase of 198.5% compared to the control group and of 249.7% compared to the high-fat diet group), *Punica granatum* fruit peel (increase of 180. 1% and 228.0% respectively), *Scutellaria baicalensis* root (163.3% and 208.4%), *Salvia sclarea* herb (136.0% and 179.4%) and *Silybum marianum* seeds (131.4% and 171.0%). The least effect on the activity of alkaline phosphatase in blood plasma was caused by the consumption of *Origanum vulgare* herb, *Echinacea purpurea* seeds and *Inula helenium* root. Here, the increase in activity of this enzyme was only 91.0% compared to the control group and 123.7% compared to the group of animals on a high-fat diet – for *Origanum vulgare*; 105.4% and 140.5% for *Echinacea purpurea*; 108.1% and 143.8%, respectively.

Therefore, the high-fat diet caused a slight decrease in the activity of alkaline phosphatase in the blood plasma of the rats compared to the control. The addition of medicinal herbs to the high-fat diet, on the other hand, greatly increased the activity of this enzyme in the blood, both in the high-fat diet group and in the control group. The highest increase in alkaline phosphatase activity in blood plasma was observed with *Melissa officinalis, Salvia officinalis, Vitex angus-castus, Rhodiola rosea* root and *Matricaria chamomilla* inflorescence, and the lowest with *Origanum vulgare*, *Echinacea purpurea* seeds and Inula helenium root.

Gamma-glutamyl transferase (GGT) is an enzyme found in the cells of the liver and bile ducts that catalyses certain biochemical reactions. GGT is not found in the circulatory system, only in cells whose destruction releases their contents into the bloodstream. Normally, there is a certain amount of cell renewal, which is why some GGT activity is present in the blood. When many cells die, the activity can increase significantly. The activity of γ-glutamyltransferase in the blood of rats in the control group (complete diet for 30 days) was 3.9 ± 1.73 U/L. Consumption of a high-fat diet for 30 days caused an increase in GGT activity to 9.3 ± 2.81 U/L, but this value did not exceed the physiological norm (Fig. 24).

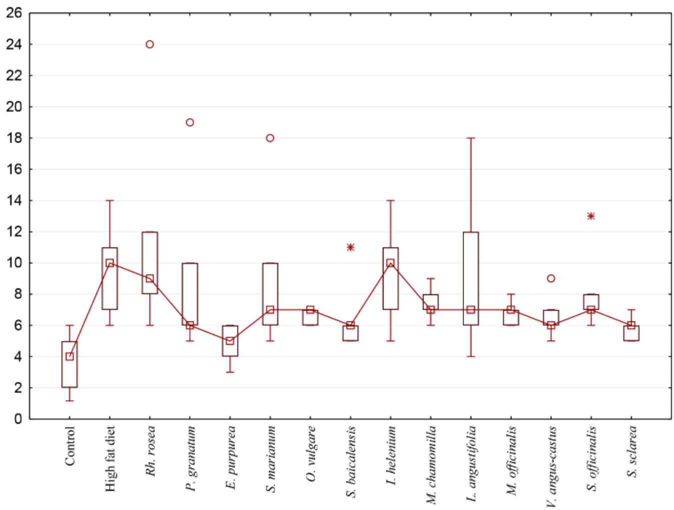

Fig. 24. γ-glutamyltransferase activity in the blood plasma of rats fed standard diet and high-fat diet supplemented with medicinal plants, U/L (x ± SD, n = 7, duration of experiment – 30 days)

When medicinal plants were added to the high-fat diet, blood GGT activity did not fall to the level of the control group, but did not exceed the reference values for this species. Compared to the high-fat diet group, only adding *Rhodiola rosea* root increased GGT activity by 18.3%. Blood GGT activity was lower in rats that also consumed *Echinacea purpurea* seeds (by 46.2%), *Salvia sclarea* herb (by 36.6%), *Scutellaria baicalensis* root and *Vitex angus-castus* herb (by 31.2%), *Melissa officinalis* and *Origanum vulgare* (by 28.0%), *Matricaria chamomilla* inflorescences (by 20.4%), *Salvia officinalis* (by 15.0%), compared to animals on the high-fat diet. And with the consumption of *Lavandula angustifolia* inflorescences, *Inula helenium* root, *Silybum marianum* seeds and *Punica granatum* fruit peel, blood GGT activity remained almost at the level of animals fed a high-fat diet.

Thus, the consumption of a high-fat diet for 30 days did not increase the activity of GGT above the physiological norm, but compared to the control group, this indicator more than doubled. The addition of medicinal plants to the high-fat diet increased the activity of GGT in the blood of rats above the control group, but remained within the physiological norm. Only the addition of *Rhodiola rosea* root increased the activity of this enzyme in the blood compared with the activity of blood GGT in the high-fat diet group. *Echinacea purpurea* seeds, *Salvia sclarea* herb, *Scutellaria baicalensis* root, *Vitex angus-castus* herb, *Melissa officinalis* herb, *Origanum vulgare* herb, *Salvia officinalis* herb, *Matricaria* *chamomilla* inflorescences contributed to a slight decrease in blood GGT activity in rats compared to animals on a high-fat diet.

Biomarkers of liver damage are the transaminase enzymes AST and ALT. An increase in their concentration in the serum is a characteristic feature of the process of cytolysis of the hepatocytes[170]. In our study, the activity of both enzymes was high in comparison with reference values. This may be due to the development of non-alcoholic fatty liver disease (NAFLD), which is common in animals and humans on a high-fat diet[171]. NAFLD is either a cause or a consequence of the development of metabolic syndrome, which is characterised by a combination of risk factors for cardiovascular disease and type 2 diabetes mellitus[172].

This factor could also stimulate an increase in alkaline phosphatase activity, the serum activity of which is largely determined by the bone isoenzyme form and increases during the period of body growth, as an increase in body weight gain was observed in the group of animals additionally treated with *M. chamomilla*[173]. *M. chamomilla* ethanolic extract stimulates osteoblast activity in bone tissue by reducing osteoclast numbers through the presence of phenolic compounds, especially flavonoids. Alkaline phosphatase activity in plasma is directly correlated with osteoblast activity, which may explain the results obtained[174].

Zarei et al (2014)[175] found a significant decrease in liver enzyme activity in a 21-day experiment in rats fed a high-fat diet and different doses of Melissa extract. In our experiment on rats fed a high-fat diet, AST, ALT and alkaline phosphatase exceeded the reference values by day 30 of the experiment, indicating damage to the cell membranes of hepatocytes. Adding molasses to the diet only reduced ALT activity, AST activity was almost the same as in animals fed a high-fat diet, and alkaline phosphatase activity was significantly higher. This may be due either to the longer duration of our experiment or to a lower dose of the active ingredients.

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CONCLUSIONS

Medicinal plants as part of a high-fat diet given to model animals during a 30-day experiment affected the rate of weight gain, the absolute weight of organs and caused changes in blood biochemical parameters. Milk thistle seeds *(Silybum marianum)* – slowed down weight gain, reduced spleen AW; increased the level of total protein, total bilirubin, creatinine, cholesterol and low-density lipoprotein (LDL) cholesterol, reduced the level of glucose, blood triglycerides and high-density lipoprotein (HDL) cholesterol, reduced the activity of AST and ALT. Oregano herb *(Origanum vulgare)* – slowed weight gain and reduced splenic AW; increased levels of total protein, globulins, total bilirubin, creatinine, inorganic phosphorus, low-density lipoprotein (LDL) cholesterol, high-density lipoprotein (HDL) cholesterol and reduced levels of C-reactive protein and glucose compared with the high-fat diet group. Clary sage herb *(Salvia sclarea)* – slowed body weight gain, increased liver and lung AW and decreased kidney and spleen AW; increased levels of total protein, globulins, total bilirubin above the reference range, decreased C-reactive protein, low-density lipoprotein (LDL) cholesterol, decreased ALT activity and increased levels of total calcium, cholesterol, compared to animals in the high-fat diet group. Elecampane root *(Inula helenium)* – slowed down body weight gain, increased liver AW and decreased spleen AW; increased the level of total bilirubin above the reference range, increased the level of total protein, globulins, C-reactive protein, cholesterol and low-density lipoprotein (LDL) cholesterol, ALT activity and decreased the level of blood triglycerides compared to the value of animals on high-fat diet. Golden root *(Rhodiola rosea)* – accelerated body weight gain; reduced AW of kidney, spleen and brain; reduced globulin levels to reference range and urea levels below reference range, increased C-reactive protein and low-density lipoprotein (LDL) cholesterol levels, decreased creatinine, cholesterol, triacylglycerols, increased ALT, alkaline phosphatase and gamma-glutamyltransferase activity, while AST activity was decreased compared to the high-fat diet group. Pomegranate fruit peel *(Punica granatum)* – accelerated weight gain, increased AW of liver, lungs, kidneys, spleen and brain, increased total protein, globulins and urea above physiological levels, and increased C-reactive protein, inorganic phosphorus, cholesterol, low-density lipoprotein and ALT activity above that of the high-fat diet group. Purple coneflower seed *(Echinacea purpurea)* – accelerated weight gain, dramatically increased AW of the liver, heart, lungs, kidneys and spleen compared to the high fat diet group; increased the levels of total protein, globulins and creatinine above the reference range, increased the levels of cholesterol and low-density lipoprotein (LDL) cholesterol, decreased the levels of blood triglycerides and high-density lipoprotein (HDL) cholesterol, increased ALT activity above the value of the high-fat diet group. Baikal skullcap roots *(Scutellaria baicalensis)* – accelerated weight gain, increased AW of liver, lung, spleen and decreased AW of brain; reduced globulins and urea to reference range, reduced C-reactive protein, glucose, blood triglycerides, decreased AST and ALT activity compared to the value of animals fed only high fat diet. Blue chamomile inflorescences *(Matricaria chamomilla)* – accelerated weight gain, increased AW of liver, heart, lungs, kidneys, spleen and brain; increased the level of glucose and decreased the level of urea in relation to the reference values, increased the level of creatinine, cholesterol, low-density lipoprotein (LDL) cholesterol and decreases the level of total protein, C-reactive protein, blood triglycerides, high-density lipoprotein (HDL) cholesterol, decreased the activity of AST and ALT and significantly increased the activity of alkaline phosphatase, compared to the high-fat diet group. Narrow-leaved lavender *(Lavandula angustifolia)* – accelerated body weight gain, increased liver, heart, spleen and brain AW and decreased brain AW; increased non-organic phosphorus levels above reference range, increased C-reactive protein, cholesterol, low-density lipoprotein (LDL) cholesterol, decreased creatinine, blood triglycerides and AST activity compared to the high-fat diet group. Lemon Balm herb *(Melissa officinalis)* – accelerated weight gain, increased liver, lung and spleen AW; increased total protein and creatinine levels above the physiological norm, decreased C-reactive protein, blood triglycerides and ALT activity and increased high-density lipoprotein (HDL) cholesterol levels and significantly increased alkaline phosphatase activity compared to animals fed a high-fat diet. Chaste Tree herb *(Vitex angus-castus)* – accelerated weight gain, increased AW of the liver, heart, lungs and spleen, increased the level of total protein, globulins and reduced urea beyond the reference range, decreased the level of blood triglycerides, high-density lipoprotein (HDL) cholesterol and increased low-density lipoprotein (LDL) cholesterol, increased the activity of ALT and alkaline phosphatase, compared to animals fed a high-fat diet. Common Sage herb *(Salvia officinalis)* – accelerated weight gain, increased liver and heart AW and decreased spleen AW; increased total protein, globulins above the reference range, increased C-reactive protein, total calcium, high-density lipoprotein (HDL) cholesterol, and increased alkaline phosphatase activity and decreased blood triglycerides compared to animals fed a high-fat diet.

SUMMARY

Excessive fat consumption is one of the most serious health problems as it causes changes in metabolism and stimulates the development of obesity, diabetes and vascular diseases. One of the trends in modern medicine is to increase the role of traditional folk medicinal plants in the treatment of metabolic disorders. Adding spicy, aromatic and medicinal plants to food is

often a solution to the problem of excessive calorie intake. However, their use can not only cause healthy changes in the body, but can also stimulate the intensification of pathological changes caused by excessive calorie intake. Therefore, in a 30-day experiment, we studied the effect of thirteen medicinal plants on the intensity of body weight gain and the absolute weight of internal organs in white laboratory rats fed a high-fat diet (15% vegetable fat). The following parameters were assessed in plasma at the end of the experiment: protein and mineral metabolism (total protein, albumin, globulin, urea, creatinine, total bilirubin, C-reactive protein, total calcium, inorganic phosphorus), carbohydrate and lipid metabolism (glucose, cholesterol, blood triglycerides, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol) and blood enzyme activity (aspartate aminotransferase (AST), alanine aminotransferase (ALT), alkaline phosphatase, γ-glutamyltransferase. It was found that adding 5% milk thistle seeds *(Silybum marianum)*, oregano herb *(Origanum vulgare)*, clary sage herb *(Salvia sclarea)*, elecampane root *(Inula helenium)* to a high-fat diet slowed weight gain, while golden root *(Rhodiola rosea)*, pomegranate fruit peel *(Punica granatum)*, purple coneflower seeds *(Echinacea purpurea)*, Baikal skullcap root *(Scutellaria baicalensis)*, blue chamomile inflorescences *(Matricaria chamomilla)*, narrow-leaved lavender inflorescences *(Lavandula angustifolia)*, lemon balm herb *(Melissa officinalis)*, chaste tree herb *(Vitex angus-castus)*, common sage herb *(Salvia officinalis)* – accelerated weight gain. Most of the studied medicinal plants caused an increase in liver AW, with the exception of golden root, milk thistle seeds and oregano herb. Medicinal plants had a significant effect on protein metabolism, causing an increase in total blood protein levels, mainly due to the globulins fraction. Milk thistle seeds, oregano herb, elecampane root, and clary sage herb increased blood bilirubin levels above the reference values, and blue chamomile inflorescences increased blood glucose levels. Both the high-fat diet and the addition of medicinal plants to it caused disturbances in lipid metabolism, with changes in different ways.

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