

Assessment of the complex-forming capacity of pectins obtained from various vegetable and fruit raw materials as a basis for creating special food products

Nataliia V. Kurdil¹, Olha O. Khudaikulova¹, Iryna O. Krapyvnytska², Yevhen O. Omelchuk², Tetyana O. Shchutska¹, Tetyana P. Kostyuchenko¹, Borys I. Palamar³

¹L.I. MEDVED'S RESEARCH CENTER OF PREVENTIVE TOXICOLOGY, FOOD AND CHEMICAL SAFETY OF THE MINISTRY OF HEALTH OF UKRAINE (STATE ENTERPRISE), KYIV, UKRAINE

²NATIONAL UNIVERSITY OF FOOD TECHNOLOGIES, KYIV, UKRAINE

³BOGOMOLETS NATIONAL MEDICAL UNIVERSITY, KYIV, UKRAINE

ABSTRACT

Aim: To study the complexing ability of pectins obtained from various vegetable and fruit raw materials with metal ions.

Materials and Methods: The content of metals was determined by the atomic emission method (SHIMADZU ICPE-9820 spectrometer); heavy metal measurement methods used were MI.C3.7.2.01-017 and MI.C3.7.2.01-018. Statistical analysis of the obtained data was performed using the IBM SPSS Statistics version 29.0.0.0 program; correlation analysis was conducted using the Kendall Tau-b method.

Results: It was found that the highest complexing ability towards the mixture of Cu²⁺, Zn²⁺, Cd²⁺, and Pb²⁺ ions was demonstrated by low-esterified sugar beet pectin ($r = 0.600$; $p < 0.01$). Citrus ($r = 0.312$; $p < 0.01$), quince ($r = 0.292$; $p < 0.01$), and apple ($r = 0.271$; $p < 0.01$) pectins also exhibited high complexing rates, while pumpkin ($r = 0.214$; $p < 0.01$) and carrot ($r = 0.156$; $p < 0.01$) pectins had slightly lower rates. In addition, pectin is found in smaller quantities in carrots and pumpkins than in sugar beet, citrus fruits, quince, and apples. To improve nutritional characteristics, reduce allergenicity, and maintain high complexing ability of the final product, the authors proposed a combination of raw materials from sugar beet and pumpkin, enriched with apple pectin and/or pectin-containing products and juices of pumpkin and apples.

Conclusions: It was established that the highest complexing ability in relation to a mixture of lead, cadmium, mercury, zinc, and copper ions is possessed by low-esterified sugar beet pectin. The addition of this pectin to apple pectin and/or pectin-containing apple products and juices increases the potential non-specific detoxification properties of the final food product.

KEY WORDS: pectins, complexation, heavy metals, food products

Pol Merkur Lek, 2025; 53(3): 361-366 doi: 10.36740/Merkur202503110

INTRODUCTION

Pectin is an important polysaccharide used in the food, pharmaceutical, and several other industries. In the food industry, pectin is added to jams, jellies, frozen foods, and, more recently, to fat and sugar substitute formulations. In the pharmaceutical industry, it is used to lower blood cholesterol levels and treat gastrointestinal disorders. Other uses of pectin include its application in edible films, paper substitutes, plasticizers, and more. Although pectin is present in the cell walls of all plants, apple pomace and orange peel are the main sources of commercial pectin [1].

The functionality of the complex macromolecule pectin in products and ingredients derived from fruits and vegetables is largely determined by the presence of the polymer homogalacturonan, which undergoes various enzymatic and non-enzymatic transformation reactions during food processing, altering its structural and functional properties [2].

Natural polysaccharides are recommended for long-term chronic diseases, such as diabetes and heart disease [3, 4]. Studies on cell and animal models, as well as clinical trials on humans, have provided supporting data that modified citrus pectin improves the course of oncological diseases [5]. The important role of pectin as a probiotic has also been proven [6].

The relevance of preserving and improving the health of the population of Ukraine today is due to the negative consequences of the Chernobyl disaster, the COVID-19 pandemic, and the catastrophic impact on the health of the population from the large-scale war unleashed by the Russian Federation against Ukraine. Natural pectin-containing products are of particular scientific interest in terms of restoring the functions of the human body. The value of pectin-containing products lies, along with the above-mentioned qualities, in their detoxification and radioprotective properties, which are attributed to the

ability of pectin molecules to complex with both metal cations and cations of organic origin [7].

AIM

The purpose of this work is to study the complexing ability of pectins obtained from various vegetable and fruit raw materials to metal ions (Cu^{2+} , Zn^{2+} , Cd^{2+} and Pb^{2+}) for further development of food formulations for special medical purposes.

MATERIALS AND METHODS

An analysis of domestic and foreign sources of scientific information on the topic of the study was carried out; methods of comparative analysis and a systematic approach were applied; experimental studies were conducted to assess the compatibility of components and select the optimal content of the ingredients in the recipe; statistical methods of information collection and processing were used.

The main recipe components of the final products were pectin-containing pumpkin puree, apple pectin extract, pumpkin and apple juices, low-esterified sugar beet pectin and its puree; the manufacturer of raw ingredients (semi-products and products) LLC "MANZANA-FOOD" LLC "MANZANA-FOOD" according to TU U 15.3-35422486-001:2009 "Juices, nectars, fruit, vegetable, vegetable-fruit juice drinks".

Technical conditions. The safety of the raw materials was investigated according to microbiological and sanitary-chemical safety indicators using instrumental methods of chemical analysis and for compliance with the State Sanitary Rules and Norms "Maximum permissible levels of individual pollutants in food products" [8], the requirements of GN 6.6.1.1-130-2006 "Permissible levels of radionuclides $^{137}\text{cesium}$ (^{137}Cs), $^{90}\text{strontium}$ (^{90}Sr) in food products and drinking water" [9] and the manufacturer's specifications. Also, in the process of work, when selecting raw pectin-containing components, the physicochemical quality indicators of the recipe components and the complexing ability of pectins from various vegetable and fruit raw materials to a mixture of Cu^{2+} , Zn^{2+} , Cd^{2+} , Pb^{2+} ions were investigated.

The choice of pectin-containing raw materials was due to the fact that the initial products, in terms of their chemical composition, should have the least probable allergenicity, which is a very important factor when consuming final food products for special medical purposes. The safety of the raw materials was investigated according to sanitary-chemical and microbiological indicators. To determine the content of pesticide residues, the method of ultra-high-performance liquid chromatography with electron spray ionization mass spectrometry (UPLC-MC/MC, Waters, USA) and the method of gas chromatography according to DSTU EN 12393-1:2003, DSTU EN 12393-2:2003, DSTU EN 12393-3:2003 and GOST 30349-96 were used. The content of lead, cadmium, mercury, zinc was determined by the atomic emission method (device – atomic emission spectrometer "SHIMADSU ICPE-9820"); methods for measuring heavy metals – MI.C3.7.2.01-017 and MI.C3.7.2.01-018. To determine radionuclides, the spectrometer "CEG-001", "AKP-C" and

spectrometer "CEB-01-70" were used (Methodology for measuring the specific activity of ^{137}Cs – MI 12-04-99. Methodology for measuring the specific activity of ^{90}Sr – MI 12-05-99).

Statistical analysis of the obtained data was carried out using the IBM SPSS Statistics version 29.0.0.0 program; correlation analysis was applied using the Kendall Tay-b method.

RESULTS

According to the results of the studies, it was found that the raw material components in terms of the content of heavy metals, radionuclides and pesticide residues meet the established medical safety criteria. The complexing ability of pectins from various vegetable and fruit raw materials to a mixture of Cu^{2+} , Zn^{2+} , Cd^{2+} and Pb^{2+} ions was (mg meth/g pectin / mmol meth/g pectin):

- from sugar beet pulp (Cu^{2+} – 148/2,32; Zn^{2+} – 85,0/1,30; Cd^{2+} – 154/1,17; Pb^{2+} – 147/0,71);
- citrus (Cu^{2+} – 127/2,00; Zn^{2+} – 82,4/1,26; Cd^{2+} – 115/1,02; Pb^{2+} – 126/0,61);
- quince (Cu^{2+} – 82,7/1,30; Zn^{2+} – 85,7/1,31; Cd^{2+} – 130/1,16; Pb^{2+} – 143/0,69);
- apple (Cu^{2+} – 99,2/1,56; Zn^{2+} – 97,5/1,49; Cd^{2+} – 88,8/0,79; Pb^{2+} – 82,9/0,40);
- carrot (Cu^{2+} – 50,9/0,80; Zn^{2+} – 46,4/0,71; Cd^{2+} – 79,8/0,71; Pb^{2+} – 78,7/0,38);
- pumpkin (Cu^{2+} – 76,3/1,20; Zn^{2+} – 53,6/0,82; Cd^{2+} – 67,4/0,60; Pb^{2+} – 66,3/0,32).

The above results are shown in Fig. 1, Fig. 2, Fig. 3, Fig. 4.

According to the Kendall Tay-b rank correlation method (two-way correlation is significant at $p < 0,01$), it was found that the lowest esterified sugar beet pectin has the highest complexing ability towards the mixture of Cu^{2+} , Zn^{2+} , Cd^{2+} and Pb^{2+} ions ($r = 0,600$; $p < 0,01$). Apple pectin has a lower complexing ability for Pb^{2+} than sugar beet, citrus and quince pectins ($r = 0,560$; $p < 0,01$).

Pumpkin ($r = 0,314$; $p < 0,01$) and carrot ($r = 0,156$; $p < 0,01$) pectins have a lower complexing ability towards heavy metals than the other pectins mentioned above.

DISCUSSION

It is known that pectin is contained in carrots and pumpkins in smaller quantities than in sugar beets, citrus fruits, quinces and apples. However, as raw materials for food formulations for special medical purposes, pectin-containing pumpkin products enriched with apple pectin and/or pectin-containing pumpkin and apple juices were chosen, since they have the least probability of causing an allergic reaction. The addition of apple pectin and/or pectin-containing apple products and juices was intended to increase the detoxification capacity of the pectin-containing food product in relation to heavy metal ions, which will further ensure the possibility of its use for special medical purposes.

The action of pectin begins from the moment it enters the stomach; the full complexing effect occurs in the colon and ends in the rectum. The most favorable conditions for

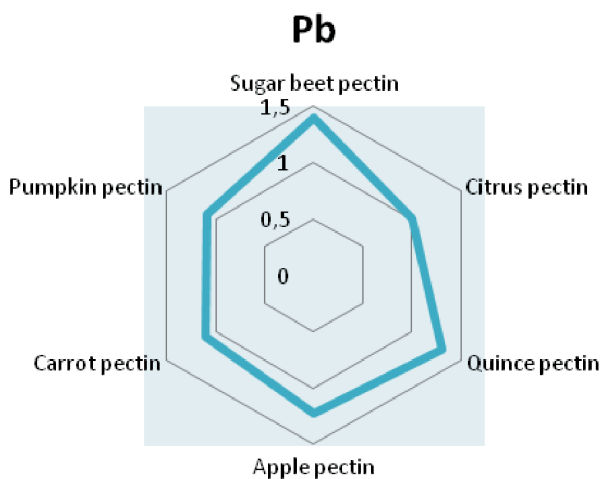


Fig. 1. Comparative characteristics of the complexing ability of pectins (mmol met/g pectin) from various vegetable and fruit raw materials to metal ions (Pb^{2+})
Source: compiled by the authors of this study

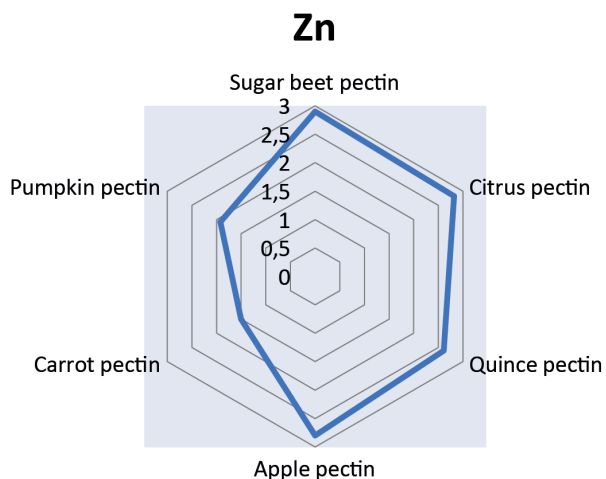


Fig. 3. Comparative characteristics of the complexing ability of pectins (mmol meth/g pectin) from various vegetable and fruit raw materials to zinc ions (Zn^{2+})
Source: compiled by the authors of this study

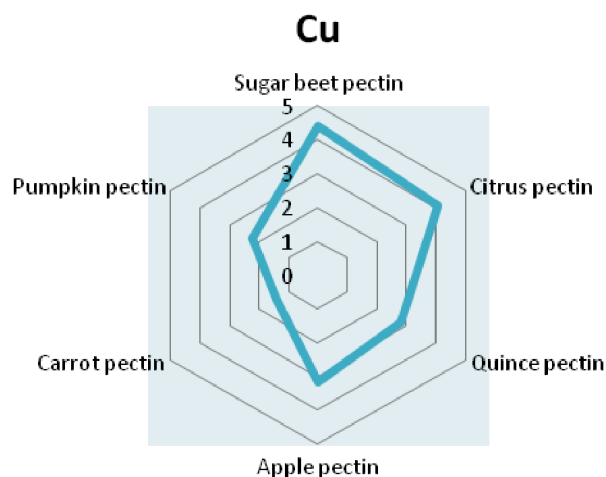


Fig. 2. Comparative characteristics of the complexing ability of pectins (mmol meth/g pectin) from various vegetable and fruit raw materials to copper ions (Cu^{2+})
Source: compiled by the authors of this study

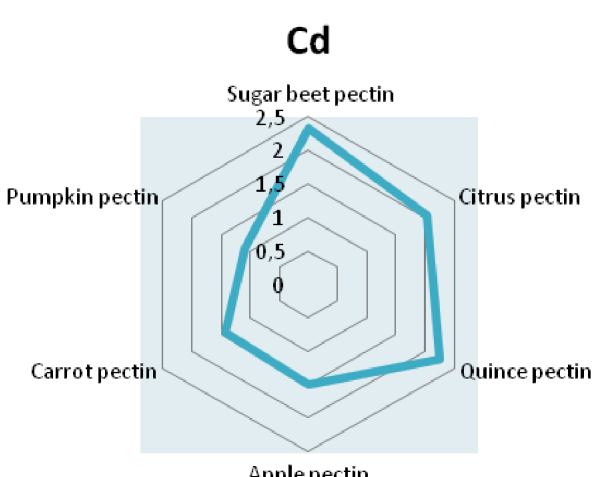


Fig. 4. Comparative characteristics of the complexing ability of pectins (mmol meth/g pectin) from various vegetable and fruit raw materials to metal ions (Cd^{2+})
Source: compiled by the authors of this study

the complexation of pectins with metals in the intestine are an alkaline environment. The acidity rate in the stomach is 1,5–2,0 (pH units). The acidity of the small intestinal juice is 7,2–7,5 (pH units); with increased secretion it increases to 8.6 (pH units). The acidity of the large intestinal juice is 8,5–9,0 (pH units). The effectiveness of apple pectin for complexation decreases under the influence of hydrochloric acid and gastric juice enzymes during food digestion, so we have developed a number of product formulations for special medical purposes with an additional content of low-esterified sugar beet pectin (and/or its puree), which is known to form complexes with metals in a wide pH range.

Also, when developing food formulations for special medical purposes that contained pectin-containing carrot raw materials, the need to maintain shelf life and increase the detoxification capacity of the final product was taken into account by adding low-esterified sugar beet and

apple pectins (or their pectin-containing purees) under the condition of maintaining the pH of the product within 4,8–5,0 (pH units).

Based on the results of studies of the complexing ability of pectins from various vegetable and fruit raw materials to each of the Cu^{2+} , Zn^{2+} , Cd^{2+} and Pb^{2+} ions separately, which are shown in Figs. 1-4, it is possible to assess the feasibility of using a particular pectin-containing raw material (or the corresponding pectin) for the purpose of removing a certain metal from the body.

The term “food products for special medical purposes” is defined in paragraph 93 of part one of article 1 as amended by the Law of Ukraine “On Amendments to Certain Legislative Acts of Ukraine on Bringing the Legislation of Ukraine in the Field of Providing Baby Food in Accordance with the Requirements of the Legislation of the European Union” No. 1822-IX dated 10/21/2021). The creation of food products

for special medical purposes containing pectin-containing extracts, purees and pectins is due to the need to restore the functions of the human body after acute infectious and non-infectious diseases and to support the body weakened by long-term and chronic diseases.

The complex-forming properties of low-esterified pectins allow them to be considered as a valuable component of special nutrition aimed at non-specific detoxification of the body in a wide range of acute and chronic diseases accompanied by metabolic disorders and multi-organ failure in a wide range of infectious, non-infectious diseases and poisonings.

The production of food products for special medical purposes in Ukraine is most economically profitable due to the use of semi-finished products and products (from pumpkin, apples, sugar beet) as raw materials, in the creation of which there is almost no production waste [2, 10, 11]. Food products manufactured according to the proposed approaches, along with the content of pectin substances, also have a valuable composition of biologically active substances (organic acids, glucose, fructose, proteins), macro- and microelements. Such food products can be intended for partial feeding of patients with various needs that cannot be satisfied by modifying the usual diet [12]. The proposed pectin-containing products should be consumed as prescribed by a doctor in a healthcare facility and/or outside it.

In many countries of the world, the search for new natural components for the creation of special nutrition formulations continues. The complexing properties of low-esterified pectins allow us to consider them as a valuable component of special nutrition aimed at non-specific detoxification of the body in a wide range of diseases.

Today, natural macromolecules are used for the adsorption of pollutants, including heavy metal ions and organic dyes, due to their low cost, availability, biodegradability and environmental friendliness. Pectin, an important natural polymer, has a large number of carboxyl and hydroxyl functional groups that can interact with inorganic and organic cations [13].

The economic efficiency of the production of pectin-containing food products is due to the fact that a cheap source of pectin is beet pulp. During the processing of sugar beet in the sugar industry, a huge amount of beet pulp is formed as waste, which can be considered a valuable by-product and a source of cellulose, hemicellulose and pectin. The transformation of sugar beet pulp into value-added products is carried out using acid hydrolysis, hydrothermal methods and enzymatic hydrolysis. Modern methods of

processing raw materials allow to obtain value-added products [14].

Scientific and technological progress has allowed to create hybrid materials of hydrogels and metal organic pectin frameworks with high adsorption capacity. For example, pectin hydrogel was obtained from by-products of tangerine peel, and calcium chloride was used as a cross-linker to combine with metal organic Fe-TAC frameworks to form a framework-pectin composite by in situ synthesis [15]. Another direction for increasing the antioxidant properties of sugar beet pectin is the integration of enzymatic modification and ultrafiltration for the production of pectin fractions with high antioxidant capacity as a green valorization of sugar beet pulp [16]. The positive effect of ultrasound treatment on the structure and antioxidant properties of sugar beet pectin has been proven [17].

Studies aimed at studying the structural characteristics and mechanisms of antioxidant activity of sugar beet pectin, in particular its subfraction rich in ferulic acid, have been conducted [18]. A separate important argument for the value of pectin, in addition to its complex-forming properties, is its high probiotic capacity [19, 20].

PERSPECTIVES FOR FURTHER RESEARCH

The large-scale war unleashed by the Russian Federation against Ukraine has created an extremely high level of chemical, biological, and radiological and nuclear threats due to the use of explosives, the destruction of critical infrastructure, and the terrorist seizure of the Zaporizhzhia NPP by Russian forces. All this confirms the need to develop effective means of protecting the health of military personnel and civilians from the effects of chemicals and ionizing radiation. A special role in this aspect belongs to food pectin-containing products with high complexing properties.

CONCLUSIONS

1. It was established that the lowest esterified sugar beet pectin has the highest complexing ability towards the mixture of Cu^{2+} , Zn^{2+} , Cd^{2+} and Pb^{2+} ions.
2. Adding apple pectin and/or pectin-containing apple products and juices to sugar beet pectin helps to reduce its allergenic properties and increases the nonspecific detoxification properties of the final product.
3. The complexing properties of low esterified pectins allow us to consider them as a valuable component of special nutrition aimed at nonspecific detoxification of the body in a wide range of infectious, non-infectious diseases and poisonings accompanied by metabolic disorders and multiorgan failure.

REFERENCES

1. Xiang T, Yang R, Li L et al. Research progress and application of pectin: A review. Review. J Food Sci. 2024;89(11):6985-7007. doi: 10.1111/1750-3841.17438.
2. Krapivnytska I, Ladyka V, Ianchik M et al. Scientific and practical aspects of pectin and pectin products Sumy-Kharkiv-Kyiv: Dissa+. 2022. https://repo.btu.kharkov.ua/bitstream/123456789/33162/1/Mon_Scientific_practical_22.pdf [Accessed 14 March 2025]

3. Dambuza A, Rungqu P, Oyedeji AO et al. Therapeutic Potential of Pectin and Its Derivatives in Chronic Diseases. Review. *Molecules*. 2024;29(4):896. doi: 10.3390/molecules29040896.
4. El-Nashar HAS, Taleb M, El-Shazly M et al. Polysaccharides (pectin, mucilage, and fructan inulin) and their fermented products: A critical analysis of their biochemical, gut interactions, and biological functions as antidiabetic agents. Review. *Phytother Res*. 2024;38(2):662-693. doi: 10.1002/ptr.8067.
5. Emran TB, Islam F, Mitra S et al. Pectin: A Bioactive Food Polysaccharide with Cancer Preventive Potential. Review *Molecules*. 2022;27(21):7405. doi: 10.3390/molecules27217405.
6. Elshahed MS, Miron A, Aprotosoiaie AC, Farag MA. Pectin in diet: Interactions with the human microbiome, role in gut homeostasis, and nutrient-drug interactions. Review *Carbohydr Polym*. 2021;255:117388. doi: 10.1016/j.carbpol.2020.117388.
7. Kurdil NV, Khudaikulova OO, Palamar BI et al. Results of research of personal hygiene products for suitability for special processing in zone of chemical, radioactive contamination and combat condition. *Wiad Lek*. 2022;75(11):2604-2608. doi: 10.36740/WLek202211109.
8. Derzhavni sanitarni pravyla i normy «Maksymal'no dopustymi rivni okremykh zabrudnyuyuchykh rehovyn u kharchovykh produktakh», zatverdzeni Nakazom MOZ Ukrayiny vid 22.05.2020r. № 1238, zareyestrovanyh v Minyusti Ukrayiny 21 lypnya 2020 r. za № 684/3467. [State sanitary rules and regulations «Maximum permissible levels of certain contaminants in food products». Approved by Order of the Ministry of Health of Ukraine dated May 22, 2020 No. 1238, registered with the Ministry of Justice of Ukraine on July 21, 2020 under No. 684/3467]. <https://zakon.rada.gov.ua/laws/show/z0684-20#Text> [Accessed 4 February 2025] (Ukrainian)
9. HN 6.6.1.1-130-2006 «Dopustymi rivni vmistu radionuklidiv ¹³⁷Cs i ⁹⁰Sr u produktakh kharchuvannya ta pytniy vodi» № 256 vid 03.05.2006 r. [GN 6.6.1.1-130-2006 "Permissible levels of radionuclides ¹³⁷Cs and ⁹⁰Sr in food and drinking water" No. 256 dated 03.05.2006.]. <https://environmentallab.com.ua/wp-content/uploads/2021/12/gn-6.6.1.1-130-2006-dopustymi-rivni-vmistu-radionuklidiv-137cs-i-90sr-u-produktah-harchuvannya-ta-pitnij-vodi.pdf> [Accessed 7 February 2025] (Ukrainian)
10. Krapyvnytska IO, Khachko VI, Voinova SM, Omelchuk YO. Sposib vyrobnytstva ridkoho pektynu [Method for making liquid pectine]: pat. 81935 Ukraine: A23L 1/0524 (2006.01). a200506456; published 25.02.2008. <https://iprop-ua.com/inv/lwn99oyk/> [Accessed 17 February 2025] (Ukrainian)
11. Sukmanov VO, Zotova IO. Sposib oderzhannia pektynu z yabluchnykh vychavok. [Making a pectin from apple pomace]: pat. Ukraine 59570: A23L 1/052 (2006.01). u201011578. <https://iprop-ua.com/inv/4yramf0k/> [Accessed 5 February 2025] (Ukrainian)
12. Weber AM, Pascale N, Gu F et al. Nutrition and health effects of pectin: A systematic scoping review of human intervention studies. Review. *Nutr Res Rev*. 2024;1-18. doi: 10.1017/S0954422424000180.
13. Li J, Yang Z-L, Ding T et al. The role of surface functional groups of pectin and pectin-based materials on the adsorption of heavy metal ions and dyes. Review. *Carbohydr Polym*. 2022;276:118789. doi: 10.1016/j.carbpol.2021.118789.
14. Usmani Z, Sharma M, Diwan D et al. Valorization of sugar beet pulp to value-added products: A review. Review *Bioresour Technol*. 2022;346:126580. doi: 10.1016/j.biortech.2021.126580.
15. Mahmoud ME, Mohamed AK. Novel derived pectin hydrogel from mandarin peel based metal-organic frameworks composite for enhanced Cr(VI) and Pb(II) ions removal. *Int J Biol Macromol*. 2020;164:920-931. doi: 10.1016/j.ijbiomac.2020.07.090.
16. Antov MA, Perović MN, Milošević MM. Integration of enzymatic modification and ultrafiltration for the production of pectin fractions with highly potent antioxidant capacity as green valorization of sugar beet pulp. *Bioprocess Biosyst Eng*. 2023;46(1):157-164. doi: 10.1007/s00449-022-02830-9.
17. Xu Y, Jian Zhang, He ZJ et al. Influences of Ultrasonic Treatments on the Structure and Antioxidant Properties of Sugar Beet Pectin. *Foods*. 2023;12(5):1020. doi: 10.3390/foods12051020.
18. Xiang C, Teng H, Sheng Z et al. Structural characterization and antioxidant activity mechanism of the ferulic acid-rich subfraction from sugar beet pectin. *Carbohydr Polym*. 2025;347:122691. doi: 10.1016/j.carbpol.2024.122691.
19. Prandi B, Baldassarre S, Babbar N et al. Pectin oligosaccharides from sugar beet pulp: molecular characterization and potential prebiotic activity. *Food Funct*. 2018;9(3):1557-1569. doi: 10.1039/c7fo01182b.
20. Tingirikari JMR. Microbiota-accessible pectic poly- and oligosaccharides in gut health. Review *Food Funct*. 2018;9(10):5059-5073. doi: 10.1039/c8fo01296b.

In this study, the authors adhered to current Ukrainian regulatory documents. The study protocol was approved by the Commission on Ethics of Medical and Biological Research of the L.I. Medved's Research Center of Preventive Toxicology, Food and Chemical Safety of the Ministry of Health of Ukraine (State Enterprise). The studies were conducted within the framework of the research work "Scientific Substantiation of Measures for the Toxicological Safety of the Human Environment in the Health Care System" (№ 0123U102087). The study did not require additional funding.

CONFLICT OF INTEREST

The Authors declare no conflict of interest

CORRESPONDING AUTHOR

Nataliia V. Kurdil

L.I. Medved's Research Center of Preventive Toxicology,
Food and Chemical Safety of the Ministry of
Health of Ukraine (State Enterprise)
6 Heroiv Oborony st., 03127 Kyiv, Ukraine
e-mail: kurdil_nv@ukr.net

ORCID AND CONTRIBUTIONSHIP

Nataliia V. Kurdil: 0000-0001-7726-503X **A C D**
Olha O. Khudaikulova: 0000-0003-3156-8208 **A B D E F**
Iryna O. Kravyvnytska: 0009-0000-5051-8885 **B D E**
Yevhen O. Omelchuk: 0000-0003-0154-4336 **B D E**
Tetyana O. Shchutska: 0000-0003-0154-4336 **B D**
Tetyana P. Kostyuchenko: 0000-0003-3608-7112 **B D**
Borys I. Palamar: 0000-0003-2510-0713 **E F**

A – Work concept and design, **B** – Data collection and analysis, **C** – Responsibility for statistical analysis, **D** – Writing the article, **E** – Critical review, **F** – Final approval of the article

RECEIVED: 17.01.2025

ACCEPTED: 04.05.2025

