

AGRICULTURAL BY-PRODUCTS: ECOLOGICAL, ECONOMIC, AND SOCIAL DIMENSIONS AND PATHWAYS TOWARD SUSTAINABLE TECHNOLOGIES

Papunidze G.R. , Chkhartishvili I.N. , S.G. Papunidze, N.R. Seidishvili, D.A. Abuladze

*Shota Rustaveli State University, Institute of Agrarian and Membrane Technologies, 6000 Batumi, Georgia
guram.papunidze@bsu.edu.ge*

Abstract. By-products arising from the industrial processing of agricultural raw materials impose considerable ecological, economic, and social challenges. The uncontrolled disposal of organic matter in landfills leads to methane emissions, which account for nearly 20% of global greenhouse gas outputs and represent a major driver of climate change and global warming. Environmental pollution further threatens human health and biodiversity while exacerbating ecosystem and soil degradation. Economically, the underutilization of agricultural by-products results in estimated annual global losses ranging from USD 780 billion to 1 trillion. Socially, approximately 1.3 billion tons of food are lost worldwide each year, even as 690–829 million people experience chronic hunger, 3 billion lack access to nutritious diets, and thousands of children die annually due to food scarcity. Within the framework of the circular economy, the valorization of agricultural by-products offers a sustainable pathway for their safe conversion into value-added food products, thereby promoting integrated economic growth, social well-being, and environmental protection. In this study, we examine the recovery of dietary fiber from by-products derived from the industrial processing of mandarin (*Citrus reticulata*) flowers and assess the biosorption capacity of the extracted fiber.

Keywords: mandarin flower by-products; waste management; biosorption; dietary fiber; circular economy

Introduction

Globally, more than 2.1 billion tons of waste are generated each year, a figure projected to increase by 70% by 2050, thereby intensifying social, economic, health, and environmental pressures. Considerable research has focused on the valorization of agro-industrial by-products, particularly those derived from fruits and vegetables, for the production of novel, value-added products that are already being successfully implemented across multiple sectors. In contrast, the valorization of floral by-products, originating from both ornamental and edible flowers, remains a critical global challenge.

Edible flowers are experiencing growing consumer interest due to their proven safety for human consumption, high nutritional value, and long-standing culinary use, which dates back to antiquity. They are further distinguished by their medicinal properties and richness in biologically active compounds, attributes that enhance their attractiveness within the food industry. Edible flowers can be incorporated into a wide range of products, including beverages, confectionery, and savory dishes, and are consumed in diverse forms. Market trends highlight the urgent need for a systematic and comprehensive analysis of edible flowers, encompassing their taxonomy, origin, bioactive constituents, nutritional characteristics, and potential applications in the food sector [1,2].

The Netherlands is responsible for approximately 52% of global flower production, whereas in India an estimated 700 million tons of floral waste are generated annually. Each year, more than 80 million tons of these wastes are discarded into rivers and landfills, negatively impacting soil quality, water resources, and aquatic ecosystems. Comparable conditions are observed in other countries, where the degradation of floral waste occurs at a considerably slower rate than that of other organic residues.

Studies on temple-derived floral waste have shown that the application of tailored microbial consortia can accelerate decomposition processes and produce high-quality biofertilizers without inflicting environmental harm. In parallel, contemporary research has increasingly emphasized the valorization of floral waste into value-added products, including compost, bioethanol, natural dyes, food ingredients, incense sticks, biofuels, organic acids, surface-active biomolecules, and handmade paper [3].

Concurrently, the problem of environmental contamination by heavy metals is becoming more acute. To mitigate these impacts, a variety of biosorption-based strategies have been developed, for instance, biomass derived from discarded flowers of *Rosa gruss* and *Canna indica* has been successfully employed for the biosorption of Pb(II) and Co(II) ions from aqueous solutions [4].

[5] reported that floral waste from *Hibiscus rosa-sinensis* (Chinese hibiscus), an environmentally friendly and low-cost raw material, can be effectively employed for the biosorption of heavy metals from water and soil. Similarly, [6] investigated the biosorption capacity of biomass derived from red rose petals for the removal of Pb(II) and Co(II) ions from aqueous solutions. Their study evaluated the impact of multiple process parameters, including pH, biosorbent dosage, particle size, temperature, contact time, initial metal concentration, and biomass pretreatment, on biosorption efficiency.

Edible flowers are increasingly recognized for their functional and nutritional properties and are widely incorporated into beverages, confectionery, and culinary preparations. Recent studies have examined the chemical composition of mandarin flowers and highlighted their potential applications in the food industry as a non-traditional raw material. Industrial processing of mandarin (*Citrus reticulata*) flowers produces extracts that serve as precursors for a wide range of products, including non-alcoholic and alcoholic beverages (e.g., liqueurs, vodka), low-alcohol drinks, tinctures, syrups, and artificial honey. The residual floral by-products generated after extract production, traditionally discarded through linear processing systems, represent an underutilized but valuable raw material for the recovery of high-quality dietary fiber.

Objective of the Study

This study aimed to evaluate the physicochemical characteristics and sorption capacity of dietary fiber obtained from industrial by-products of mandarin (*Citrus unshiu*) flowers.

Materials

The experimental material consisted of dietary fiber isolated from the by-products generated during the industrial processing of mandarin (*Citrus unshiu*) flowers.

Reagents and Methods

All reagents used were of analytical grade. Activated carbon and Pb(NO₃)₂ were procured from Sigma-Aldrich (Taufkirchen, Germany). Physicochemical properties were assessed using the following standard procedures: determination of dry matter (AOAC Official Method); measurement of active acidity (pH) (AOAC Official Method); and phytochemical analysis by spectrophotometry (Shimadzu, Japan). Sorption parameters were evaluated using titrimetric methods [8],

Technological Scheme for By-product Processing

Dietary fiber was extracted from floral by-products following a standardized technological process. The floral waste was dried at 40–45 °C for 40–60 minutes, milled to a uniform particle size, and packaged under oxygen-free conditions. The packaged material was then stored at +4 °C until subsequent analyses.

Sorption properties of dietary fiber

Water Retention Capacity (WRC) and Fat Absorption Capacity (FAC) were determined using the gravity method described by Núñez-Gómez et al. [7]. WRC – 1 g of sample was mixed with 20 mL of distilled water and maintained at 25°C for 24 hours, then centrifuged at 3000×g for 15 minutes. The supernatants were removed, the mass of the residue after hydration was measured and WRC was determined.

$$\text{WRC (g/g)} = m_2 - m_1 / m_1$$

where m_1 – the mass of the dry sample (g) before hydration, m_2 – the mass of the sample (g) after hydration. FAC – 0.5 g of sample was mixed with 20 mL of sunflower oil in the centrifuge tube and incubated at 37 °C for 1 hour. After incubation, the sample was centrifuged at 3000 rpm for 15 minutes. The supernatant was removed, and the residue was weighed.

Fat Absorption Capacity (FAC) is measured by the amount of absorbed oil (in grams) using the following formula:

$$\text{FAC (g/g)} = m_2 - m_1 / m_1$$

where m_1 – weight of the sample (g) before incubation with oil, m_2 – weight of the sample (g) after incubation with oil. [7].

Sorption capacity of dietary fibers toward lead ions – Lead ions were used in the form of analytical grade $\text{Pb}(\text{NO}_3)_2$ solution (0.025 mol/L). One gram of dietary fiber was mixed with 50 mL of the metal salt solution. Six flasks were incubated for 5, 10, 15, 20, 25, and 30 minutes, respectively, to obtain the sorption kinetics. The quantitative analysis of lead cations in the solution was carried out by titrimetric method [8]. From each flask, 2 mL of the test solution was transferred into a titration vessel using a volumetric pipette. Then, 0.1–0.2 g of dry hexamethylenetetramine (urotropine) was added to adjust the pH to 5.0, followed by three drops of Xylenol Orange indicator. The solution was then titrated with a standard EDTA solution (0.025 M) until the color changed from violet to lemon yellow.

To obtain sorption kinetic curves, 1 g of sorbent (m) was placed in a series of test tubes and treated with 50 mL (V) of aqueous metal salt solution. Contact time varies from 5 minutes to 1 hour. At specified time intervals, the solution was separated from the sorbent, and the concentration of metal ions (C_t) in the filtrate was determined using titration. The sorption capacity (A_t) of the sorbents at each time point was calculated using the following formula:

$$A_t = (C_0 - C_t) \times V / m$$

The removal efficiency (α) of lead ions was calculated using the equation:

$$\alpha = (C_0 - C_t) / C_0 \times 100\%$$

Statistical Analysis. All measurements were performed in triplicate. Data was processed using R Studio (version 4.0.5) supported by the R Foundation for Statistical Computing. Mean values and standard deviations were calculated. Differences among means were evaluated using Stewart's t-test at a significance level of $p < 0.05$. Pearson correlation coefficients were used to assess relationships between functional and phytochemical properties.

Results and Discussion

The chemical composition of mandarin flowers and their corresponding by-products (dietary fiber) is summarized in **Table 1**.

Table 1. Chemical composition of mandarin flowers (fresh weight basis) and floral by-products/dietary fiber (dry weight basis) (%).

№	Parameter	Mandarin flower (fresh weight)	Floral by-product / dietary fiber (dry weight)
1	Dry matter (%)	18.3 ± 0.21	6.8 ± 0.23
2	Acidity (%)	0.45 ± 0.08	0.08 ± 0.06
3	Total sugars (%)	14.7 ± 0.12	1.5 ± 0.10
4	Total pectin (%)	2.2 ± 0.21	11.5 ± 0.18
5	Hemicellulose (%)	0.9 ± 0.15	4.6 ± 0.16
6	Cellulose (%)	1.7 ± 0.08	8.5 ± 0.08
7	Lignin (%)	3.2 ± 0.20	17.4 ± 0.20
8	Total nitrogen (%)	0.3 ± 0.01	1.1 ± 0.01
9	Essential oil (%)	0.05 ± 0.03	0.008 ± 0.03
10	Vitamin C (mg/%)	366.7 ± 4.0	8.1 ± 3.0
11	Vitamin P (mg/%)	3.5 ± 0.14	18.0 ± 0.14
12	Vitamin B1 (thiamine, mg/kg)	2.3 ± 3.8	13.8 ± 4.1
13	Vitamin B2 (riboflavin, mg/kg)	2.8 ± 3.2	14.1 ± 3.2
14	Vitamin B6 (pyridoxine, mg/kg)	18.5 ± 3.3	88.6 ± 3.2

Different letters within rows indicate statistically significant differences between groups ($p < 0.05$).

The results demonstrate that, in comparison with mandarin flowers, mandarin floral by-products contain significantly higher levels of key constituents, including pectin, hemicellulose, cellulose, dietary fiber, vitamin P, and B-complex vitamins. The dietary fiber extracted from these by-products exhibited a low content of simple sugars ($1.5 \pm 0.02\%$) and a correspondingly high proportion of structural polysaccharides ($89.3 \pm 0.1\%$). A lower proportion of low-molecular-weight compounds (simple sugars) is generally associated with improved dietary fiber quality, enhanced sorption capacity, and greater physiological functionality [9].

Table 2. The content of fibrous polysaccharides (raw mass)

A way to get dietary fiber	Dry matter%	Simple sugars %	Fibrous Polysaccharide %
Mandarin flower	90.4 $\pm$ 0.1	1.2 $\pm$ 0.02	89.3 $\pm$ 0.1

The sorption characteristics of the dietary fiber, namely water retention capacity (WRC), fat absorption capacity (FAC), and Pb(II) adsorption capacity are presented in Table 3.

The assessment of sorption properties demonstrated that dietary fiber derived from mandarin flowers exhibits a high capacity for binding water, fat, bile acids, and lead. Comparative data reported by [9] indicated that the functional parameters of dietary fiber obtained from black currant, cranberry, and sea buckthorn press residues (powders) were as follows: WRC (g/g) – 2.78 ± 0.02 , 3.87 ± 0.18 , and 4.24 ± 0.02 , respectively; and FAC (g/g) – 1.14 ± 0.01 , 1.57 ± 0.05 , and 1.09 ± 0.02 , respectively.

Table 3. Sorption properties of floral dietary fiber

Sorption properties	WRC (g/g)	FAC (g)	Lead Sorption Capacity (mg/g)
Mandarin flower by-product fiber	13.3 $\pm$ 0.02	2.1 $\pm$ 0.05	20.1 $\pm$ 0.4

(Different letters among columns indicate significant differences ($p < 0.05$)).

For dietary fiber obtained from mandarin flowers, the measured values were WRC – 13.3 ± 0.42 g/g, FAC – 2.1 ± 0.05 g/g, and Pb(II) adsorption capacity – 9.2 ± 0.02 mg/g. These results indicate that mandarin flower dietary fiber possesses substantially higher water- and fat-binding capacities compared with berry-derived fibers [9].

The functional properties of dietary fiber are strongly influenced by its hydration and lipid-binding capacities. Consequently, its incorporation into food formulations as a bioactive additive is of considerable importance, as it can confer beneficial physiological effects, including hypoglycemic and hypolipidemic activities.

Contamination by toxic heavy metals represents a critical global environmental challenge. Lead [Pb(II)] is among the most hazardous metals, with major anthropogenic sources including automobile exhaust and lead-based paints. Elevated Pb(II) concentrations in the human body can cause anemia, hypertension, and neurological damage. Furthermore, Pb(II) exposure has been linked to neurotoxicity and genotoxicity, while chronic accumulation may contribute to carcinogenesis [6].

Adsorption is one of the most widely adopted techniques for heavy metal remediation, owing to its operational simplicity, cost-effectiveness, and high efficiency in removing toxic compounds. It has been extensively applied in wastewater treatment through biosorption. The adsorption performance of sorbents is influenced by multiple parameters, including adsorbent dosage, contact time, solution pH, initial adsorbate concentration, particle size, and temperature, with pH generally considered the most critical factor [10].

The experiment was carried out following the methodology described in [8] under conditions of pH = 5, employing floral by-product fiber and activated carbon as sorbents. The adsorption capacity (AT) of the sorbents at each time interval is presented in **Fig. 1**, which depicts the relationship between adsorption efficiency and contact time with Pb(II) ions. From these data, the adsorption activity-defined as the degree of Pb(II) ion removal-was calculated (**Fig. 2**).

The kinetic analysis demonstrated that Pb(II) ion binding occurred considerably faster with floral by-product fiber than with activated carbon. After 5 minutes, floral fiber adsorbed 20% of Pb(II) ions, whereas activated carbon adsorbed only 4.54%. Thus, within the first 5 minutes, the binding efficiency of floral fiber was approximately four times greater.

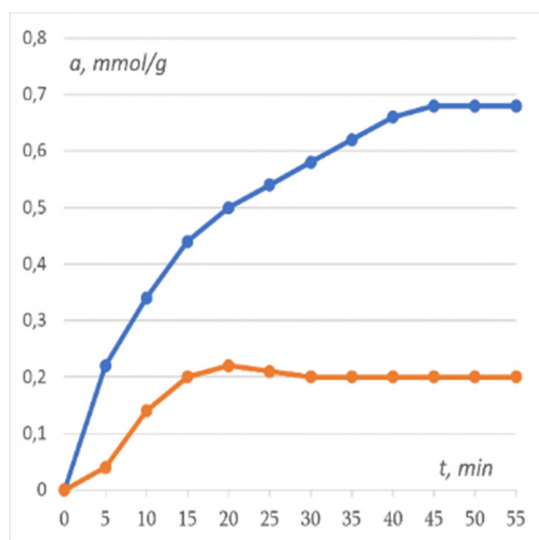


Fig. 1. Kinetics of Pb(II) ion adsorption by enterosorbents: ● – floral by-product fiber; ● – activated carbon.

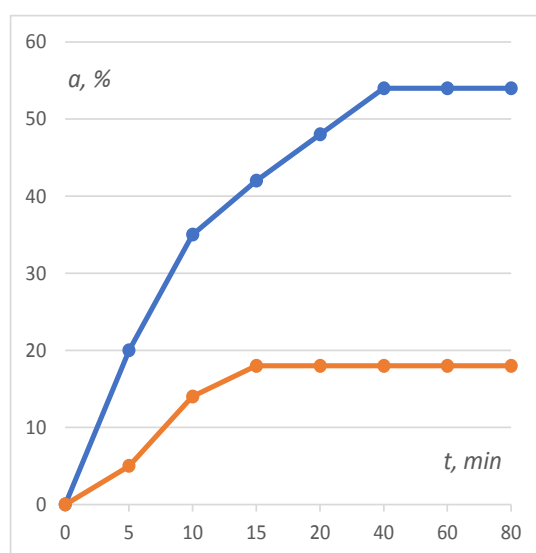


Fig. 2. Adsorption efficiency of Pb(II) ions by enterosorbents: ● – floral by-product fiber; ● – activated carbon.

The maximum adsorption capacity of Pb(II) ions was determined to be 51.8 mg/g for activated carbon and 140 mg/g for floral by-product fiber. These results indicate that floral by-product fiber exhibits superior sorption performance and may be considered a promising candidate for application as a natural detoxifying agent for Pb(II) ions.

Conclusion

The article considers a global problem in the world, which is created using the linear economy model. Processing of agricultural raw materials in a circular economy contributes to the transformation of waste into safe and attractive food products and sustainable development. According to the studies, highly purified dietary fibers with a high content of fibrous polysaccharides (89.3 ± 0.1) and a low content of low-molecular compounds (1.2 ± 0.2), with a high water-binding capacity (WRC) and fat (FAC) were obtained from the waste of industrial processing of mandarin flowers (*Citrus Unshiu*), which can be used as a prebiotic additive in bread, cookies, confectionery, dairy and meat products, improving the rheological, organoleptic and functional properties of products, promoting health and disease prevention. Cheap and high-value biomass of flower waste as a biosorbent of lead ions can be recommended for the development of a dosage form, as a detoxifier, as well as for wastewater purification from Pb (II) ions. The amount of waste discharged into the environment will be reduced and the negative environmental impact on it will be reduced.

Acknowledgments. This research was financed by Shota Rustaveli National Science Foundation of Georgia, Project FR-23-1945 „Multifunctional bio supplements for functional products from waste remaining after processing subtropical raw material following the model of circular economy“.

References

1. Kaza S., Yao L.C., Bhada-Tata P., Van Woerden F., What a Waste //2.0: A Global Snapshot of Solid Waste Management to 2050; World Bank Publications: Washington, DC, USA, 2018. <https://doi.org/10.1596/978-1-4648-1329-0>
2. Duggirala K., Mummaleti G., Kong F., Roy A. and Mohan A. Edible flowers: a sustainable source of natural food ingredient. // J. Food Bioact. 2024;000:000–000 **DOI:** <https://doi.org/10.26599/JFB.2024.95027383>
3. Jadhav A.R., Flower Waste Degradation Using Microbial Consortium. J. Agric. Vet. Sci. 2013, 3, 1–4 www.iosrjournals.org
4. Bhatti H., Khadim R., Hanif M., Biosorption of Pb (II) and Co (II) on red rose waste biomass. // Iranian J. Chem. Chem Eng. 30, 2011, pp. 81–88 . www.iosrjournals.org
5. Venkata K., Srivani M., Health benefits of Hibiscus rosa sinensis and its role in removing heavy metals- Review. //International Journal of Botany. India. 2021. Volume 6, Issue 3, 2021, pp. .592-595 www.botanyjournals.com
6. Haq Nawaz B., Khadim R., Hanif M., Biosorption of Pb (II) and Co(II) on Red Rose Waste Biomass. // Iran. J. Chem. Chem. Eng. Vol. 30, No. 4, 2011. 10.30492/ijcce.2011.6093
7. Núñez-Gómez V., San Mateo M, González-Barrio R and Periago M.J., Chemical Composition, Functional and Antioxidant Properties of Dietary Fiber Extracted from Lemon Peel after Enzymatic Treatment// Molecules, 29, 2024, p. 269. <https://doi.org/10.3390/>
8. Ryabinina E.I., Zotova E.E., Ponomareva N.I., Timashova A.A., Andreeva N.A., Sorption activity of sugar beet pulp towards lead ions. // Young scientist. 19(99), 2015, pp. 71-74. <https://moluch.ru/archive/99/22218/>
9. Jureviciute I., Keršiene M., Bašinskiene L., Leskauskaite D. An Jasutiene d. Characterization of Berry Pomace Powders as Dietary Fiber-Rich Food Ingredients with Functional Properties. // Foods 11, 2022, p. 716. <https://doi.org/10.3390/foods11050716>
10. Pathak P.D., Mandavgane S.A., Kulkarni B.D., Fruit peel waste as a novel low-cost bio adsorbent. // Rev. Chem. Eng. 31(4), 2015, pp. 361–381. <https://doi.org/10.1515/revce-2014-0041>