VALORIZATION OF PERSIMMON (*DIOSPYROS KAKI L.*) BY-PRODUCTS UNDER CIRCULAR ECONOMY CONDITIONS

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Abstract. *Persimmon (Diospyros kaki L.) is a widely cultivated subtropical fruit rich in nutrients and bioactive compounds with demonstrated antimicrobial, anticancer, antidiabetic, antithrombotic, and anti-inflammatory activities. However, its production, processing, and commercialization generate substantial amounts of by-products that are rarely recovered or properly managed, resulting in environmentally harmful disposal practices. Owing to their high content of bioactive constituents, these by-products represent an underutilized source of high-value compounds for the food and nutraceutical industries. This study assessed the potential of industrial persimmon by-products as raw materials for the development of value-added products and examined low-waste and zero-waste processing technologies suitable for their recovery. In Georgia, persimmon by-products remain largely unexploited and are typically discarded, contributing to the contamination of water, soil, and air and posing significant ecological risks.Through experimental research, innovative technological processes were developed to ensure the efficient utilization of persimmon raw materials and by-products. These processes enable the conversion of processing residues into biologically active, nutrient-rich additives with enhanced nutritional and functional value. The outcomes of this study support the valorization of persimmon by-products, contributing to the sustainability of the agri-food sector and fostering the advancement of circular economy practices.*

Keywords: *persimmon, phytochemicals, food additives, valorization, environmental pollution.*

Ensuring the sustainability and integrity of the human environment necessitates the improvement of food quality, the provision of safe drinking water, and the prevention of atmospheric, aquatic, and soil pollution. These challenges are particularly relevant to enterprises within the food industry, which constitute one of the strategic sectors of the national economy.

Among the environmental impacts of food industry enterprises, the most significant effect is exerted on water resources. In addition, harmful influences extend to soil and air. Wastewater containing plant-derived residues is poorly filtered, undergoes decomposition, releases malodorous compounds, and negatively affects human health. When discharged into water bodies, it deteriorates water quality, and at certain concentrations, it can cause the death of fish and plankton populations.

To address this problem, it is essential to implement the ecologization of production, that is, the development of zero-waste technological processes aligned with the principles of the circular economy.

The circular economy represents a modern economic model whose core objective is the efficient use of resources through reduced consumption, extended product life cycles, elimination of primary resource depletion, and the recycling and re-utilization of products and their components.

The circular economy has the potential to become the main paradigm of sustainable development, as the linear economic model exerts harmful effects on the environment and leads to the depletion of natural resources [1].

The introduction of low-waste and zero-waste technologies allows, on the one hand, for the maximum and comprehensive extraction of valuable components from raw materials and their conversion into useful products, and on the other hand, for the elimination or reduction of environmental damage caused by industrial waste.

At present, most technological processes used in production are highly waste-intensive. A significant portion of these wastes is generated by food processing and agro-industrial enterprises. The recycling of secondary raw materials enables the production of new products without the need for additional primary resources.

Fruit by-products, as the main category of secondary raw materials, typically contain 5–15% dry matter, which makes them highly perishable. They rapidly ferment and acidify, leading to the loss of valuable bioactive components and contributing to environmental pollution. Their storage life does not exceed 2–3 days, which necessitates the intensification of raw material utilization, enhancement of processing depth, and comprehensive valorization through the application of advanced, environmentally safe technologies that ensure the maximum recovery of high-value compounds.

Scientific research has established that in the food industry, comprehensive utilization of raw materials allows for the effective recovery and reuse of nearly all waste streams and co-products. Reintroducing these by-products into production as secondary raw materials enables the creation of new, health-beneficial products through sustainable technologies, thereby generating added value within the food industry [3].

According to FAO data, approximately 50% of total food loss and waste originates from fruits and vegetables, with the majority generated during fresh fruit consumption and industrial processing [4].

In recent years, the management and valorization of solid residues remaining after food production have become a major global environmental challenge. While the industrial processing of fruit crops helps reduce post-harvest losses, it simultaneously produces large amounts of processing by-products, primarily consisting of peels, pulp membranes, juice residues, and seeds.

In our study, we conducted a chemical analysis of by-products derived from the processing of two main persimmon (*Diospyros kaki* L.) cultivars, *Hachiya* and *Hyakume*.

Hachiya: dry matter (by drying) – 18.45%, pectin – 4.5%, dietary fiber – 3.9%, cellulose – 0.8%, total carotenoids – 20.2 mg%, phenolic compounds – 2.0%, protein – 0.48%.

Hyakume: dry matter (by drying) – 20.25%, pectin – 3.9%, dietary fiber – 2.9%, total carotenoids – 18.2 mg%, phenolic compounds – 1.0%.

Unfortunately, only about 0.5% of fruit by-products are currently converted into useful value-added products [5].

The subtropical persimmon is an ancient cultivated species encompassing a large diversity of varieties. Persimmon (*Diospyros kaki* L.) is produced in many countries worldwide, including China, Japan, the United States, Italy, Israel, Brazil, and others. According to current international statistical databases, global persimmon production has reached approximately 5 million tons [6].

In Georgia, the potential exists to produce up to 45,000 tons of fresh fruit annually.

The fruit of the subtropical persimmon possesses high nutritional value, containing 14–24% extractive substances, including 17–20% total sugars, as well as polyphenols, pectic substances, proteins, minerals, vitamin C, α- and β-carotene, and lycopene – compounds that determine its dietary and therapeutic properties [7].

The concentration of nutritional and functional bioactive compounds is higher in the peel than in the pulp; however, the fruit peel is typically disregarded and not subjected to further processing. One of the reasons for this is the broad varietal diversity and pronounced seasonality of persimmon, which complicates raw material processing and the rational utilization of the harvest.

Additionally, a significant proportion of the harvested fruit is non-standard in size and consequently discarded. As a result, 35–40% of the total yield remains unutilized. Another critical issue is that current processing technologies generate 35–45% of by-products and waste, for which no utilization methods currently exist, posing a serious risk of environmental pollution.

The comprehensive and rational utilization of the harvest requires the development of scientifically substantiated technologies for industrial processing. To ensure the full exploitation of the beneficial compounds in persimmon fruits, it is necessary to design integrated processing technologies that consider the chemical and technological characteristics specific to each variety.

Since persimmon contains a significant number of extractive substances and carbohydrates, a considerable portion of these components – along with plant residues – enters the wastewater during processing, resulting in the loss of valuable compounds.

The novelty of this research lies in its focus on the development of new value-added products derived from persimmon and on the valorization of persimmon by-products.

To achieve the complete utilization of persimmon's bioactive components, considering its chemical-technological characteristics, we are developing scientifically validated innovative technologies for both the fruit and its by-products. These include the production of functional extracts and concentrates for preventive use, as well as nutritional powders and pastes enriched with high levels of carbohydrates (glucose, fructose), phenolic compounds, pectic substances, and carotenoids.

In addition to the main product, further processing of by-products allows the production of nutrient-dense food products and additives of high nutritional value.

The proposed technologies also enable the reduction of energy consumption through the optimization of technological operations, improvement of product quality and yield, and the conversion of processing by-products into useful materials, thereby minimizing adverse environmental impacts.

The proposed methods and technologies include the following:

– Preliminary thermal and CO_2 (carbon dioxide) treatment of raw materials, which will regulate the level of astringency in both the raw material and the extracts, enabling the production of balanced phenolic profiles and high organoleptic quality products such as extracts, powders, pastes, and confitures.
– Intensification of the concentration (thickening) process of persimmon extracts will be achieved through a combination of membrane filtration (fractionation of extracts based on molecular weight) and vacuum evaporation (water removal under low-temperature conditions). This approach enhances energy efficiency while preserving thermolabile bioactive compounds.
– During the extraction of biologically active compounds rich in phenolic constituents from the fruit, the ultrasound-assisted extraction method will be employed. This is one of the recognized "green extraction" techniques, suitable for the efficient recovery of bioactive compounds, particularly polyphenols, while minimizing solvent use and thermal degradation.

Based on the conducted studies, persimmon paste enriched with carotenoids and dietary fiber will be produced from whole fruits, including overripe, transport-unsuitable, and astringent varieties.

The application of high-efficiency methods and advanced technical solutions will enhance the technological processes for by-product utilization, establishing an industrial circular system that ensures the targeted valorization of industrial by-products and promotes the development of the region's agri-food sector.

Conclusion

The implementation of low-waste and zero-waste technologies in industrial production will facilitate the manufacture of valuable food products and additives derived from persimmon raw materials and their processing by-products, while simultaneously contributing to environmental improvement and sustainability.

For the persimmon industry, the current challenge lies in developing strategies that enhance the value of discarded fruits and increase the utilization efficiency of processing by-products, thereby creating opportunities for a more sustainable production system that actively contributes to the circular economy.

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