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VALORIZATION OF VEGETAL BY-PRODUCTS IN NEW MATRICES FOR THE IMPROVED FOOD SUSTAINABILITY SYSTEMS

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Abstract

This reviw paper is based on a bibliographic study of over 70 articles published in the period 2001-2023 and presents the need for the valorization of agro-industrial by-products, a review of the main research directions for the valorization of plant by-products for the purpose of better environmental sustainability, as well as the most used methods of valorization of this nutritionally valuable waste. The recycling of waste in the cascade represents the engine of the circular bioeconomy that supports finding solutions to problems related to the sustainability of the environment, economic, ethical, social. The methods and procedures for valorizing plant waste are diversified depending on the type of waste and aim to develop new sustainable food system on the consumer benefits. Vegetal by-products still contain valuable bioactive compounds such as fibers, vitamins, minerals, which can contribute to obtaining new products with added value and can become good sources of raw materials for the food industry.

Key words*: vegetal by-products, food waste, food sustainability, processing methods, trends and perspectives.*

INTRODUCTION

Agriculture and the food industry are the most representative branches of the agro-food industry in Europe (Palvic et al., 2023), and an important source of organic waste in the form of food waste (Raksasat et al., 2020). Inadequate management of the waste resulting from the primary processing of raw materials of plant origin, as well as the waste resulting from the processing of products results in the quantitative formation of waste, which leads to environmental pollution (Awasthi et al., 2021).
The waste resulting from the food industry produces pollution (Ilyas et al., 2021), being responsible for approximately 26% of global greenhouse gas emissions (Zioga et al., 2022). The global problem of waste could be solved by implementing zero-waste production technologies, using different methods aimed at the valorization of plant-based waste by emphasizing the importance of raw materials and achieving sustainable development objectives (Sabater et al., 2021; Liu et al., 2021).
Earth represents an important source of natural resources that, in connection with the activities of operators in different sectors, generate a vast range of waste (Srivastava et al., 2023).
The use of by-products in new matrices promote the circular and sustainable economy by implementing innovative methods and strategic approaches for the recovery of valuable products and the minimization of waste through several methods (Stanciu et al., 2023).
The review aims to identify the main directions of valorization of various by-products of plant origin, resulting from agriculture and processing in the food industry, for the purpose of environmental sustainability.

THE CONTENT OF PLANT BY-PRODUCTS IN BIOACTIVE COMPOUNDS

Food waste is composed of complex ingredients (vitamins, mineral salts, fibers, bioactive substances) that have been removed from the original material (Galanakis, 2012). Fruits, vegetables and other food products are rich in dietary carbohydrates, bioactive phytochemicals that provide health benefits in addition to basic nutrition (Liu, 2013; Dranca & Oroian, 2018).
They represent important sources of bioactive compounds that contribute to the prevention of

degenerative diseases (diabetes, Alzheimer, Parkinson) (Renard, 2018).

The presence of carotenoids in waste of vegetal origin offers wide opportunities to sustainable productions, due to their bioactive properties: antioxidant role, antitumor role, etc. (Cassani et al., 2022). Following the industrial processing of eggplants, secondary products are obtained (eggplant skins, etc.) which are thrown away without further recovery.

Eggplant skin is an important source of anthocyanins, with antioxidant, antimicrobial and antitumor properties (Karimi et al., 2021).

The industrial processing of sugar beet to obtain sugar releases large amounts of sugar beet pulp, waste that can be considered a valuable by-product as a source of hemicellulose, cellulose, pectin (Usmani et al., 2023).

Melon (*Cucumis melo* L.) extracts, especially the peel, contain phytochemical compounds with antimicrobial, antiviral, antioxidant, anti-inflammatory, antidiabetic effects, etc. (Gómez-Garcia et al., 2020).

Avocado processing leads to the generation of impressive amounts of pits that represent 13%-18% of the fruit's mass. Avocado seeds contain starch (66.3%), protein (4.9%), arabiose (4.12%), pentosans (3.3%) (Tesfaye et al., 2022). Sari et al. (2022) studied the processing of almonds, walnuts, cashews is done with the production of large amounts of waste rich in protein (45-55%), carbohydrates (30-35%), fiber, etc. (Sari et al., 2022).

By-products resulting from wine and olive oil industry are rich in bioactive compounds which may be used in obtaining novel functional food products (Balli et al., 2021). Olive waste contains phenolic compounds, their concentration being influenced by the growing area and variety. The phenolic fraction consists of different groups: phenolic acids, phenolic alcohols, flavonoids and secoiridoids (Veneziani et al., 2017).

Studies conducted in the last 15-20 years have shown that grape pomace could be a potential source of bioactive compounds (Chowdhary et al., 2021).

White grape pomace (unfermented waste) represents 10% to 30% of the crushed grape mass. The main macromolecules detected in grape pomace are polyphenols, proteins, etc. (Canalejo et al., 2021). In Table 1are presented some information on bioactive compounds found in grapes are given.

Table 1. Reporting of polyphenols from grapes/juice in the literature (Source: Majeedet et al., 2023)

Compound name	Fruit grapes	References
Quertin	Grape	Rockenbach et al., 2011; Bruno Romani et al., 2021; Gomez-Mejia et al., 2022.
Catecchin	Grape	Ferri et al., 2017; Rockenbach et al., 2011; Meini et al., 2019; Deshales et al., 2022; Ferri et al., 2017.
Catechin gallate	Grape (*Vitis vinifiera* L.)/Pomace	Ferri et al., 2017; Perez-Navarro et al., 2019.
Epicatechin gallate	Grape (*Vitis vinifiera* L.)	Ferri et al., 2017; Ivanova et al., 2011; Arts et al., 2000; Perez-Navarro et al., 2019.
Gallic acid	Grape (*Vitis vinifiera* L.)	Pedras et al., 2020; Meini et al., 2019; Alvareda et al., 2019; Bruno R. et al., 2021; Ferrari et al. 2017.
Malvidin-3-glucoside	Grape (*Vitis vinifiera* L.)	Perez-Navarro et al., 2019; Assayed & Adb El-Aty, 2009; Kammerer et al., 2004.
Malvidin-3-O-glucoside	Grape	Meini et al., 2019
Chlorogenic acid	Grape	Karunanidhi et al., 2013; Ferri et al., 2027.

TRENDS IN VALORIZATION OF VEGETABLE BY-PRODUCTS

About 1.3 billion tons of waste and by-products are produced annually (Gottardi et al., 2021). The valorization of products and by-products by ensuring food quality and safety is an important aspect in the evaluation of valorization strategies (Socas-Rodrigues et al., 2021).

The valorization of waste resulting from the food industry aims to stimulate innovative technologies in order to improve the use of resources in the cascade (Javourez et al., 2021). Due to the presence of carotenoids and their bioactive properties, waste of vegetal origin provides wide opportunities for sustainable productions, being able to be used to color fruit juices, pasta, meat, etc. (Cassani et al., 2022).

Vegetable and fruit co-products contain high concentrations of bioactive compounds, which makes the extraction of bioactive substances a capitalization strategy (Renard Chaterine, 2018). Anthocyanins from eggplant peel are an important alternative of synthetic additives that can be used to extend the shelf life of food products (Karimi et al., 2021).

The research paper "Geophagy: The earth-eaters of lower Southwestern Australia" recommends further studies for the red root vegetable (*Haemodorum spicatum*), which is part of the Haemodoraceae family, and which grows mainly in Western Australia. The bulbs, stem, leaves and seeds of the vegetable produce natural dyes: red, pink, purple and green. Red pigments (Hemocorina) are responsible for the spicy and hot flavor of the bulbs (Macintyre & Dobson, 2017).

The red pigment of *Haemodorum spicatum* can be considered as a sustainable alternative substitute to replace artificial dyes with natural dyes for increasing the demand for environmentally friendly, non-toxic and healthy eco-dye foods. (Liang et al., 2023). Sugar beet pulp has been mainly used as feed in animal nutrition, recent developments indicate the utilization of sugar beet pulp to obtain biofuels, biohydrogen, platform chemicals such as: alcohols, microbial enzymes, lactic acid, citric acid, proteins unicellular and biodegradable plastic materials (Usmani et al., 2023).

By-products resulting from different processing stages such as molasses, starch, fruits, fresh vegetables, etc. can be used in order to develop new food matrices thus obtaining edible bioproducts (lactic acid, cellular proteins). Contaminated, altered, expired waste can be used in some anaerobic digestion (Awasthi et al., 2022; Awasthi et al., 2022b).

In the food sector, pectin is used as a gelling or thickening agent because of the health benefits and its role as a health-promoting functional agent or fat substitute. The isolation of pectin from plant material or agro-food by-products also has non-food applications that include the pharmaceutical, medical industry (Dranca & Oroian, 2018).

The processing of melons (*Cucumis melo* L.) results in seeds and peels that contain important bioactive compounds, which are of interest in the food, pharmaceutical and cosmetic industries. These findings strengthen the support of researchers in analyzing the functional and nutritional potential of these wastes and the formulation of new functional foods (Gómez-Garcia et al., 2020).

Throwing avocado pits in the landfill or incinerating them has the effect of polluting the environment, which is why studies and researches aimed at overcoming technical-economic barriers are encouraged in order to develop and sell new products, as well as to establish model biorefineries (Tesfaye et al., 2022).

The techno-economic feasibility of biorefineries is the basis of the exploitation of avocado kernels, aiming at a circular bioeconomy (Rodriguez-Martinez et al., 2022). The processing of walnuts, almonds, cashews, hazelnuts, produces large amounts of waste that could be used to produce bioactive peptides, biofuels, etc. (Sari et al., 2022).

The by-products resulting from the processing of peanuts are a valuable source of nutrients, natural antioxidants, antimicrobials.

Antioxidants are used in food to prevent oxidative reactions and undesirable effects on food quality during processing and storage (Lorenzo et al., 2018).

Grape pomace is the main by-product of the wine industry. New applications related to waste from the wine industry led to different sectors: agriculture, animal husbandry, cosmetics, pharmaceuticals, as well as the bioenergy recovery sector regarding the potential for health and a sustainable environment (Chowdhary et al., 2021), and an attractive option of transforming biodegradable waste into stable products, excellent sources of plant growth or soil fertilizer (Xu et al., 2022).

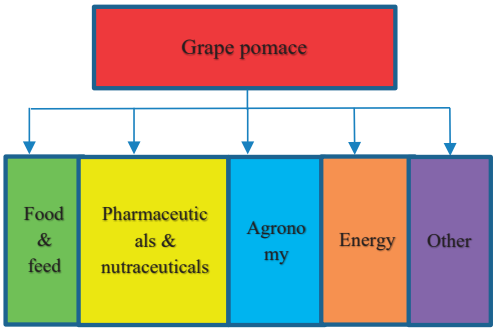

Figure 1. Application of grape pomace (Madaddian et al., 2022)

Grape seeds contain polyphenols, such as flavanols, flavonols, anthocyanins and stilbenes, being mainly located in the skin, while others, such as catechins and procyanidins, are only present in the seeds in concentrations that vary according to terrain, variety, etc. (Moro et al., 2021).

Studies show that the use of 7% of grape pomace or olive residue in the profile of some pasta leads to their fortification, showing good resistance to cooking, an optimal texture after cooking, increasing the nutritional profile of the pasta through the amount of phenolic compounds and fibers (Balli et al., 2021).

Wheat, barley are the dominant crops in countries with a medium and high level of development. By grinding wheat, rolled barley, bran or straw are obtained as secondary products, rich in protein and dietary fiber (Galanakis, 2012).

Over the years, studies have been carried out to enrich the nutritional composition of bread, by adding different flours or ingredients with large amounts of bioactive compounds with health benefits (Stanciu et al., 2023).

Figure 2. Sorana organic seabuckthorn - fresh, pomace and in form of powder (Source: Popa et al., 2022)

The use of sea buckthorn powder as an ingredient has led to promising experimental results regarding bread making (Popa et al., 2022).

Agro-industrial by-products, from bakery products, etc., are used as a source of cheap fermentation contributing to improving the economy and increasing productivity (Arya et al., 2022).

The earliest forms of biotechnology date back several thousand years, before the discovery of the existence of microbes. Microbes are widely used as living organisms, indispensable due to their involvement in the realization of bio productions such as food additives, cosmetic products, valuable chemical products, biopharmaceutical products, etc. (Pfeifer et al., 2021).

MATERIALS, METHODS AND TECHNIQUES

For this research I analyzed Scopus, the Elsevier database and SprinerLink Journals and entered key words such as "sustainability" or "vegetable by products". I analyzed the data from various reviews to have an overall picture of the methods used for the valorization of vegetable and animal by-products for the purpose of environmental sustainability.

It is estimated that the world population will reach approximately 10 billion people in 2050, which means an increase in the amount of food and/or biomass to be processed, but also a high amount of waste (Vicente et al., 2023).

Food waste is usually organic residues generated by the processing of raw materials into food, while a by-product is obtained as a result of the manufacturing process of the main product, often with a market value (Tiwari & Khawas, 2021; Rodriques-Ramos et al., 2022).

The full recovery of eggplant waste, through the extraction of anthocyanins and pectin, is carried out by different methods and techniques developed and improved, with ultrasound and microwaves (Karimi et al., 2021). The pressed drupes resulting as waste after obtaining the oils could be exploited by hydrolysis in order to obtain therapeutic benefits that would have a higher value than the current one as animal feed (Sari et al., 2022). A review indicates the need to capitalize on indigenous African leafy vegetables, altered by bacteria pseudomonadaceae, enterobacteriaceae, etc., fermentation being deepened in this case as a form of cheap capitalization. The controlled fermentation carried out with the help of lactic acid bacteria leads to the improvement of the nutritional content and the extension of the shelf life of the vegetables (Misci et al., 2022).

Anaerobic digestion technology is becoming more and more important due to its contribution to the sustainability of the environment and the circular bioeconomy (Tavera-Ruiz et al., 2023), anaerobic digestion being a way of valorizing agricultural waste (Nagarajan A. et al, 2023).

Pretreatment of melon skins, peanut skins, etc., is a necessary step in obtaining value-added products (Ajayi & Lateff, 2023).

Biorefineries are new state-of-the-art concept where multiple by-products are manufactured from renewable feedstock (Kasani et al., 2022). The waste streams generated by the food industry, especially the sugar industry, make it possible to replace plastic materials with ecological bioplastics in the form of polyhydroxyalkanoates, which represent an attractive alternative due to their biodegradability and biocompostability properties (Saratale et al., 2021).

Organic waste from the food and agricultural industry represents a major source of recoverable biomass for energy (Akbi et al., 2017). The main raw material for renewable energy production is biomass waste, which can contribute to reducing traditional energy sources and changing climate conditions (Usmani et al., 2023).

Manea (2017) studied the use of carrot juice, beetroot or pomace powder in some meat products to improve color (Manea, 2017). Composition of grape pomace varies considerably between different varieties (Ribeiro et al., 2015; Gongalves et al., 2017). The pomace powder was obtained after pressing the grapes and separating the juice. The remaining residue was dried at 20-25˚C, then ground with an electric stirrer. After obtaining, the powder was stored in hermetically sealed glass containers protected from sunlight and heat protected from sunlight and heat (Manea, 2017). In the Table 2 various processing methods of grape pomace are presented to obtain bioactive compounds.

Table 2. Processing grape pomace by different methods and obtaining by-products with added value (Source: Ilyas et al., 2021)

Initial processing	Traditional & conventional methods	By-products with added value
Grape Pomace	**Methods Traditional:**	
	Soxhlet extraction Maceration Reflux extraction	Phenolic compounds
	Methods Conventional:	
	Solid-Liquid extraction	Flavonoids
	Supercritical fluid extraction	Antioxidants
	Accelerated solvent extraction	Anthocyanin
	Dynamic superheated liquid extraction	Hemicellulose
	Ultraound assited extraction	Polyphenols
	Pulsed electric field extraction	Acetaldehydes
	Enzyme assisted extraction	

TRENDS AND PERSPECTIVES

Waste management represents a potential solution towards the circular economy in the food system (Jurgilevich A. et al., 2016; Lavelli, 2021). The circular economy is the main element of the Green Deal, food traceability being a key element of environmental sustainability, the goal being the production of healthy and environmentally friendly foods (Tesfaye et al., 2022).

The current trends regarding the recovery of waste from the food sector, but also the finding of innovative solutions regarding the partial or total replacement of animal proteins with vegetable proteins are evaluated by scientists from the food sector, which contribute to the need to find answers to some ethical demands, pro-health and last but not least environmental sustainability (Kotecka-Majchrzak et al., 2020). The current trend of plant-based dairy and meat alternatives has the potential to contribute to environmental sustainability by reducing gas emissions and food systems (Giacalone et al., 2022), and technological innovation approaches essentially have ways to optimize food quality according to consumer requirements and preferences, environmental sustainability (Abecassis et al., 2018).

CONFLICT OF INTEREST

Both authors declare no conflict of intertest.

CONCLUSIONS

The concept of valorization of agri-food waste is based on the realization of a circular bioeconomy, starting from the valorization of food by-products in new food matrices, continuing with research, the development of

innovative technologies, the creation of new food products with added value.

The vegetable waste obtained from the processing of raw materials of vegetable origin contains important bioactive compounds, which are of interest in the food, pharmaceutical and cosmetic industries. These findings strengthen support for researchers in analyzing the functional and nutritional potential of these wastes and in formulating new functional foods such as meat analogs.

Research and innovative technologies support environmental sustainability by finding alternatives, such as meat analogues, soy-based foods enjoying a promising future on the international market.

In the context of the cascading valorization of raw materials, but also of environmental sustainability, ecological agriculture represents an alternative that offers farmers the opportunity to satisfy the demand for ecological products, etc. The studies and research aim at overcoming the technical-economic barriers in order to develop and sell new products, as well as the establishment of model biorefineries.

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