

Valorization of Kiwi by-Products for the Recovery of Bioactive Compounds: Circular Economy Model [†]

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Abstract: Currently, agricultural production generates large amounts of organic waste, both from the maintenance of farms and crops, and from the industrialization of the product. Generally, these wastes are accumulated in landfills or burned, sometimes causing environmental problems. However, many scientific studies suggest that these residues are rich in bioactive compounds, so these matrices could be revalued for their use in food, cosmetic, or pharmaceutical industries. In this way, the circular and sustainable economy is favored, while obtaining products with high added value. In this case, this approach is applied to the residues generated from kiwi production, since numerous studies have shown the high content of kiwi in bioactive compounds of interest, such as phenolic compounds, vitamins, and carotenoids. These compounds have been reported for their antioxidant, anti-inflammatory, and antimicrobial activities, among other beneficial properties for health such as its use as prebiotic. Therefore, this article reviews the potential of residues derived from industrial processing and agricultural maintenance of kiwi as promising matrices for the development of new nutraceutical, cosmetic, or pharmacological products, obtaining, at the same time, economic returns and a reduction of the environmental impact of this industry, attaching it to the perspective of the circular economy.

Keywords: kiwi residues; circular economy; food applications; phenolic compounds; vitamins

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1. Introduction

The kiwi is the best known fruit of the *Actinidia* genus (*Actinidiaceae* family), which has become a very popular product throughout the world due to its nutritional and organoleptic properties and its health benefits. It is native to China, and it is widely distributed, from regions with a tropical climate to areas with temperate-cold climates [1–3]. It comprises more than 70 species, of which three have great commercial interest: yellow (*Actinidia chinensis*), green (*A. deliciosa*), and resistant kiwi (*A. arguta*, also known as kiwiberry) [4,5]. This fruit is currently cultivated in several countries such as the United States, New Zealand, China, Japan, and Chile, and in European countries [6,7]. The latest data show that world kiwi production is around 4 million tons per year, with Asia in the lead and China standing as the region responsible for the half of world kiwi production [8,9].

In general, this fruit is consumed mostly raw; however, it is also used for the production of juices, wines, jams, and ice creams, among other products [2]. This industrialization produces wastes with biological capacities that could be of interest to the food, cosmetic, and pharmaceutical industries because they contain bioactive molecules with recognized health-promoting properties [1,3,10].

In a parallel context, in recent years, the interest of consumers for more natural and healthy products has led to the research and development of natural compounds with bioactive properties that can replace synthetic additives [11]. The use of fruit by-products is one of the global trends to address sustainability in food production [12]. In addition, the high awareness of society to adopt preventive health measures, such as a healthy and balanced diet and the use of food supplements with beneficial effects, has led to an increase in the demand for these new natural additives with bioactive capabilities such as having antioxidant, anti-inflammatory, or anti-cancer capabilities, as well as showing fewer side effects than synthetic ingredients [13].

2. Associated Waste to Kiwi Production

2.1. Waste Derived from the Industrial Production of Kiwi Fruit

The agricultural and food industries are responsible for generating millions of tons of by-products around the world [14]. As a consequence, the concepts of agriculture and circular economy usually appear together, because the residues derived from agricultural production can be used as a matrix to obtain compounds of interest [11]. Within the kiwi industry, the main residues are the skin, the seeds, and the pulp, in addition to the fruit that is not acceptable for commercialization or for processing due to strict quality and presentation standards. Regarding the skin, it has greater biological activity than the pulp [6,15]. Specifically, some authors claim that the skin is a good source of phenolic compounds (PCs) [16,17]. In the case of seeds, they are rich in unsaturated fatty acids, mainly linoleic acid [18,1].

As regards the pulp bagasse, it is a rich source of various nutrients including vitamins, minerals, carbohydrates, some fatty acids, and carotenoids [18]. Its high content in vitamin C stands out in addition to its high levels of vitamin E, fiber, potassium, and folic acid [8,10], and the presence of pigments: carotenoids, chlorophylls, and anthocyanins [7,19]. The recovery of these fractions would be interesting in regards to their incorporation back into the commercial chain through new products [2,3], as exhibited in Figure 1.

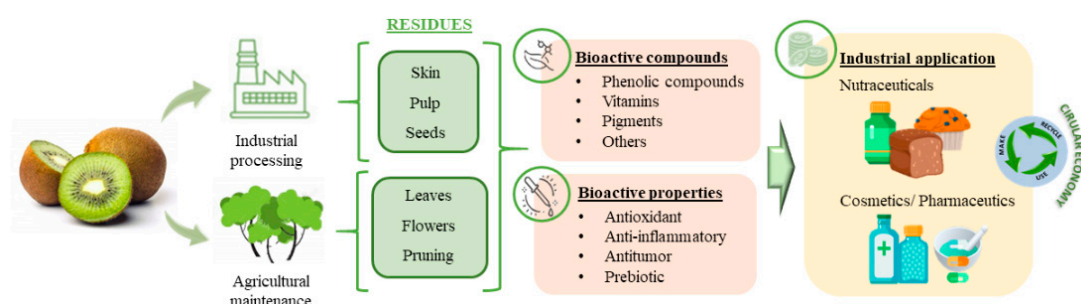


Figure 1. Global diagram of the circular economy of waste materials.

2.2. Waste Derived from the Maintenance of Industrial Operations of the Kiwi Plant

The exploitation of kiwi generates waste that is not usable and ends up incinerated or used as a substrate for the production of compost [3]. These residues include the leaves, stems, and, to a lesser extent, the flowers [14,19]. In general, they are rich in PCs, including neochlorogenic, chlorogenic, cryptochlorogenic, and caffeoylquinic acids, glycosylated quercetin and kaempferol derivatives, catechin, and type B procyanidin dimers [20].

The pruning process required in summer and winter gives rise to a significant mass of stems and leaves used as an extraction matrix. However, the woody stem of this plant complicates extraction processes due to the presence of lignin, which, on the other hand, is useful for the production of bioethanol [19,21]. The composition is similar to the leaves regarding PCs, with differences in pigment levels [22]. In respect of kiwi flowers, even though they are not categorized as a priori residue, in order to maintain optimum production, it is necessary to carry out maintenance tasks before and after flowering, called

“clearing” [23]. Its richness and high concentration in volatile and PCs, coupled with the ease of their extraction, makes flowers an important source of PCs yet to be explored [24].

3. Biological Activity

Table 1 shows the different PCs described in kiwi fruit with free radical neutralization capabilities and, therefore, excellent antioxidant and anti-inflammatory properties [1,25]. Even so, the antioxidant capacity of kiwi has been proven in different studies, and it has been related to hydrophilic molecules, mainly vitamin C, followed by polyphenols [26]. For instance, the decoctions of kiwi pulp present antioxidant activity and capacity to capture reactive oxygen and nitrogen species [5].

Table 1. Phenolic compounds of Actinidia fruits.

Composition	Chemical Structure	Res-	Ref.	Composition	Chemical Structure	Res-	Ref.
Flavanols (derived from quercetin and kaempferol)	Kaempferol-3-O-galactoside	P	[13]	Caffeoliquinic acid		P	[25]
		L	[3,27]	Di-O-caffeoylquinic acid		P	[25]
	Quercetin-3-O-rutinoside	P	[13]	Epigallocatechin gallate		P	[25]
Other flavanols	Epicatechin	Sk	[16]	Procatechuic acid		Se	[28]
		L	[3,27]	P-coumaric acid		Se	[28]
	Catechin	Sk	[29]			L	[3,27]
		L	[3,27]	Ferulic acid		Se	[28]
	Quercetin	B	[3,1,30]		α -tocopherol	Sk	[16]
Flavan-3-ols	Polymeric procyanidins	Sk	[16]		β -tocopherol	Sk	[16]
	Procyanidin dimer type B			Tocopherols	γ -tocopherol	Sk	[16]
		L	[3,27]			Se	[28]
Phenolic acids	Caffeic acid	P	[13]	Organic acids	g-tocotrienol	Se	[18]
		Se	[28]		Malic acid	Sk	[16]
	Chlorogenic acid	P	[13]		Citric acid	Sk	[16]
		L	[3,27]		Ascorbic acid	Sk	[16]
	Quinic acid	P, Sk	[13,16]				
Anthocyanins	Cyanidin-3-O-sambubioside	P	[13]	Fatty acids	Linoleic acid	Se	[28]

Res.: residues, P: pulp, L: leaves, Sk: skin, f: Flowers, Se: seeds, B: branches.

The anti-inflammatory activity has also been tested in in vivo and in vitro models [18]. At a cellular level, polyphenols (mainly certain phenolic acids) that are found in the seed oil decreased the secretion of pro-inflammatory cytokines IL-1 β and TNF- α in RAW 264.7 cells induced by lipopolysaccharides (LPS) [28].

Kiwi extracts have been used to treat intestinal diseases such as constipation [31]. This function is attributed to the content of dietary fiber, mainly cellulose, pectin polysaccharides, and hemicelluloses, as well as the presence of glucuronoxylans and xyloglycans and the action of actinidin [10,32]. The presence of fiber could prevent the colonization of pathogenic bacteria and generate favorable changes in the intestinal microbiota, improving systemic health [10,33].

It is important to highlight the antitumor activity of the different kiwi compounds, highlighting the water-soluble and thermolabile PCs. In this way, kiwi can be considered as an antitumor agent, acting in two different ways. On the one hand, it can contribute to

the protection or reduction of DNA damage and mutagenesis processes, constituting a chemoprevention strategy [34] and, on the other hand, the prebiotic effect that has been above referred to could also contribute to the modulation of colon bacteria, contributing to the reduction of mutagens production [33].

Finally, kiwi extracts (skin, pulp, seeds, and stems) have shown bactericidal capacity against *Staphylococcus aureus*, *Streptococcus pyogenes*, *Enterococcus faecalis*, *Salmonella typhi*, *Proteus mirabilis*, *Pseudomonas aeruginosa*, *Escherichia coli*, and *K. pneumoniae*, among others [18].

4. Sustainable Valorization

Due to the phytochemical profile and biological properties of kiwi, it can be considered as a food with great potential for valorization, promoting new applications in the food, cosmetic, nutraceutical, and pharmaceutical industries [3,18,20,22]. To begin with, citric acid can be extracted from kiwi juice, being used in the food and pharmaceutical industry as an acidifying agent and flavor enhancer [35]. As regards natural antioxidants, PCs (obtained from the skin of kiwi) can be used in specific concentrations as an alternative to synthetic antioxidants [36]. Additionally, several articles have indicated that the injection of a kiwi-based solution (actinidin rich) confers tenderness benefits to the meat, which may be due to modifications in the myofibrillar components [37]. Another potential additive that can be extracted, in this case, from the kiwi skin, are pectins, which can be used for commercial purposes thanks to their thickening, texturizing, stabilizing, and gelling capacities [38]. Alternatively, PCs of kiwi can be used in nutraceutical formulations or to fortify foods or beverages, mainly for its effects as a prebiotic due to its beneficial effects on digestive health [6,35].

The potential for kiwi waste is much broader. For example, PCs have been investigated for their use as antioxidants in novel application forms, such as active packaging [36]. On the other hand, proanthocyanidins from kiwi skin have been used as insecticides, food preservatives, and cosmetic additives, given their ability to inhibit tyrosinase activity [39]. Finally, the use of kiwi pruning has also been suggested as an energy source with values similar to those of other forest resources [40].

5. Conclusions

This review aims to highlight the possibility of revaluing the residues from the industrial production and agricultural maintenance of kiwi fruit. The chemical components of kiwi show a variety with beneficial health effects, so kiwi could be considered a natural source of ingredients to develop functional products with applications such as additives or colorants, among other things. In this sense, residues from the cultivation and processing of kiwi could be revalued and transformed into new products, favoring the model of a circular economy that contributes to the reduction of the biological and environmental impact of the industrial and economic exploitation of this fruit.

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