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RESEARCH NOTE

Evaluation of the antioxidant capacity of vegetable waste from a wholesale market in Chile

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Abstract

X. Rodríguez Palleres, M. Castillo-Ruiz, S. Correa Alfaro, and F. Rojas González. 2023. Evaluation of the antioxidant capacity of vegetable waste from a wholesale market in Chile. Int. J. Agric. Nat. Resour. 130-137. Consumption of vegetables is associated with lower risks of cancer, diabetes, coronary diseases and obesity, but parts of vegetables such as the peels, stems and leaves are not valued, which increases waste and impacts the environment. The aim of the present study was to determine the antioxidant capacity of the leaves and stems of celery, broccoli and beet discarded from the patios of the Lo Valledor Wholesale Market, the main fruit and vegetable distribution center in Santiago, Chile. The leaves and stems were separated to analyze total polyphenol content and antioxidant capacity (ORAC). The total polyphenol contents in celery, broccoli and beet leaves were 155.5, 144.7 and 117.1 mg EAG 100 g^{-1} mta, respectively, while in the stems, they were between 22.7, 41.4 and 69.3 mg EAG 100 g^{-1} mta, respectively. Similarly, the leaves showed higher antioxidant capacity than the stems. The ORAC for celery, broccoli and beet stems was 2,325.2, 2,098.1 and 1,756.5 µmol TE 100 g^{-1} mta, respectively, while for stems, it was 317.8, 625.1 and 970.2 µmol TE 100 g^{-1} mta, respectively. The antioxidant capacity of the leaves and stems of celery, beets and broccoli suggest that they are healthy eating options and that their valorization should be considered.

Keywords: Beet, broccoli, celery, circular economy, leaves, polyphenols, stems

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Introduction

Agricultural production is responsible for 21% of greenhouse gas emissions and has created greater pressure on the environment, causing negative impacts on soil and water resources. According to the FAO, one-third of the food produced for human consumption is lost or wasted, which is equivalent to approximately 1.3 billion tons per year. These losses occur throughout the food supply chain from initial agricultural production to final domestic consumption (Kowalska, 2017). Data suggest that annually, between 55% of fruits and vegetables and 40% of roots and tubers are lost and wasted (ODEPA, 2017). One of the causes of this waste is superficial and aesthetic imperfections since the produce size, shape and weight do not meet the selection criteria for sale. In addition, parts of vegetables such as peels, stems and leaves are not valued since they are not main components of food and are discarded without considering their nutritional contribution.

In 2016, the highest amount of waste was produced in East Asia and the Pacific region, with 468 million tons of waste, and the main percentage of this waste was disposed of in landfills or incinerated (Nattassha et al., 2020). On the other hand, this high amount of waste produced in the agriculture sector presents excellent opportunities for the generation of new ingredients and products. However, the main challenge for the valorization of discarded fruits and vegetables, or parts of these products, is the maintenance of food safety; the process must include sanitization and a verifiable and auditable supply chain (Socas-Rodríguez et al., 2021)

Beet is consumed either raw in the form of salads or is further processed. Additionally, it is used as a natural colorant, is a good source of vitamins and dietary fiber and possesses high antioxidant capacity. However, in most cases, only the tuber is used and not the leaves, which could also be a source of vitamins and antioxidants. Broccoli is a source of glucosinolates, essential minerals, phenolic compounds and other antioxidants, such as vitamin C and vitamin K1 (Moreno et al., 2006). However, only 15% of the aerial biomass of broccoli is consumed; in some cases, people consume a part of the stems and leaves, but this is not common. Since broccoli leaves and stems are not usually consumed, nutritional information and data on the compounds found in them are limited (Liu et al., 2018). The leaves and stalks of celery are consumed mainly in salad or soups. Celery contains different health-promoting constituents, such as dietary fiber, vitamins, minerals, and the amino acid tryptophan (Consentino et al., 2020). However, many leaves and stems are eliminated due to superficial and aesthetic imperfections.

A high intake of vegetables has been widely recommended to the general population due to benefits such as a reduced risk of chronic diseases such as cancer, type 2 diabetes, coronary diseases, overweight and/or obesity, and they may prevent excess weight gain. Vegetables are rich in a variety of nutrients and components, including dietary fibers, vitamin C, vitamin A, potassium, selenium, antioxidants (carotenoids and tocopherols) and phytochemicals (flavonoids, glucosinolates and isothiocyanates), which possibly act synergistically through various biological mechanisms, which could involve antioxidation, anti-inflammatory, antiplatelet, blood glucose regulation, lipid metabolism modification, blood pressure lowering and myocardial damage attenuation (Tang et al., 2017). However, the human intake of fruits and vegetables is generally below the recommended levels.

Reactive oxygen species (ROS) can damage cellular components, such as proteins, cell membranes and nucleic acids. Although our body has enzymatic mechanisms to protect itself from ROS, including superoxide dismutase (SOD), catalase, and glutathione peroxidase, among others, exogenous antioxidants are obtained from foods such as fruits and vegetables, and these include vitamins C and E, carotenoids and phenolic compounds (Kuciel-Lewandowska et al., 2020). Phytochemical compounds, particularly polyphenols, including flavonoids and phenolic acids, play a crucial role in the capture of free radicals and the antioxidant functions of plants.

Although the importance of maintaining good health through antioxidant intake is well established, it is essential to recognize that vegetables, or parts of them, that are rich in antioxidants are often lost in the food distribution chain. The aim of the present study was to evaluate the antioxidant capacity of the discarded leaves and stems of celery, broccoli, and beets recovered from the patios of the Lo Valledor Wholesale Market.

Materials and methods

Sample collection

Stems and leaves of celery, broccoli and beet were collected from the Wholesale Market Lo Valledor (33°28′58″S 70°41′01″O), located in the commune of Pedro Aguirre Cerda, in the city of Santiago, Chile. The Wholesale Market Lo Valledor is the main center for the sale and distribution of fresh fruits and vegetables in Santiago, Chile. Samples of celery, broccoli, and beets were taken from the courtyard, specifically from the trucks of intermediaries and farmers who enter the market daily to sell their products (Figure 1A).

Sample preparation

For the valorization of discarded vegetables, a cleaning and sanitization process was considered, which is detailed below. **Rinsing** is the first stage of this process. It is carried out by placing the vegetables in a washing machine with water. The washing machine is turned on for 5 minutes and the agitation level of the water is adjusted to loosen dirt particles from the vegetables. The second phase is **sanitization,** which involves the introduction of a sanitizing solution diluted in water into the washing machine (2 mL of benzalkonium chloride (MG Quat Sanitizer) per 1 L of water to reach a concentration of 200 ppm). The washing machine is turned on for 7 min and the agitation level of the water is adjusted. Then, the water with the disinfectant solution is discharged from the machine. The last stage is the **washing** process, in which the washing machine with the vegetables is filled with water. The machine is turned on, and agitation is used to rinse the sanitizing solution off the vegetables for 5 min. The rinse water is discharged, and when the vegetables are removed from the machine, they are drained to remove as much of the water as possible.

Before analyses, the samples were prepared on a counter disinfected with 70% denatured alcohol with 2 grams of ethyl phthalate per liter and covered with sterile absorbent paper. The utensils used for cutting were also disinfected with the

Figure 1. A. Courtyard of the Lo Valledor Wholesale Market, 2021; B. Celery, broccoli and beet leaves.

same alcohol. The researchers carrying out the procedures wore surgical gloves. The following 6 samples, each at least 600 g, were prepared: (1) celery leaf, for which the upper third of the celery plants were cropped, along with the leaves, thin stems less than 0.5 cm in diameter were included; (2) celery stalks devoid of leaves; the sample was made up of stalks of more than 0.5 cm in diameter cut from the upper third of the celery plant; (3) beet leaves; (4) beet stems not including the edible fruit; (5) broccoli leaves; (6) broccoli stems not including the edible part (Figure 1B). Each sample was wrapped in sterile absorbent paper and stored in a properly labeled bag for transfer.

Evaluation of total polyphenols and antioxidant capacity

Total polyphenol analysis was based on the Folin-Ciocalteu method (Singleton et al., 1999). Gallic acid calibration solutions (100, 80, 60, 40, and 20 mg/dL) were made and analyzed on an Analette analyzer to obtain a standard curve. The total polyphenols in food samples were determined from the AWA (acetone, water, acetic acid) extracts and were calculated on the basis of the standard curve for gallic acid. The results were expressed as milligrams of gallic acid equivalents per gram (mg of GAE g^{-1}). The oxygen radical absorbance capacity (ORAC) was measured by following the Wu et al. (2004) procedure.

Results and Discussion

In this study, analysis of the total polyphenol content of leaves and stems for celery, beet and broccoli was performed by using the Folin-Ciocalteu method (Singleton et al., 1999). It is well known that polyphenols are complex compounds derived from plants that have the same characteristic aromatic rings with one or two hydroxyl functional groups. Polyphenol compounds have significant biological properties and offer valuable benefits to human health because they have antioxidant, antiradical and anticariogenic properties. Thus, they control and prevent cardiovascular diseases and cancers by inhibiting pathogens in food and by carrying out antiproliferation and antimutagenic functions (Cory et al., 2018).

The content of total phenolic (TPC) and oxygen radical absorbance capacity (ORAC) of the leaves and stems of celery, beet, and broccoli is presented in Table 1. In relation to the TPC, contrary to the reported relation between broccoli and celery leaves (Sepúlveda et al., 2021), the data show a slightly higher TPC content for celery leaves, which was probably influenced by the properties of the cultivation soil. On the other hand, broccoli stems have a TPC content 1.2 higher than that of beet, which is consistent with the literature (Hwang & Lim, 2015; Sepúlveda et al., 2021).

The polyphenolic composition of celery stems includes p-coumaric, ferulic, and caffeic acids, as well as flavonoids such as apigenin, luteolin, and kaempferol (Yao & Ren, 2011). On the other hand, in broccoli leaves and stems, the predominant phenolic compounds are sinapic and ferulic acids, along with flavonoid kaempferol (Hwang & Lim, 2015). Beet leaves also contribute significantly to the polyphenolic and flavonoid content, with gallic and rosmarinic acids, along with quercetin, being the primary polyphenolic compounds, as identified by (Goyeneche et al., 2020).

Furthermore, it is important to note that there is a noticeable disparity in polyphenol content between leaves and stems. Generally, leaves exhibit 2 to 7 times higher total polyphenolic content (TPC) than stems. This discrepancy can be attributed to the varied functions that different plant parts and organs fulfill in the plant life cycle. Plants often accumulate secondary metabolites as a defense mechanism, and higher TPC levels could be present in leaves because leaves are subject to greater amounts of solar radiation and higher air temperatures; this, combined with the probability of phytopathogen attack, e.g., insects, fungi, or bacteria, stimulates the synthesis of polyphenols in response to these environmental stresses (Biswas et al., 2023).

The above discussion suggests that the polyphenolic compounds (phenolic acids and flavonoids) present in the leaves and stems of vegetables have the ability to donate hydrogen atoms or electrons and eliminate free radicals (Huang et al., 2005). This could represent an important source of natural antioxidants and an attractive alternative for valorization, mostly for stems. A positive correlation has been reported between the polyphenol content and the antioxidant capacity of different vegetables (Yao & Ren, 2011), and an additive effect has been noted on the total antioxidant capacity when various vegetables are consumed at the same time (Apak et al., 2016). Therefore, antioxidant capacity is a relevant parameter to be considered.

Table 1 shows the oxygen radical absorbance capacity (ORAC) values in leaves and stems for celery, beet, and broccoli. ORAC is a parameter that shows the efficiency of antioxidant compounds in scavenging free radicals. Its value depends on the quality and quantity of the antioxidants contained in vegetables. As expected, there was a major contribution of leaves to the ORAC values, while stems showed lower values. The variation in antioxidant capacity among leaves and stems is noteworthy, with leaves showing 1.8 to 7.0 times higher antioxidant capacity than stems. Notably, celery exhibited the highest value, while intriguingly, celery stems demonstrated the lowest antioxidant capacity. This observed pattern aligns with the TPC data discussed earlier, confirming that leaves indeed possess higher polyphenolic content.

The consumption of fresh fruits and vegetables rich in polyphenols is known to mitigate oxidative stress induced by ROS. This phenomenon may elucidate the inverse correlation observed between a high intake of vegetables and the risk of developing coronary heart disease and cardiovascular conditions. However, it is important to acknowledge that the human consumption of fruits and vegetables remains below the minimum recommended daily intake levels. Hence, the development of products derived from these sources could serve as a viable alternative for individuals seeking to incorporate compounds with health benefits into their diets. The use of wastes derived from beet, celery and broccoli could contribute to a reduction in waste accumulation and result in significant health and financial benefits. In addition, the valorization of byproducts could promote new forms of employment, and these new business opportunities could directly benefit communities (Halog & Anieke, 2021).

The world population is growing at high rates, and the need to produce larger amounts of food is great. Furthermore, many natural resources are consumed in food production, which has negative impacts on the environment. For this reason, sustainable growth in food production is needed. Circular economy is a system in which

Table 1. Antioxidant content of leaf and stems of vegetables waste from the Lo Valledor Wholesale Market.

Vegetables	Antioxidants	
	Total Polyphenols (mg EAG 100 g^{-1} mta)	ORAC (µmol ET 100 g^{-1} mta)
Celery leaf	155.5	2,325.2
Celery stem	22.7	317.8
Beet leaf	117.1	1,756.5
Beet stem	69.3	970.2
Broccoli leaf	144.7	2,098.1
Broccoli stem	41.4	625.1

GAE = Gallic acid equivalent
ET = Troloxâ equivalent

wastes become the resources for a process (Halog & Anieke, 2021). The agricultural sector is particular interesting in terms of a circular economy due to the large amount of waste that is produced throughout the production chain, which can be converted into fertilizers, energy, materials and compounds. In particular, agricultural wastes and byproducts derived from the wastes could be an important source of food additives for human consumption. For example, mango seed kernels contain phenolic compounds, essential amino acids and a high amount of palmitic, linoleic and linolenic acids (Abdalla et al., 2007), which have been suggested to be good ingredients for infant and adult diets.

Undoubtedly, a challenge for the use of these food surpluses is the rigorous cleaning and sanitation process that these residues must undergo so that these raw materials can be used in the development of new food products while complying with food safety standards. However, given that more than 25,000 thousand tons per year of organic waste generated in the Lo Valledor Wholesale Market, of which 80% are organic wastes, an excellent opportunity is presented for surplus valorization at the national level considering the antioxidant capacity of some vegetable stems and leaves.

Conclusions

According to the antioxidant capacity of the leaves and stems of celery, beets and broccoli, these plant parts represent a promising resource of polyphenols, and their valorization should be considered. The recuperation of these underutilized parts that are traditionally discarded during food processing is crucial for environmental sustainability. This can minimize waste, reduce their environmental impact, result in the conservation of natural resources, and limit greenhouse gas emissions. In addition, this approach could promote healthier dietary habits through the creation of new foods aligned with responsible resource management for a more sustainable future.

Resumen

X. Rodríguez Palleres, M. Castillo-Ruiz, S. Correa Alfaro, y F. Rojas González. 2023. Evaluación de la capacidad antioxidante de residuos vegetales de un mercado mayorista de Chile. Int. J. Agric. Nat. Resour. 130-137. El consumo de hortalizas se asocia a un menor riesgo de cáncer, diabetes, enfermedades coronarias y obesidad, pero partes de las hortalizas como cáscaras, tallos y hojas no son valorizadas, aumentando los desperdicios e impactando al medio ambiente. El objetivo fue determinar la capacidad antioxidante de hojas y tallos de apio, brócoli y betarraga desechados desde los patios del Mercado Mayorista Lo Valledor, el principal centro de distribución de frutas y verduras de Santiago, Chile. Las hojas y tallos de estas verduras fueron luego separadas para analizar polifenoles totales y la capacidad antioxidante (ORAC). Los resultados obtenidos para polifenoles totales en hojas de apio, brócoli y betarraga fue 155,5, 144,7 y 117,1 mg EAG 100 g^{-1} mta, mientras que en tallos fue de entre 22,7, 41,4 y 69,3 mg EAG 100 g^{-1} mta, respectivamente. En esta misma línea, las hojas evidenciaron una mayor capacidad antioxidante que los tallos. El ORAC para las hojas de apio, brócoli y betarraga fue de 2.325,2, 2.098,1 y 1.756,5 µmol ET 100 g^{-1} mta, mientras que para tallos fue de 317,8, 625,1 y 970,2 µmol ET 100 g^{-1} mta, respectivamente. De acuerdo con la capacidad antioxidante de las hojas y tallos de apio, betarraga y brócoli, son una opción de alimentación saludable y su valorización debe ser considerada.

Palabras claves: Apio, betarraga, brócoli, economía circular, hojas, polifenoles, tallos.

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