Bell Peppers (Capsicum annum L.)

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The bell pepper is highly consumed worldwide due to its exotic colors (green, red, yellow, orange, and purple), flavor, and nutritional value. However, after processing bell pepper products, waste remains (seeds, peel, stem, and leaves), representing desirable raw material to obtain phytochemical compounds. They contain diverse bioactive compounds with interesting biological activities (in vivo and in vitro) and applications.

Keywords: food revalorization ; bioactive compounds ; biological activities ; health benefits

1. Introduction

Despite the nutritional contribution of food (regardless of its plant or animal origin), much of it will not be consumed by humans or animals and will be discarded as waste [1]. Thus, the prevention of food loss and waste promotes a favorable impact on the environment and food security of the world population, contributing to economic development [2]. Besides prevention, the revalorization of these food wastes is a technologically viable strategy, using them as bioactive ingredients to generate new, potentially functional or nutraceutical products [3]. Worldwide, food losses and waste mainly occur in fresh fruits and vegetables (>40%), and are mainly associated with poor handling and storage during post-harvest [2][3][4], which can be a raw source of bioactive compounds.

The Capsicum genus belongs to the Solanaceae family, Solanoicleae subfamily, Solaneae tribe. Chili (*Capsicum*), along with corn, beans, and squash, is one of the oldest cultivated plants in America [4]. There are five commercially cultivated species of chili (*C . chinense, C . annuum , C . pubescens , C . baccatum, and C . frutescens*) and around 25 wild and semi-cultivated species [5]. Peppers (*C . annuum L.*) are classified as hot or sweet; they are grown in subtropical climate regions throughout the world, including Mexico [6][7].

The production of bell peppers has increased considerably in recent years; however, the annual losses of this crop are estimated to be 40% [8]. Bell peppers can be of different colors (red, green, orange, and yellow) depending on their ripening stages and capacity to synthesize chlorophylls or carotenoids. Besides having an exotic flavor, bell peppers are an important source of vitamins (provitamin A, E, and C) and various bioactive compounds (phenolic compounds and carotenoids) that are beneficial for the health of consumers [9]. Additionally, scientific evidence shows that bioactive compounds extracted from bell peppers have anti-inflammatory, antidiabetic, antimicrobial, and immunomodulatory effects, among others [10][11][12].

2. Description of Bell Peppers

Capsicum annuum is an annual or biennial herbaceous plant. Its lifecycle comprises four phases: seedling, vegetation, flowering and fruiting [13]. The bell pepper fruit is large and fleshy, quadrangular, of variable size (7–16 cm long/6–11 cm width) and weight (from 100 to 500 g). The consumers appreciate them for their exotic colors (green, red, yellow, and orange), flavor, and texture. Furthermore, they are usually consumed fresh, but are also frequently used to enhance food dishes or other food products [14][15]. Moreover, they can be processed in commercial products, such as sauces, puree, and powders, among others [16]. On the other hand, bell pepper fruits could be a good source of human nutrition and health by providing energy and bioactive compounds [17], as discussed below.

According to the literature, bell peppers have high levels of water and carbohydrates with a low protein and fat content, which makes them a low-calorie food; they also have an adequate content of dietary fiber to be considered a food that is high in fiber, which has important implications for the health and nutrition levels of consumers. Additionally, bell peppers contain some nutritionally important compounds such as vitamins (B, A, D, C, E, and K) and minerals (potassium, sodium, magnesium, calcium, and phosphorus) [18]. In this sense, the frequent consumption of bell peppers provides essential nutrients for human health [19][20][21]. For example, fresh bell pepper consumption (100 g) provides the total ascorbic acid recommended daily intake [22]. On the other hand, the nutritional content of bell peppers depends directly on the color of the fruit, growing conditions, and postharvest processing, among other factors [23].

Additionally, the total pepper production has increased significantly (25%) in recent years (from 2006 to 2016) [24], and it is one of the most commercially cultivated vegetable crops worldwide [25]. For example, in Mexico, the total production of bell peppers was 676,216 tons during 2019 [13]. Therefore, the recovery of bell pepper phytochemicals offers a viable strategy to obtain bioactive compounds, which could be used as natural ingredients for the food and pharmaceutical industries, as an alternative to replacing synthetic compounds and also in the revalorization of a plant's wastes and losses [26].

3. Phytochemicals Present in Bell Peppers

In general, the concentration of polyphenol compounds in bell peppers varies with variety and color, ranging from 5.59 to 52.65 mg of gallic acid equivalent per gram of edible portion [18][19][20]. The main phenolic compounds found in green bell peppers include myricetin (658 µg/g), pyrogallol (572 µg/g), chlorogenic acid (290 µg/g), catechol (279 µg/g), protocatechuic acid (116 µg/g), caffeic acid (108 µg/g), ellagic acid (106 µg/g), and gallic acid (89 µg/g) [19][23][27]. In red bell pepper, pyrogallol (757 µg/g), P-OH benzoic acid (395 µg/g), myricetin (244 µg/g), chlorogenic acid (221 µg/g), ellagic acid (172 µg/g), gallic acid (115 µg/g), and benzoic acid (111 µg/g) [19][22][23][27] were found; while in yellow bell pepper, pyrogallol (2175 µg/g), catechol (225 µg/g), ellagic acid, benzoic acid (173 µg/g), myricetin (151 µg/g), ellagic acid (144 µg/g), chlorogenic acid (136 µg/g), and P-OH benzoic acid (123 µg/g) [19][23] were found. Furthermore, it has been reported that orange bell pepper contains gallic acid (900 µg/g), chlorogenic acid (117 µg/g), myricetin (100 µg/g), resveratrol (89 µg/g), caffeic (38 µg/g), ferulic (13.45 µg/g) and p-coumaric acids (13.45 µg/g) [25][28][27]. Additionally, the presence of gallic acid has been reported in purple (1200 µg/g) and dark violet (1150 µg/g) bell peppers [27]. These compounds exert potent antioxidant activity against reactive oxygen species and reactive nitrogen species [29].

Evidence indicates that bell pepper fruits are rich in phenolic compounds and flavonoids that may improve the human health status [18][19]; moreover, there is an association between uptake diets rich in phytochemicals and the risk reduction of chronic non-communicable diseases such as diabetes, osteoporosis, and cancer [26]. In most cases, the biological effects of polyphenols and flavonoids have been attributable to their antioxidant capacity, which can mitigate oxidative stress [23]. Thus, the regular consumption of bell peppers can improve human health and prevent degenerative diseases [30][31].

In general, the concentration of carotenoids in bell pepper depends on their color [22] and ripening state [32], where the highest concentration was reported in red bell pepper (7137–8800 µg/g), followed by orange (5292 µg/g), yellow (2236.3–2834 µg/g), and green (1219–1513.5 µg/g) peppers [19][22][23][33]. The main carotenoids reported in green peppers include neoxanthin (190 µg/g), chlorophyll (150 µg/g), lutein (76 µg/g), zeaxanthin (35 µg/g), and capsanthin (16 µg/g) [18][20][34][32], while, in red bell peppers, the most reported carotenoids were 5,6,-epoxide capsanthin (513 µg/g), lycopene (322 µg/g), capsanthin (178 µg/g), cucurbitaxanthin (81 µg/g), and Zeaxanthin (70 µg/g) [18][23][34][32][35][36]. In yellow bell peppers, the most common were lutein (115 µg/g), chlorophyll (61 µg/g), zeaxanthin (48 µg/g), capsanthin (45 µg/g), and α-carotene (21 µg/g) [18][20][37][32][38]. Moreover, the main carotenoids reported in orange bell peppers were zeaxanthin (191 µg/g), β-carotene (56 µg/g), lutein (45 µg/g), capsanthin (45 µg/g), and β-cryptoxanthin (19 µg/g) [18][23][37][32][38]. Carotenoids are excellent antioxidant compounds with several human health benefits; their consumption may prevent coronary heart diseases and some types of cancer (gastrointestinal, lung, prostate, and breast), and can reduce the risk of age-related macular degeneration, as well as having a beneficial effect on cognitive function [35]. However, specific carotenoids may provide specific health benefits; for example, α- carotene, β-carotene, and β- cryptoxanthin are provitamin A compounds [39]. Moreover, β-carotene has positive effects on cognitive functions, while lutein and zeaxanthin provide eye protection [39]. Furthermore, lycopene exhibited potent antioxidant activity and may reduce cholesterol in animals [39]. According to these data, the regular consumption of bell pepper fruits may improve human health.

Additionally, Dias-Games et al. [40] isolated a Hevein-like peptide from the leaves of bell pepper crops. These compounds showed antibacterial and antifungal activities and exhibited great potential for biotechnological use [41].

4. Biological Activities of Bell Pepper Extracts

As discussed in the preceding sections, bell pepper fruits, seeds, and leaves contain bioactive compounds (phenolic, flavonoid, carotenoids, tocopherol, and pectic polysaccharides), which are associated with different biological activities for diverse applications, as described below.

The antioxidant activity of any fruit or vegetable is determined by different bioactive compounds, showing different action mechanisms to inhibit radicals. Therefore, more than one method should be used to clarify the mode of action of each extract or compound from bell peppers. In this context, the antioxidant properties of bell peppers are an important parameter for establishing their health functionality.

Park et al. [42] investigated the antioxidant activity of methanolic extracts from four different-colored bell peppers by different methods (ABTS, DPPH, and SOD-like activity). They informed that extracts from orange bell peppers showed the highest antioxidant activity by ABTS test (880 µmol TE/g) compared to the red (800 µmol TE/g), yellow (790 µmol TE/g), and green (630 µmol TE/g) bell peppers; in contrast, the green bell pepper exhibited the highest antioxidant activity by DPPH assay (1153 µg/mL) compared to red (882 µg/mL) , yellow (811 µg/mL), and orange (694 µg/mL) bell peppers. Furthermore, the green bell pepper showed the highest SOD-like activity (IC 50 = 1472 µg/mL) compared to the yellow (IC 50 = 1676 µg/mL), red (IC 50 = 1826 µg/mL), and orange (IC 50 = 1893 µg/mL) bell peppers. The authors argued that differences in results in colored bell peppers are attributable to the mode of action of each bioactive compound present in the extract and their ability to reduce or inhibit oxidative stress, which is dependent on the color of the fruit. Additionally, the extracts from the four bell peppers exhibited a protective effect against H 2O 2- and HNE-induced DNA damage at low concentrations (1 µg/mL), preventing cellular damage at physiological levels. These compounds could form a reversible complex that may act as a desmutagenic molecule or interceptor, inhibiting genotoxicity [42].

In an other hand, it has been reported that the extracts from bell pepper fruits or leaves exhibited antibacterial and antifungal activities, which could be potentially used for food and pharmaceutical applications [[1][2][3][53][54][55][56][57][58]]. Also, it has been studied the effects of bell pepper extracts on diverse pathologies, showing [43][44][45][46][47][48]it´s anti-hyperglycemic, cytotoxic, and neuroprotective effects (Table 1)

Table 1 Effects of bell pepper extracts on diverse pathologies

Pathology	Bell Pepper Color	Source	Bioactive Extracts or Compounds	Dose	Model Assay	Effect	Ref.
	Green	**Fruit juice**	**Whole juice/ethanol extracts**	**50 mg/mL**	**α-glucosidase inhibitory activity**	**Extract exhibited α-glucosidase inhibitory effects.**	[49]
	Green	**Fruit juice**	**Ethanol extracts**	**100 µg/mL**	**growth of 3T3-L1 preadipocytes**	**Extract increased the survive rate of preadipocyte cells**	[49]
	Green	**Fruit juice**	**Ethanol extracts**	**100 µg/mL**	**3T3-L1 differentiation into adipocytes induced**	**Extracts promote the 3T3-L1 cells differentiation rate**	[49]
Diabetes	**NI**	**Fruit juice**	**Fruit juice**	**100 mL/twice a day**	**Randomized controlled study in humans**	**Fruit juice reduces post-prandial blood glucose and blood pressure.**	[50]
	Red	**Fruit pulp**	**Ethyl acetate extracts**	**20 µL**	**In vitro in HeLa cells**	**Extract inhibited the protein islet amyloid polypeptide.**	[51]
	Red	**Fruit pulp**	**Extract mixed with virgin olive oil**	**2 to 8 mL/kg body weight**	**In vivo animal assay in adult male rats**	**The mixture inhibited amylase and α-glucosidase activity.**	[52]
	Green Red Yellow	**NI**	**methanol extract**	**NI**	**NI**	**Extracts had α-glucosidase-inhibitory effects.**	[53]

Pathology	Bell Pepper Color	Source	Bioactive Extracts or Compounds	Dose	Model Assay	Effect	Ref.
Cancer	NI	Powdered	Aqueous extracts	10% *v*/*w*	animal assay with *Drosophila* larval (SMART assay)	Aqueous extracts showed antimutagenic activity.	[54]
	Red	Fruit pulp	Methanol extract	125 µg/mL	In vitro in NIH3T3 and A549 cells	The extract exhibited strong cytotoxicity in A549 cells.	[55]
	Yellow	Fruit pulp	Methanol extract	125 µg/mL	In vitro in NIH3T3 and A549 cells	Selective cytotoxic activity against A549 cells.	[55]
	Green	Fruit pulp	Pectic polysaccharides	150 mg/kg	In vivo animal model in Ehrlich tumor-bearing mice	Significantly reduced tumor growth.	[56]
	Green	Fruit pulp	Pectic polysaccharides	0.1 mg/mL	In vitro in lineages of human mammary cancer cells (MCF-7, MDA-MB-231, and MDA-MB-436)	Selective cytotoxic activity against MCF-7, MDA-MB-231, and MDA-MB-436 cell lines.	[56]
	Green Yellow Red	Fruit pulp	Polyphenol mixtures	1.2 mg/L	In vitro in human gastric adenocarcinoma cells, A549 human lung carcinoma cells, and HeLa human cervical carcinoma cells	Extracts showed cytotoxic effects against all cancer cell lines in a dose-dependent response.	[57]
Alzheimer's disease	NI	Powdered	Aqueous extracts / E-capsiate, Z-capsiate, dihydrocapsiate and nor-dihydrocapsiate,	1–10 g/L	In vitro Peptides agregation test	Bell pepper extracts were able to inhibit b-secretase activity and aggregation of Ab1–40 peptides	[58]

NI: no information.

5. Concluding Remarks

Sustainability in food production and consumption benefits all food chain and the environment. Efficient food production and supply chains lead to less food loss is only part of sustainability. The other part is the use through the revalorization of waste and food losses. The valorization of food waste for edible purposes is an area of opportunity for researchers due to the significant content of biactive compounds present, which can be reused in numerous products to which they will add value and thereby reducing the generation of waste food.

The revalorization of waste from fruits and vegetables, particularly bell pepper, mainly focuses on the use of bioactive compounds whose presence depends on the variety, color, growing conditions, degree of maturity at harvest and post-harvest handling of the fruit; in addition to the source (seeds or leaves). In general, the bioactive compounds reported in bell pepper are phenolic compounds, flavonoids, carotenoids, tocopherol and pectic polysaccharides, which have antioxidant, antimicrobial, immunomodulatory activity. Besides having positive effects in the treatment of diseases such as diabetes mellitus, cancer and Alzheimer's. Also, bell pepper extracts can be used as food additives (preservatives and colorants).

In this context, the revalorization of food waste is an area of opportunity for research and technological innovation with beneficial effects for the population, the economy and the environment. However, most studies have been carried out in vitro, so in vivo investigations are also necessary to demonstrate the effectiveness of the aforementioned compounds, in addition to guaranteeing their safety and understanding their mechanisms of action.

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