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Review Article:

Bell Pepper Biowaste Products as Medicinally Valuable Nutraceuticals: A Comprehensive Review

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Abstract

Background: The numerous additional valued substances present within plant biowaste products have a wide range of candidates regarding their recycling, promoting the idea of the circular economy. The bell pepper (BP, *Capsicum annum L.*) has high concentrations of various vitamins and minerals. Also, the biowastes of this plant, including the peels, seeds, and leaves, can represent valuable starting factors for creating medicinal chemicals as an alternative for increasing outcomes and waste in BP production and utilization in the food industrial fields. **Aim**: This article evaluates the necessary information about the chemical compositions of various colored BP fruits and their associated biomedical characteristics. The BP seeds, fruits, or leaves are rich in bioactive substances such as phenols, flavonoids, carotenoids, α-tocopherol, and pectic polysaccharides. These bioactive molecules may have the ability to be utilized as nutritional substances and display antioxidant, antifungal, antimicrobial, immune-suppressive, and immune-stimulant characteristics. Revalorization of food biowaste products appears in this way as a highly technological and unique field of study with beneficial effects on consumers, finance, and the health of the planet. **Conclusion**: To make sure that the use of these molecules is effective and to understand their principles of action, more study is required.

1. Introduction

Urinary Although nutrient-supplying sources afford the essentials for human and animal lives, they are the biggest supplier of biowaste worldwide (1). As a consequence, minimizing waste and loss of food has an advantageous effect on the natural world and the dietary needs of the world's population, which promotes growth in the economy (2). A scientifically feasible option for reduction was enhancing this dietary waste, utilizing it to extract biologically active substances for producing original, possibly effective, or health supplies (3). Fresh vegetables and fruits constitute over 40 percent of the loss and disposal of food worldwide, and improper handling and storage measures throughout the following harvest period might result in beneficial compounds becoming destroyed or discarded (4). It could be an uncontrolled form of substances that are bioactive. The family relatives to Solanoicleae subfamily, and Solaneae tribe together contain the Capsicum genus. A number of the earliest plants to be successfully introduced in the United States, as well as squash, beans, and corn, are the species of chili (Capsicum) (4).

There are currently approximately 25 naturally occurring kinds of chili peppers and 5 commercially developed types (*Capsicum chinense, Capsicum annuum, Capsicum pubescens, Capsicum baccatum, and Capsicum frutescens*), as well as maybe twenty five wild and semi-domesticated types (5). The pepper (*Capsicum annuum L.*) may taste spicy or delicious, which is why it can be grown internationally in warm regions of the world, especially Mexico (6,7). There has been an important rise in pepper's farming in the past few years; 40 percent is thought to account for the plant's yearly loss (8). Depending on the stage of maturity and ability to produce chlorophyll or carotenoids, chili peppers may vary in color from red to green to orange to yellow. Other than

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providing an unusual taste, the peppers themselves are useful sources of vitamin A, E, and C, along with a variety of bioactive ingredients (carotenoids and aromatic compounds), which have positive effects on human health (9). Furthermore, research supports the claims that the chili pepper's biologically active elements offer a variety of health benefits, including those related to inflammation reduction, diabetes management, antibacterial defense, and immune modulation (10). As an alternative to utilizing waste and trash in the processing of bell peppers for nutrition, beauty products, and medicinal purposes, this article analyzes and addresses suitable information on the chemical makeup of the BP fruits and their related biologic characteristics.

2. Food biowastes and circular economy

It must be done to modify the ideas about how to estimate to render the farming sector stronger in regard to the reduction in susceptible areas in agriculture and farm animal behavior as a result of degradation methods or the arrival of diseases and insects that minimize yields from agriculture and for humans to effectively maximize the productive potential of the planet's resources, it requires a growth of environmental, biotechnological, legal, and social methods (11), which will result in bio-economic stability programs throughout every step of the food supply chain (12). According to Brunori (3), "the ultimate objective of the biological economy is to be capable of use knowledge to get large bio-value yields via inexpensive organisms such as waste that is organic, which includes the intrinsic worth of items that are not linked to farm and feed." This technique offers the rise to an emerging sector called the bio-refinery, that's depends on the concept of treating plant matter step-by-step, including the separation of the elements with the greatest value added and proceeding out to the production of electrical power, in order to maximize the use of the scarce biomass production readily accessible (cascading approach). The variety of items generated is dependent on the sequence of the events (13).

Bio-refineries utilize many different raw parts and its mediators for making a wide range of items, thereby enhancing the worth obtained from the plant-based fuel. In this context, the idea of a biological refinery is frequently viewed for improving the bio-economy's profitability (4,5). The bio-refinery's power for assessing food scraps to use as sustainable starting point to regenerate polymers and manufacture biofuel via biotechnological methods is a key characteristic. Applying a wide range of technologies, this holistic viewpoint blends resource recovery and remediation (6).

Based on a bio-economic standpoint, it is necessary to attain many objectives at the same time, like (a) efficient utilization of resources, (b) natural beauty and preservation of soil, (c) trust of eco-systemic goods or services, (e) measurement of dietary decreases and debris, and (f) the generation of bioenergy via bio-refineries (14). To deal with the worldwide agricultural problems related to lowering emissions of greenhouse gases and modifying them, limiting degradation of land and dryness, and providing adequate supply of food. The authors of Smith and coworkers (7) discussed the need to change ways of handling land and cultivation techniques. The activities that depend on the value chain , risk management and land are the three categories into which Smith and coworkers (7) practices can be divided. Changes in diet and methods for reducing waste may be of significant assistance with the prevention of the harmful effects of warming temperatures. In addition, reduce waste and loss of food may reduce stress on the supply of freshwater around the world, and will help with adaptations (7). Technologies that allow for the biomass valorization of waste represent a range of activities vital to the bio-economy and promotes the circular economy approach as well (15). Agricultural and food wastes, waste products from other natural activities, and biological wastes from non-biobased items such wastewater and urban organic wastes are some of a sources of bio-wastes (16).

Lack of knowledge regarding biowaste availability and the lack of integrated modular systems continue to impede the usage of biowastes, approaches, technological advancements, and governmental restrictions (8). The key areas that is important for ensuring a circular economy, according to a European Commission (9), is : (a) The cascade strategy for employ bio-mass reuse, such as food waste. (b) possibility for novel bio-mass substances, compounds, as well as procedures to be developed that support the circular economy (c) collection of biowaste separately as well as the recycling of wood packaging (17).

In order to meet the growing demand, horticulture crop production and processing have expanded dramatically. This is also due to the expanding population and changing dietary preferences (18). However, because much food is wasted and lost during the generation of meals, there are now more socioeconomic and environmental concerns. According to estimates of waste and food loss, that the Food-Agriculture Organization (FAO) has released, waste and losses in vegetables and fruits are the greatest of every category of food and may perhaps exceed 60%. Up to 30% of food waste can be produced by processing of a single raw material group (greens and fruits). The crucial point is that waste and loss of food are significant sources of bioactive material, such as complex soluble polysaccharides, antioxidant, vitamins, fatty acids and enzymes, among other bioreagents that can be used in a variety of processing, such as the health, food pharmaceutical, and medical manufacture (19). Additionally, due to their antioxidative, anti-inflammatory, immune-modulatory, and numerous other biomedical properties (20) each of these bioreagents can be used to improve the health of humans as well as animals. Therefore, using food waste and losses to produce different biological active substance is crucial for responsive development (21).

Lost and discarded fruits and vegetables are a significant source of bioactive chemicals that need to be isolated and valued rather than disposed of as trash in landfills. Due to the nature of their bioactive materials, there are a variety of choices that may be used in the culinary, pharmaceutical industries, and cosmetic from a business point of view, separate from using them as animal feed or biogas generation (22). On the ecological front, the effects of wasted and lost fruits and vegetables on the ecosystem and public health are significant. Thus, an multifaceted strategy must be created and associated with successful citizen awareness efforts to reduce wasted food in accordance with national and international regulations to guaranty the consensus and safety of any fresh item introduced to market (23).

The idea of a "circular economy" is develop via promoting a shift from the standard "take-make-use-dispose" business model to one that uses recycling, repair, sharing, remanufacturing, refurbishment and reusing to create a system with closed loop that reduces both the consumption of natural resources as well as production of carbon emissions, contaminants, and waste. Food waste and losses that contain high-added-value molecules present a range of chance for evaluation as well as repurposing as envisioned by the regenerative economy theory (24).The bio-refineries are one of the solutions for valorizing agro-food industry leftovers that can have a beneficial environmental effect due to their flexibility and interest in adopting the concepts of the circular bio-economy. In this context, *Capsicum annum*, especially bell peppers, is one of the most commonly grown crops in the world (25). Although BP are regarded as a nutritious unique fruit with significant health benefits, they also contain bioactive compounds that have shown promise for use in both industrial and pharmaceutical applications (26,27).

3. Bell Peppers (BP)

Concerning a seasonal or yearly flowering plant, *Capsicum annuum*, four stages make up its lifecycle: fruiting, vegetation, blooming, and seedling (27). BP fruit is quadrangular, large and meaty, and can range in weight and dimension from 100 to 500 g (7–16 cm long, 6–11 cm wide), as shown in **Figure 1.** Customers enjoy them for their unique flavors, textures, and distinctive hues (red, orange, yellow, and green), texture, as well as flavor (28). Additionally, these are frequently utilized to improve food items or other kinds of food, but they are typically consumed fresh (29,30). Additionally, it may be used in variety of industrial products like condiments, purees, and powdered material (31). By delivering calories and bioactive substances, however, BP fruits can be an essential component of human nutrition and health (32), as will be explained below.

Figure 1. The physical appearance of BP fruits

Based on the research, BP are heavy in water and carbs, as well as little amounts of fat & protein, as a result, they are foods with few calories (33). Additionally, they contain sufficient fiber in their diet to be categorized as a food that is rich in fiber, that has important effects in consumers' medical and nutritional status, as recorded in Table 1. BP also contain various nutrients that are crucial for health, such as vitamins A,B,C,D,K and E, as well as the minerals sodium, phosphorus, magnesium, calcium, and potassium (34). As a result, regular green BP eating offers vital minerals for human health (35,36). For instance, 100 g of fresh BP fruit provide the daily required amount of ascorbic acid (37). Contrarily, the nutritional value of BP is directly influenced by the color of the fruit as well as other elements like growing conditions and postharvest processing (38).

Table 1. The BP principal nutritional content/100 g

Component	Value	Vitamins	Value	Minerals	Value
Moisture (g)	92.2	Vitamin C (mg)	127.7	Sodium (mg)	4
Carbohydrates (g)	6.03	Vitamin K (Âµg)	4.9	Magnesium (mg)	12
Energy (Kcal/KJ)	26/111	Vitamin A (IU)	3131	Calcium (mg)	7
Protein (g)	0.99	Vitamin E (mg)	1.58	Potassium (mg)	211
food fiber (g)	2.1	Niacin (mg)	0.979		
all fat (g)	0.30	Pyridoxine (mg)	0.291		
Ash (g)	0.47				

Source: USDA National Nutrient data base (2019) (39).

In addition, the general yield of BP has risen dramatically (25%) in the past few years (from 2006 to 2016) (25), and it is one of the most widely grown vegetable crops for commercial purposes globally (39). For instance, Mexico produced 676216 tons of BP overall in 2019 (40). As a consequence, the separation of BP phytochemicals presents a workable method for obtaining bioactive compounds, which may be used as natural alternatives to synthetic compounds in the food and pharmaceutical industries as well as with the valorization of losses and plant wastes (27).

4. BP-derived phytochemical molecules

Because of their unique coloration (red, green, yellow, purple, and orange), flavor, and nutritional content, BP fruits are widely consumed throughout the world (41). However, biowaste materials (seeds, peel, stem, and leaves) from the processing of BP products serve as ideal raw materials for the production of phytochemical compounds (31). They contain a variety of bioactive substances with intriguing *in vivo* and *in vitro* biological activities and uses (42). According to the definition given by the term "bioactive compounds", they are "inherent non-nutrient components of food plants with anticipated health-promoting, beneficial, and/or toxic effects when ingested" (43). Their content varies according to the fruit's component (pulp, seeds, and peel), the cultivar and variety, and after harvest circumstances like maturation phase, methods of processing, and circumstances of storage (27). Generally speaking, BP fruits are subject to thorough bioactive ingredient screening (quantitative or qualitative), and found compounds including carotenoids, phenolic, and flavonoids (44). Each of these substances exhibit excellent prospects to utilization in the food and pharmaceutical sectors, as will be covered next.

4.1 Flavonoids, polyphenols, and some related products

Some of the compounds most frequently found in vegetables and fruits are polyphenols and flavonoids. They have demonstrated antioxidant properties and prospective health advantages for humans (45). As shown in **Table 2**, the BP Fruit are a great source of flavonoids and phenolic acids. (46).

Dark violet and purple BP fruits have been found to contain (1150 g/g) and (1200 g/g) of gallic acid, respectively (47). These fruits accordingly have strong antioxidant effects against reactive nitrogen and oxygen species (49). Comparable to phenolic acids, the amount of flavonoids in BP differs based on type and color, approximately 2.1–41 mg of flavonoid per gram of food (35,46,48). There is a link between consuming diets high in phytochemicals and the risk reduction of chronic non-communicable diseases like diabetes, osteoporosis, and cancer (27). Studies shows that BP and other related fruit is abundant in flavonoids and phenolic substances that may enhance human health (35,50–52). The majority of the times, the physiological effects of flavonoids and polyphenols have been linked to their ability to reduce oxidative stress through their free radical scavenger capacity (38). As a result, eating BP fruit frequently can enhance health and stave against degenerative disorders (53,54).

4.2 Carotenoids

Colored vegetables and fruits have carotenoids, which are lipophilic and natural pigments (27). In red, yellow, and orange BP, these isoprenoid-based substances are what give them their unusual color (55). Carotenoids generally act as antioxidants and perform crucial roles in human nutrition and health (56). The amounts of carotenoids in various colored BP fruits are displayed in **Table 3.**

The quantity of carotenoids in the seeds of BP fruits varies based on their color (37) and stage of maturation (58), with green BP (1219–1513.5 g/g), followed by yellow (2236.3–2834 g/g), orange (5292 g/g), and red BP having the highest concentration (7137-8800 g/g) (35,37,38). Consuming carotenoids can lower the risk of age-related macular degeneration, some cancers (gastrointestinal, lung, prostate, and breast), and have a positive impact on cognitive function (61). Carotenoids are also excellent free radical removal with a number of benefits for human health. The pro-vitamin A molecules β-cryptoxanthin, β-carotene, and α-carotene are instances of specialized carotenoids that may have particular health advantages (63). Additionally, lutein and zeaxanthin offer eye protection, whereas β-carotene has positive effects on cognitive processes. Additionally, lycopene showed strong antioxidant potential and may lower cholesterol in animals (63). These findings suggest that consuming BP fruits regularly may enhance human health (64).

Table 2. Lists of the polyphenol, flavonoid, and some related product levels from BP

Bioactive Compound	BP distinct color				Ref.
	Red	**Orange**	**Green**	**Yellow**	
Protocatechuic acid (µg/g)	0.4				(37)
α-coumaric acid (µg/g)	7.65		3.36	6.41	(35)
Total polyphenols (GAE mg/g)	7.86	12.35	4.51-52.65	7.44-43.59	(34) (38)
3,4,5-methoxy-cinnamic acid(µg/g)	13.82		14.69	13.61	(35)
4-Aminobenzoic acid (µg/g)	21.34		22.09	50.19	(35)
Benzoic acid (µg/g)	23.17–111.81		66.55	173.04	(35) (37)
Chlorogenic acid (µg/g)	60.47–221.53	117.54	60.84–290.08	103.78–136.51	(35) (38)
Catechol (µg/g)	89.77		279.42	225.73	(35)
Cinnamic acid (µg/g)	8.11		3.51	4.65	(35)
Gallic acid (µg/g)	115.74	900	89.98	119.48	(35) (47)
Ferulic acid (µg/g)	11.88–27.67	13.45	23.59–48.42	24.75–35.14	(34) (35)
Caffeic acid (µg/g)	41.33-67.78	38.03	18.09-108.82	52.42–62.96	(35)
Ellagic acid (µg/g)	172.18		106.67	144.52	(35)
Myricetin (µg/g)	244.33	100.62	658.19	151.35	(38)
P-Coumaric acid (µg/g)	9.96–26.07	13.45	19.62–46.69	18.14–24.75	(34) (35)
Protocatechuic acid (µg/g)	97.21		116.09	95.37	(35)
P-OH-benzoic acid (µg/g)	395.16		65.85	123.19	(35)
Rosmarinic acid (µg/g)	120				(31)
Pyrogallol (µg/g)	757.66		572.77	2175.89	(35)
Resveratrol (µg/g)	111.57	89.72	174.34	90.78	(38)
Vanillin (µg/g)	0.11				(37)
Sinapic acid (µg/g)	117				(31)
4-hydroxy-3-methoxybenzoic acid) (µg/g)	11–17.70		43.85	31.62	(37)
Flavonoids	**Red**	**Orange**	**Green**	**Yellow**	**Ref.**
Total flavonoids (QE mg/g)	3.5–39	12.35	2.1–41	2.4–33	(48) (38)(46)
Apig. 6-rhamnose 8-glucose (µg/g)	314.70		170.96	77.31	(35)
Apig. 6-arbinose 8-galactose (µg/g)	156.42		151.66	67.88	(35)
Apigenin.7-O-neohespiroside(µg/g)	40.27		33.55	4.51	(35)
Catechin (µg/g)	793.50	4.81	295.39	745.53	(35)
Apegnin (µg/g)	36.28		2.12	1.54	(35)
Polyphenols	**Red**	**Orange**	**Green**	**Yellow**	**Ref.**
Kampferol (µg/g)	31.15		22.48	9.53	(35)
Hespirdin (µg/g)	1513.13		1065.65	213.06	(35)
Epicatechin (µg/g)	505				(31)
Hespirtin (µg/g)	37.00		38.05	7.07	(35)
Luteolin (µg/g dw)	68.43	56.34-154.03	62.31	95.89	(34) (38)
Luteolin 7-glucose (µg/g)	413.57		181.12	92.21	(35)
Rutin (µg/g)	290.39		93.43	49.51	(35)
Quercetin (µg/g)	46.36–91.98	92	16.24–71.71	9.66–102.33	(35)
Quercetrin (µg/g)	9.97–241.83	42.87	394.23	62.34	(47)
Naringin (µg/g)	50.13		275.00	190.19	(35)
Naringenin (µg/g)	1.54		13.64	2.12	(35)

GAE means gallic acid equivalent, while QE refers to quercetin equivalent.

Table 3. BP fruits' carotenoid content

The carotenoids	BP colored				Ref.
	Red	Orange	Green	Yellow	
All carotenoids (μg/g)	7137–8800	5292	1219–1513.5	2236.3–2834	(35) (37)(38)(57)
β-carotene (μg/g)	0.70–43.9	56.6	1.86–12.2	3.86–15.9	(38) (46) (58)
5,6-epoxide capsanthin (μg/g)	513				(59)
13-Cis-β-carotene (μg/g)	36	12	10.7		(60)
α-carotene (μg/g)		9.02	3.56	4.22–21.27	(58)
9,13-Cis-β-carotene (μg/g)	139	12.5	11.6		(60)
9-Cis-β-carotene (μg/g)	38		12.9	3.2	(60)
α-cryptoxanthin (μg/g)	0.9–27	0.3	27		(60)
Cis-β-cryptoxanthin (μg/g)	20	0.3	20	1.1	(58)
β-Zea-carotene (μg/g)		4.6	97.3		(60)
β-cryptoxanthin (μg/g)	40.49	19.45	4	7.55–19.5	(34)(58)
Capsorubin (μg/g)	1.4–48				(59)
Antheraxanthin (μg/g)	44				(59)
Cis-beta-carotene (μg/g)	34.28	8.32	9.64	6.81	(34)
Capsanthin (μg/g)	178.20	45.48	16.13	45.48	(34)
Chlorophyll (μg/g)	52.3		150.8	61.4	(48)
Cis-capsanthin	3.8				(59)
Cryptoxanthin (μg/g)	3.2				(46)
Cis-zeaxanthin (μg/g)	1.5				(46)
Cryptoflavin (μg/g)	2.1				(46)
all-trans lycopene (μg/g)	322-4.8			2.5	(61)(62)
Cucurbitaxanthin (μg/g)	81				(59)
Lutein (μg/g)		45.16	60.04–76.5	95.5–115.16	(58)(34)
All-trans-lutein	37		14	58	(60)
13-Cis-luteion	12		3		(60)
Mutatoxanthin (μg/g)	49				(59)
vitamin A (RE μg/g)			0.313	1.57	(58)
Neoxanthin (μg/g)			190		(59)
Trans-β-Carotene (μg/g)	41.72	8.32	13.09	6.81	(34)
15-cis-Violaxanthin (μg/g)	174		0.5	1.8	(60)
Violaxanthin (μg/g)	48		12		(59)
Cis-zeaxanthin (μg/g)	24				(60)
Zeaxanthin (μg/g)	8.8–70.71	191.76	35	48.3	(34)(38)(58)

4.3 Miscellaneous phytochemical molecules

In red and yellow BP fruits, numerous bioactive substances including blumenol C glucoside, colneleic acid, gingerglycolipid A, and capsoside A have been subjectively found (49). The green, yellow, and red BP fruits, Coworkers and Stuliff (42) found glycerophospholipids and 57 glycerolipids, ceramides and two sphingomyelin compound. These substances might have intriguing biological effects. The identification of certain alkaloids, glycosides, and saponins in green, yellow, and red BP fruits has been made (35). Additionally, according to Adami and coworkers (65), green delicious BP contains pectic polymers made up primarily of glucose (4.4%), uronic acids (67%), galactose (6.7%), arabinose (6.4%), xylose (0.3%), and minor amounts of rhamnose (1.6%) . This substances were found to have antitumor properties against mammary tumor cells (66).

Red, green, yellow, and orange, BP all contained vitamin E in varying amounts (3.65, 0.98, 1.23, and 1.92 mg/g, respectively), according to Blanco-Rios and coworkers (38), who also emphasized the substance's significance to the health of humans due to its potent free radical scavenger action. González-coworkers (67) have been also claimed that. In contrast, silva and coworkers (68) reported that BP seeds contain triterpenes such as campesterol (54.1 mg/kg), botulin (161 mg/kg), β-sistosterol (67.4 mg/kg), stigmasterol (9.3 mg/kg), and β-sistosterol (67.4 mg/kg), sterols and fatty acids such as pentadecylic (157 mg/kg), myristic (236 mg/kg), palmitoleic (764 mg/kg), margaric

(22,463 mg/kg), palmitic (15,041 mg/kg), arachidic (689 mg/kg), and stearic (11,693 mg/kg). These substances have anti-oxidant and acetyl-cholinesterase-inhibitory properties. A Hevein-like peptide was also identified by Dias-Games and coworkers (69) from the leaves of BP plants. These substances demonstrated antimicrobial properties as well as significant biotechnology application potential (70).

5. Biomedical-related potentials of BP extracts

The bioactive substances (phenolic, flavonoid, carotenoids, α-tocopherol, and pectic polysaccharides) that exist in the BP seeds, fruits and leaves have been discussed in the incoming sections and are linked to a variety of biomedical potentials for a variety of uses (71).

5.1 Antioxidant potential

The BP fruits are known for their bright color and high nutritional content, but they also contain large amounts of phytochemicals such as phenols, flavonoids, and carotenoids that have potent free radical scavenger properties (72). Some of the most extensively researched models include DPPH, ABTS, and FRAP. **Table 4** summarizes numerous publications on the free radical scavenger properties of BP fruit (seeds, juice and pulp) extracts (73).

In research on the antimicrobial characteristics of BP fruit extracts toward some food-borne harmful bacteria, Dorantes and coworkers (104) discovered that the presence of m-coumaric and cinnamic acid was associated with the ability of the BP extracts to effectively inhibit *Staphylococcus aureus* (inhibition zone of 7mm), *Bacillus cereus* (inhibition zone of 11 mm), and *Listeria monocytogenes* (inhibition zone of 12 mm) .Similar reports claim that EtOH-based extracts from red and yellow BP fruits have antibacterial potential against a number of harmful microorganisms. Red and yellow BP fruit extracts were shown by Hu and coworkers (101) to have a minimal inhibitory concentration that inhibited the growth of bacteria in a strain-dependent manner. For example, compared to the yellow BP fruit extraction (0.40, 0.50, 0.40, and 0.60 mg/ml, respectively), the red BP fruit extraction was more effective against *P. aeruginosa* (0.60 mg/ml), *E. coli* (0.50 mg/ml), *B. cereus* (0.20 mg/ml), and *S. aureus* (0.30 mg/ml). The each extract's botanical compounds profile, according to the authors, may be the cause of these variations. However, both BP fruit extracts caused cell wall destruction, as shown by investigations using transmission electron microscopy (105).

As reported by Mokhtar and coworkers (106), a polyphenol-rich BP fruit extract had antimicrobial properties toward *bacterium L. monocytogenes*, *S. aureus, S. typhimurium*, *E. coli, B. subtilis*, *P. mirabilis, and E. coli* in a way that depends on the type of strain and dose . Plus, they demonstrated that the presence of polyphenols encourages the development of *L. plantarum* and *Lactobacillus acidophilus* , and they stated that these substances may have a prebiotic-like effect by modulating the bacteria in the gut, (107). Researchers contend that polyphenol can change the pathogens' cell walls, causing the death of cells. The growth of bacteria such as *S. typhimurium* and *P. aeruginosa* as well can be stopped by BP fruit extracts, based to a study by Careaga and coworkers (108). Researchers also noted that the extract had a dose-dependent bacterial growth inhibitor (0.3 ml/100 g of meat) or bacterial killer (3 ml/100 g of meat) effect.

Similarly, to this, Aljaloud and coworkers (109) discovered that raw extract from BP had dose-dependent antibacterial efficacy against *E. coli* O157H7. These kinds of extracts may be utilized to prevent the growth of bacteria and to keep cattle meat fresh (108,109), identifying that the bioactive substances derived from BP leaves had *in vitro* antimicrobial properties. They demonstrated that the extract had antibacterial effect against *Clavibacter michiganensis spp. michiganensis, Ralstoniasolanacearum, Xanthomonas axonopodis pv. phaseoli, Erwinia carotovora spp., Pseudomonas syringae pv. tomato,* and *Erwinia carotovora* in a concentration and strain related sensitivity, and they suggested that the peptide substance might be employed as a biotechnology option for the biological management of phyto-pathogens (110).

Comparable to this, Dias-Games and coworkers (69) observed that the Heveinlike peptide isolated from BP leaves had antimicrobial effects against both Gram-negative and Gram-positive *Clavibacter michiganensis spp.* These findings were connected to the cationic nature of the compound because of its chitin-binding area, that can alter the microbial cell wall and cause death of the cell (111). Also, noted that the red BP fruit extract containing EtOH exhibited antifungal capabilities against *F. andiyasi* and *Cochliobolus spp.* This action is due to the extract's phenolic content and its capacity to disrupt the fungal cell wall, which causes cell death (103). *Colletotrichum gloeosporioides* was resistant to the antifungal activities of red BP-EtOH extract in a dose-dependent manner, suggesting a potential replacement for bio-control of pathogenic plants (102). These findings indicated that the fruits or leaves of BP displayed antimicrobial properties that might be employed in food and pharmaceutical applications (112).

5.3 Immune-modulatory potential

Many reports concerning the different immune-modulatory effects of the BP (fruits and leaves) extracts indicated that they have various immune-suppressive and immune-stimulant effects, Nordihydrocapsiate (NHC), a substance derived from sweet BP, showed anti-inflammatory actions in a concentration-dependent manner, as shown by Sancho and coworkers (113). They observed that NCH decreased anti-CD28, anti-CD3 plus, and anti-CD3, increased cell death (a route in-dependent of VR1) in primary T cells, and inhibited NF-kBi by phosphorylating MAPK p38. Hazekawa and coworkers (114) discovered similar patterns and established that the water-based extract from BP leaves after 72 hours of stimuli, Con-A significantly and dose-dependently reduced the levels of iNOS and NF-B expression, promoted T-cell activation, and mice spleen cells. Further, a male BALB/c mouse model displaying the anti-inflammatory effects of a pectic polysaccharide obtained from BP fruit was also published (115).

Popov and coworkers (115) observed that after 24 hours of consumption the TNF release was decreased by pectic polysaccharides at doses of 40 to 100 mg/kg but number of monocytes and neutrophils was unaffected. Red and green BP fruit extracts are said to increase the formation of antibodies in murine spleen cells (116,117). As reported by Goto and coworkers (117), the red BPE increased IgM production (by up to 350%) in mouse spleen cells in a dose-dependent manner (1.5 mg/mL), which was caused by a rise in the synthesis of DNA in B cells and CD138+ cells. Sarker and coworkers (118) have found that red BP fruit extract stimulates the formation of anti-keyhole limpet hemocyanin IgM and IgG antibodies in a dose-dependent manner (from 0.75 to 1.5 mg/ml). This extract also encourages B cells to differentiate into plasma cells, which increases the production of antibodies that are specific to an antigen. Also, Sarker and coworkers (118) observed that the phytochemical composition of red BP fruit extract enhanced both IgG and IgM antibody production in murine spleen cells. The research claims that eating BP fruits strengthens the immune system, and this effect is mostly related to the peppers' phenolic, flavonoid, and carotene content (101).

The authors of this paper concluded from the above that the fruits and leaves of BP have extracts that, in general, can modify the immune response by acting as anti-inflammatory agents and stimulating the formation of antibodies. To fully comprehend the mechanism of action and possible uses, however, more research is required.

Table 4. Some documented antioxidant potential of BP fruit extracts

BP Color	Source	Extract phenotype	Methods for evaluating the antioxidant potential			Ref.
			ABTS. (µmol TE/g)	DPPH (%)	FRAP (µg TE/g)	
Green	Fruit pulp (FP)	MeOH	630	* 1153		(74)
		MeOH		80	1400	(75)
		EtOH		78		(72)
		EtOH		40		(60)
		MeOH		* 1114		(35)
		MeOH		90		(76)
		EtOH	17.17	**2.28	** 3.99	(77)
		EtOH		** 25.15	30.15	(34)
		MeOH		90		(76)
	Fruit juice (FJ)	EtOH	8.64	**0.86		(78)
		Water		0.413		(68)
	Seeds	EtOH	89.25	**11.32	**9.94	(77)
		MeOH		**10		(79)
		MeOH	4	**25	39	(80)
		EtOH		50		(81)
		MeOH	55.64	76		(82)
		MeOH		80		(76)
		Water		*366	*125	(37)
Red	FP	MeOH		* 1832		(35)
		EtOH		**23.79	28.12	(34)
		MeOH		18		(47)
		MeOH	800	*882		(74)
		EtOH		50		(60)
		Hydrophobic	4.05			(83)
		EtOH		80		(61)
		MeOH		54–70		(57)
		EtOH		79.65		(72)
	FJ	EtOH	14.02	**1.05		(78)
		EtOH		** 22.20	25.20	(41)
	FP	MeOH		21		(47)
Orange	FJ	MeOH	880	* 694		(74)
		EtOH		75		(60)
		Hydrophobic	5.20			(83)
		EtOH		70		(72)
		EtOH	13.66	**1.12		(78)
		EtOH		64.90		(72)
		EtOH		70		(61)
		Hydrophobic	3.33			(83)
		EtOH		80		(60)
Yellow	FP	MeOH	790	* 811		(74)
		MeOH		22		(47)
		Aqueous-EtOH		** 18.23	19.87	(34)
		MeOH		* 3267		(35)
		MeOH	5	**35	40	(80)
Dark violet	FP	MeOH		15		(47)
Purple	FP	MeOH		20		(47)

MeOH, EtOH, , and ** are the abbreviations for methanol, ethanol,* IC_{50} *= µg/ml; and µmol TE/g.*

5.2 Antimicrobial potential

Ordinarily, natural leaf, seed, and fruit extracts are frequently utilized as antibacterial agents in the past and current times (98–100). The antibacterial properties of BP extracts are displayed in **Table 5**.

Table 5. The antimicrobial potential of various studied BP extracts.

BP color	Source	Extract Phenotype	Dose	Model Assay	Effect	Ref.
Yellow	FP	EtOH	20 mg/ml	*B. cereus, E. coli, S. aureus,* and *P. aeruginosa*	Strain-dependent antimicrobial effect.	(101)
Red	FP	EtOH	20 µg/ml	*B. cereus, E. coli, S. aureus,* and *P. aeruginosa*	Strain-dependent antimicrobial effect.	(101)
			5% v/v	*Cholletotrichum gloeosporioides*	Extracts showed antifungal effect.	(102)
			300 mg/l	*F. andiyasi and Cochliobolus spp*	Extracts showed fungistatic effect	(103)

5.4 Miscellaneous biomedical potentials of BP extracts

Studies describing the cytotoxic, neuroprotective, and anti-hyperglycemic properties of various BP extracts are listed in **Table 6**.

The BP fruit extract's potential as an antidiabetic applicant has recently come under examination. As a potential treatment for this metabolic disease, Park and coworkers (123) analyzed the inhibitory properties of an EtOH-extract from green BP on α-glucosidase and its insulin-like potential (127). Because they can decrease the absorption of intestinal glucose, the extracts were discovered to have antidiabetic effects. also showed insulin-like actions that may promote 3T3-L1 cell differentiation (128). The exact mechanisms that regulate the potential of each extract component that supports hypoglycemic characteristics, however, still require more research.

6. Food-related industrial applications of BP fruit extracts

Natural chemicals from BP fruits have been exploited for a variety of food-related commercial uses in addition to their biomedical functions, as shown in **Table 7**.

Table 6. Miscellaneous biomedical potentials of BP extracts against some common pathologies

Pathology	BP color	Source	Extract phenotype	Dose	Inhibitory effect	Ref.
Diabetes	Green, red, and yellow	Un	EtOH	Un	α-glucosidase	(119)
	Red	FP	Extract mixed with virgin olive oil	2 to 8 ml/kg body weight	α-amylase and α-glucosidase	(120)
	Red	FP	Ethyl acetate	20 µl	Protein islet amyloid polypeptide.	(121)
	Un	FJ	FJ	100 ml/twice a day	Post-prandial blood glucose and blood pressure.	(122)
	Green	FJ	EtOH	100 µg/ml	3T3-L1 cells differentiation rate	(123)
	Green	FJ	EtOH	100 µg/ml	Preadipocyte cell death	(123)
	Green	FJ	Whole juice/EtOH extracts	50 mg/ml	α-glucosidase .	(123)
Alzheimer's disease	Un	Powdered	Water	1–10 g/l	β-secretase potential and aggregation of Ab1–40 peptides	(124)
Cancer	Green, yellow, and red	FP	Polyphenol mixtures	1.2 mg/l	Cancer cell lines in a dose-dependent response	(125)
	Green	FP	Pectic polysaccharides	0.1 mg/ml	Tumor growth	(65)
	Green	FP	Pectic polysaccharides	150 mg/kg	Tumor growth	(65)
	Yellow	FP	EtOH	125 µg/ml	Tumor growth	(101)
	Red	FP	EtOH	125 µg/ml	Tumor growth	(101)
	Un	Powdered	Water	10% v/w	Tumor growth	(126)

Un means undetected.

Table 7. Food-related industrial applications of various BP fruit extracts

Application	BP color	Source	Extract phenotype	Dose	Improving effect	Ref.
Natural colorant	Red	FP	EtOH	10% w/v	Sensory attributes of yogurt	(31)
	Red	FP	EtOH	Un	Color of yogurt	(129)
	Yellow	FP	EtOH	0.6 g/l	Drink color	(130)
Food preservation	Un	FP	EtOH	1.5 mg/100 g	Extend the shelf life of beef meat	(108)
	Un	FP	Un	5% v/v	Extend the shelf life of ground meat	(109)

In the opinion of Careaga and coworkers (108), BP fruit extract has a bactericidal effect (3 ml/100 g of meat), which helps to increase the duration of storage of raw beef meat (7 days when stored at 7 °C) as well as avoid the growth of various pathogens involving *Salmonella typhimurium* and *Pseudomonas aeruginosa*. In a similar vein, red BP fruit extract (5% v/v) notably prolongs the expiration date of ground beef due to the natural extract's capacity to inhibit microbial development, especially for *Escherichia coli* (109). However, red BP's biologically active elements have been employed as natural dyes in yogurt and isotonic beverages (31,129,130). For the purpose of enhancing yogurt's color, sensory qualities, and dietary value.

Mendes-Gomes and coworkers (129) employed encapsulated bioactive elements isolated from BP, and Eregelj and coworkers (31) have also been demonstrated that adding natural colorants derived from BP biowastes to yogurt enhanced its sensory qualities and benefited the viability of lactic acid bacteria during storage. Additionally, Lobo and coworkers (130) demonstrated how yellow BP fruit extract might be employed as an organic coloring agent in isotonic beverages. In contrast to increasing the value of food biowastes, adding bioactive components from BP scraps as a beneficial component to foods is a highly technological and practical option (131). The plant-based compounds included in BP fruit may be applied as enhancements or reactive elements in complex dietary supplements that may enhance human health or as antibacterial substances for food preservation, according to the research.

7. Conclusion

The whole food system as well as the surroundings benefit from nutritious food manufacturing and eating. Sustainability is an expansive idea that goes beyond smart production processes and supply systems that reduce food loss. The other component is usage, which valorizes food losses and waste. Due to the substantial amount of bioactive substances that are already present and may be reused in a variety of items where they will add value, there is a chance for researchers to value biowaste food for edible uses, which will reduce the production of biowaste food. The quality and quantity of the bioactive substances are dependent on many factors concerning BP. These include the color, growth factors, and level of fruit age at harvesting and fruit handling after delivery, and which plant part is employed as a source. Generally speaking, pectic polysaccharides, carotenoids, phenolic compound, α-tocopherol, and flavonoids are the bioactive chemicals found in BP fruits. These compounds have antioxidant, antimicrobial, and immune-modulatory potentials. Various BP fruit extracts may be utilized as colorant, preservatives, and food additives, in addition to their beneficial benefits in the treatment of illnesses like Alzheimer's, diabetes mellitus, and cancer.

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المخلفات البيولوجية للفلفل الحلو كمواد صيدلانية طبيعية ذات قيمة طبية: مراجعة شاملة

الخلاصة

المقدمة: المواد القيمة الإضافية العديدة الموجودة في منتجات النفايات الحيوية النباتية لديها مجموعة واسعة من المرشحين فيما يتعلق بإعادة تدويرها ، مما يعزز فكرة الاقتصاد الدائري. يحتوي الفلفل الحلوBP) ، Capsicum annum L.)على تركيزات عالية من الفيتامينات والمعادن المختلفة. أيضًا ، يمكن أن تمثل المخلفات الحيوية لهذا النبات ، بما في ذلك القشور والبذور والأوراق ، عوامل بداية قيمة لإنشاء المواد الكيميائية الطبية كبديل لزيادة النتائج والنفايات في إنتاج BP واستخدامها في مجالات الصناعات الغذائية. **الهدف**: تقيّم هذه المقالة المعلومات الضرورية حول التركيبات الكيميائية لفاكهة BP الملونة المختلفة وخصائصها الطبية الحيوية المرتبطة بها. بذور أو فواكه أو أوراق BP غنية بالمواد النشطة بيولوجيًا مثل الفينولات والفلافونويدات والكاروتينات و ɑ-tocopherol و .pectic polysaccharides قد يكون لهذه الجزيئات النشطة بيولوجيًا القدرة على استخدامها كمواد غذائية وعرض خصائص مضادات الأكسدة ، ومضادات الفطريات ، ومضادات الميكروبات ، والمقاومة المناعية ، والمنبهات المناعية. تظهر إعادة تقييم منتجات النفايات الحيوية الغذائية بهذه الطريقة كمجال دراسي فريد من نوعه وتكنولوجي للغاية وله آثار مفيدة على المستهلكين والتمويل وصحة الكوكب. **الخلاصة**: للتأكد من أن استخدام هذه الجزيئات فعال ولفهم مبادئ عملها ، هناك حاجة إلى مزيد من الدراسة.

الكلمات المفتاحية: فلفل حلو، المغذيات النباتية. الاقتصاد الدائري ، المواد الكيميائية النباتية ، القدرات الحيوي