From Pomegranate Byproducts Waste to Worth

Subjects: Food Science & Technology

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The food industry is quite interested in the use of (techno)-functional bioactive compounds from by-products to develop ‘Clean label’ foods in a circular economy. Most studies are mainly focused on ultrasound extraction, which has been widely developed compared to microwave or enzymatic extractions, which should be deeply studied including combinations. After extraction, pomegranate peel by-products (in powders, liquid extract, and/or encapsulated, among others) have been incorporated into several food matrixes, as a good tool to preserve ‘Clean label’ foods without altering their composition and improving their functional properties. Future studies must clearly evaluate the energy efficiency/consumption, the cost, and the environmental impact leading to sustainable extraction of the key bio-compounds. Moreover, predictive models are needed to optimize the phytochemical extraction to help taking decisions along the supply chain

Punica granatum | peel | food | circular economy | sustainability | antioxidants | phenolics | encapsulation | green-technology | food losses | clean label | minimally processed

1. Introduction

In accordance with the Food and Agriculture Organization of the United Nations (FAO) definition, ‘food waste’ is the decrease in the quantity and/or quality of food obtaining from decisions and/or actions of retailers, food service providers, and consumers, while ‘food loss’ refers to any food that is discarded along the food supply chain, from harvest up to retail sale [1]. FAO indicates that around one third of global food production is lost or wasted at some step in the food chain. The degree of loss greatly varies depending on the state and the basket item.

In the case of fruit and vegetables (F&V), losses over the whole supply chain could reach up to ~50%. FAO’s future challenge is to reduce ~50% of food waste by 2050, as one of the objectives for sustainable development (OSD). The circular economy has been considered as the principle for eco-innovation, being focused on a ‘zero waste’ society and economy, using wastes as raw materials.

Between 2016 and 2018, FAO Statistics Division developed a food loss estimation model called ‘*The Food Loss and Waste database*’, an online collection of data including food loss and food waste. The boxes show where ~50% of the collected data falls into, and the mid-value of the percentage loss at every stage in the supply chain is shown by a line. In this sense, postharvest and retailing are the steps in the food chain where the F&V losses represent the highest mean percentages. The mean percentage during processing is less than 10%, but in some cases, it reaches ~40%. Moreover, although the mean percentage during distribution represents less than 10%, the range is from <5% to >30%. Therefore, several strategies have been developed around the creation of active packaging with encapsulated key compounds, to avoid the high percentage of food waste/loss [2]. The range of loss percentages at each step is wide since the value depends on the type of F&V, the country, and the year.

2. Nutritional Composition of Pomegranate Byproducts

Both primary (sugars, pectins, proteins, and fats) and secondary (polyphenols, pigments, and sulfur compounds) metabolites have been found in F&V byproducts [3]. The food industry and researchers are interested in reducing the environmental impact, and then focus on the recovery of the target compounds [4]. Carbohydrates (around 60%) [5], pectin (yield range from 6 to 25%) [6][7], proteins (around 3%) [8][9], and fats (<1%) [9] have been previously identified in pomegranate peel. Since this research is focused on the extraction of secondary metabolites from pomegranate peel, especially phenolic compounds, **Figure 1** shows the classification of the main ones found [9][10].

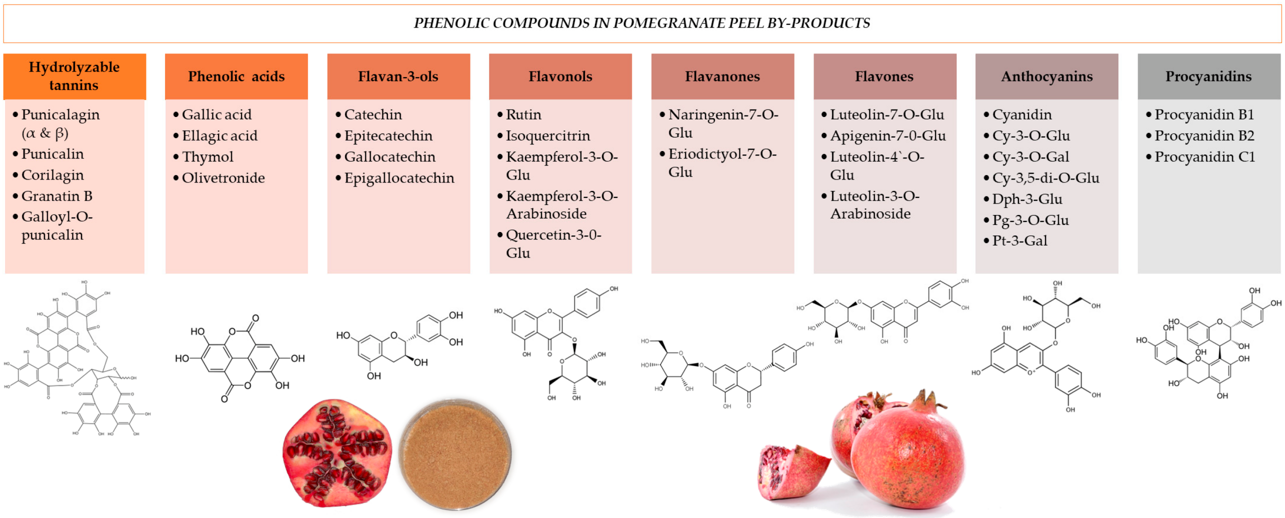

Figure 1. Classification of the main phenolic compounds in pomegranate peel [9][10]. Glu: glucoside; Cy: cyanidin; Dph: delphinidin; Pg: pelargonidin; Pt: petunidin; Gal: galactoside.

Among them, the top ten have recently been identified and quantified [11], being punicalagin (28,000–104,000 µg/g) the major compound found, followed by ellagic acid (1580–4514 µg/g), and others such as punicalin (203–840 µg/g), catechin (115–613 µg/g), corilagin (71–418 µg/g), gallic acid (10–73 µg/g), gallocatechin (69–1429 µg/g), epigallocatechin (5–106 µg/g), epigallocatechin gallate (4–70 µg/g), and kaempferol-3-O-glucoside (16–99 µg/g) [11].

Apart from pomegranate peel, seeds (wooden part) are generated after juice processing as a byproduct. Although this research is not focused on pomegranate seeds revalorization, previous studies have indicated that pomegranate seeds are rich in polyunsaturated fatty acids (88–92%), the most abundant being linolenic acid, especially punicic acid which ranges in terms of percentage of total fatty acid profile from 59.7 to 74.3% [12][13].

3. Pomegranate Peel Byproducts Incorporation Techniques

3.1. Powders/Flours

Pomegranate peel powder/flour is commonly acquired by drying and grinding until obtaining the desired particle size. Similar drying technology applied to edible fruit and plant material could be used in F&V byproducts to avoid undesirable bioactive compound changes [14]. The most common drying technologies are convective drying, sun-drying, MW drying, and freeze-drying in which key variables should be optimized (for instance, temperature and time). Moreover, spray-drying is commonly catalogued as a good tool for byproducts drying. This powder could be applied as a solid ingredient for the fortification of different products such as meat-based, F&V-based, and bakery products since this material presented high dietary fiber and techno-functional properties (high water- and oil-holding capacity, and low water absorption) in previous studies [15]. Similarly, powders can be obtained from liquid extracts after bioactive compounds extraction using different technologies such as freeze-drying or spray-drying [16]. Such technologies are included in the section on encapsulation due to the need for different processes to be carried out.

3.2. Liquid Extracts

With pomegranate peel powders obtained as previously detailed, extraction techniques with different solvents can be used, including those reported in this research. These liquid extracts are not suitable for direct incorporation into the different food matrixes, except when the solvents may be classified as a food ingredient (e.g., water). Therefore, these solvents must be removed through evaporation. Once they have been evaporated, drying should be carried out (for instance convective or freeze-drying) to later redissolve it in water, as the most common liquid. In this way, the liquid extract is ready to be incorporated into the matrixes at different solid–liquid ratio. In addition, liquid extracts can be used to obtain coatings, and can be encapsulated by different carriers and techniques.

3.3. Encapsulation

Encapsulation is a means to protect sensitive key bioactive compounds found in the food industry byproducts against undesirable heat, oxygen, light, and pH conditions [17]. The process needs a carrier agent and a technique to create the protective capsules. Different techniques may be used for the encapsulation of target compounds from F&V byproducts, such as spray-drying, freeze-drying, complex coacervation, and ion gelation [18], among others. Spray-drying is the liquid food drying method and has been widely used to obtain powders from F&V juices [14][19][20][21]. Currently, the transformation of F&V byproduct extracts (liquid) into powders using a spray-drier (the extracts are sprayed into a hot air chamber) has garnered attention because the process is complex, although this technique is one of the fastest, cheapest, and more reproducible, despite its complexity. In lyophilization as well as in spray-drying, a solution, dispersion, or emulsion is first obtained depending on the encapsulating agent and the active compound. The first step of freeze-drying-based encapsulation consists in creating an emulsion between the carriers and the target compounds, followed by a conversion into microcapsules by applying the freeze-drying technique [22], which consists of water removal by sublimation (primary drying) and secondary drying. **Table 1** shows the main technologies (spray-drying, freeze-drying, double emulsion, and ion gelation) and the carriers used to encapsulate target bioactive compounds from pomegranate peel. It can be seen that there is an interest in using novel carriers such as citrus byproducts.

Table 1. Main technologies used to encapsulate target compounds from pomegranate peel.

Technology	Carriers	Target Compound/Activity	Ref.
Spray-drying	Maltrodextrin	F-TPC, UPLC-TPC, Pn, EA, P, GA	[23] [24]
	Maltrodextrin + others: Tween 80 (99:1); Skimmed milk powder (50:50); Whey protein isolate (50:50); Gum arabic (50:50)	NA (Yield/Stability)	[25] [26]
	Skimmed milk power	NA (Yield/Stability)	[25] [26]
	Orange juice byproduct	F-TPC, DPPH	[27] [28]
	Maltodextrin/Pectin	TPC, Pn, EA	[29]
	Whey protein	Pn, EA, P, GA	[24]
	Arabic gum	Pn, EA	[30]
	Chitosan	Pn, EA	[30] [31]
	Pectin	Pn, EA	[30]
	Modified starch	Pn, TPC, HTC, DPPH	[32]
	Alginate	NA (Yield/Stability)	[31]
Freeze-drying	Soy phosphatidylcholine liposomes	Pn, EA, rutin, epifallocatechin, TPC	[33]
	Maltodextrin (5 and 10%) and b-cyclodextrin (5 and 10%).	F-TPC, FRAP	[34]
	Prunus armeniaca gum exudates	FRAP, DPPH	[35]
	Chitosan	FRAP, DPPH	[35]
	Maltrodextrin	TPC, TFC, Pn, EA, FRAP, DPPH	[36]

Technology	Carriers	Target Compound/Activity	Ref.
	Maltodextrin and calcium alginate	ANCs, FRAP, DPPH	[37]
	Maltodextrin and soy lecitin	NA (Yield/Stability)	[38]
Double emulsion	Water[1] in Oil in Water[2]: Water[1] (ethanolic solutions) in Oil (castor, soybean, sunflower, medium chain triglyceride and orange) in Water[2] (aqueous solution with Tween[80])	NA (Yield/Stability)	[39]
Ion gelation	Chitosan gel (1%):gelatin 2:1	F-TPC, DPPH	[40]
	Spirulina	TPC, DPPH	[17]
	Microalgae	EA	[41]
	Chitosan + others: Dialdehyde guar gum Gelatin-based materials	F-TPC, DPPH	[42]

NA: Data not available; cv: cultivar; EA: ellagic acid; F-TPC: total polyphenolic content by Folin assay; UPLC-TPC: total polyphenolic content by UPLC; TFC: total flavonoid content; PT: punicalagin; P: punicalin; GA: gallic acid; HTC: hydrolysable tanin content; ANCs: anthocyanins.

… vation, to … uid phase … [43] … teraction, … d optimal processing conditions [44]. After encapsulation processing, the encapsulated material presents the characteristics to be incorporated in other matrixes.

4. Potential Applications in the Food Industry

Pomegranate peel (in powders, liquid extract, and/or encapsulated, among others) have been reported in several food matrixes [45] such as F&V-based (**Table 5**), meat-based [9], fish-based [46][47], oil [48], dairy-based [49], confectionary [50], and baking products [28][51][52], among others. Packaging evidence have been reported by other authors, which has proven to be a good tool to preserve foods without altering their composition [53].

Since the bibliography on the incorporation of pomegranate byproducts into different food matrixes is extensive, this research has been focused on the scientific evidence related to the use of pomegranate peel byproducts during F&V handling and processing in the form of fresh whole, fresh-cut, minimally processed F&V, and beverages. **Table 5** includes information about the characteristics of pomegranate peel byproducts (drying technique, particle size, and cultivar), extraction technique (US, maceration), incorporation method (liquid extracts, coating, dipping), and benefits tested after its incorporation (shelf life, bioactive compounds fortification). In the following sections, more specifications related to F&V based products are detailed.

4.1. Fresh Whole F&V

In this case, more than 15 types of evidence have been found, in which pomegranate peel extracts were incorporated in different F&V (**Table 5**), being >25% incorporated into citrus fruits. The incorporation of pomegranate peel extract as a postharvest technique in fresh whole F&V has been reported in ~90% of the included studies. A coating enriched with pomegranate peel extract is described in 42% of them, the control formulation in which the extracts were added being chitosan and alginate solutions. Additionally, scientific evidence related to preharvest application is reported (pomegranate peel atomization in tomato leaves and the incorporation of the soil in a sage herb field). **Table 5** shows specific information related to the drying technique, particle size, and cultivar of pomegranate; the extraction technique; the extracts formulation and incorporation method (atomization, liquid extracts, coating, dipping); and the main results obtained by the authors.

4.2. Minimally Processed, or Fresh-Cut F&V

Since fresh-cut F&V usually present a short shelf life mainly due to enzymatic browning, dehydration, and microbial growth, it is necessary to look for innovative tools to preserve its quality and safety. **Table 5** shows the scientific evidence in which pomegranate peel extracts were used in minimally processed or fresh-cut F&V. There is a need to focus on the different ways of incorporating extracts into other fresh-cut F&V, and salads (for instance, baby leaves and younger plants such as sprouts or microgreens). There is a lack of knowledge on the effect of pomegranate peel extracts on vegetable commodities.

4.3. F&V Based Beverages

The fortification of F&V based beverages with bioactive compounds has been recently reviewed and reported [54]. The goal of the fortification with target compounds could be to enhance functionality (high content of polyphenols and other compounds) and/or techno-functional properties (color maintenance, sensory quality, inhibition of microbial growth). Moreover, if the key biocompounds have been extracted by green technologies from F&V byproducts, their incorporation replaces or reduces synthetic additives. **Table 2** shows the incorporation of pomegranate peel extracts in F&V juices as an alternative to enhance quality parameters. Future research should be focused on the fortification of other F&V-based matrixes such as cold/hot/dried soups and culinary sauces with pomegranate peel. For instance, a previous study indicated that the incorporation of horticultural byproducts improved the quality and shelf life of a kale pesto sauce [55].

Table 2. Application of pomegranate peel in fresh fruit and vegetable, minimally processed fruit and vegetable, and beverages.

	Matrix	Pomegranate Peel Byproduct	Extraction	Incorporation Method	Benefit	Ref.
Fresh whole F&V (pre- and postharvest)	Tomato	Drier (50–60 °C, 72 h) Fine powder (more information NA) cv information NA	Ratio 3:10 EtOH 48 h + evaporator (65 °C) + re-dissolved in sterile distilled water (0.05%, 0.5%, 1% and 5% *w*/*v*)	Preharvest. Tomato plants were sprayed in the leaves (bacteria inoculation) with the aqueous extract + 24 h drying	Antibacterial activity at least 15 days Replacing, reducing, or even alternating treatments involving copper compounds	[56]
	Sage herb	Air dried (more information	1:10 solid–liquid ratio in water or	Preharvest. Added in the soil	Higher dry mass and essential oils	[57]

Matrix	Pomegranate Peel Byproduct	Extraction	Incorporation Method	Benefit	Ref.
	NA) Grinder (more information NA) cv information NA	EtOH 80% 24 h + evaporator + water dilution	(2, 4, and 6 g per plot)	Inhibition of free radical scavenging	
Olive	Oven drier (40 °C) Powder home grinder (more information NA) Wonderful cv	120 g/L EtOH solvent (50 and 80%) + 1% Citric acid	Postharvest. Treatment of 1 × 1-mm injuries and inoculated (*C. acutatum*) by 10 µL of pomegranate peel extract (12, 1.2, or 0.12 g/L)	Reduction of fungal and bacterial population	[58]
Potato tubers	Air drier (28 °C, 10–15 days) Fine powder (more information NA) Baladi cv	1:10 solid–liquid (MetOH) 48 h 28 °C + evaporator + oven 50 °C 48 h	Postharvest. Wound (3 × 3 mm φ and deep) + inoculation (*F. sambucinum*) (24 h) + dipping (1.25, 2.5, 5, 10, and 20 mg/mL water) + air dried (2 h at 28 °C).	Antifungal activity on the mycelial growth and spore germination	[59]
Strawberry	Drying and particle size information NA Dente di caballo cv	US 40 °C 80% A 3 min (3 on, 8 off) Ratio 1:10 (H_2O 25%, propanol 25%, ethanol 25% and methanol 25%) + evaporator + Freeze-drier + re-dissolved in water	Postharvest. Immersion (30 s in a 2 L solution of pomegranate peel extract) + air-drying (1 h)	Extension of shelf life Substitution of synthetic pesticides	[60]
Sweet cherry	Oven drier (40 °C) Particle size NA	EtOH solvent (50 and 80%) + 1% Citric acid	Postharvest. Dipping (2 min) in the pomegranate extract (12, 2.4 or	Inhibition of all fungal spore germination	[61]

	Matrix	Pomegranate Peel Byproduct	Extraction	Incorporation Method	Benefit	Ref.
		Mollar de Elche cv	+evaporator + Water dilution	1.2 g/L) + air drying (2 h, 28 °C) + storage at 1 °C		
Fresh whole F&V (pre- and postharvest)	Sweet cherry	Oven drier (40 °C) Fine powder < 470 µm cv information NA	1:8 solid–liquid ratio (Water 28 °C 24 h)	Postharvest. Immersion in pomegranate peel extracts (3 min 20 °C) + room temperature drying	Pomegranate peel extracts and calcium sulphate coatings, alone or in combination, decreased weight loss, decay, respiration rate, and increased acidity, firmness, ascorbic acid, DPPH, TPC, and TAC	[62]
	Apple	Oven drier (40 °C) Particle size NA Mollar de Elche cv	EtOH solvent (50 and 80%) + 1% citric acid + evaporator + water dilution	Postharvest. Wounds treated with 10 µL of pomegranate peel extract (12, 1.2 or 0.12 g/L) + inoculation (10 µL *P. expansum*)	Inhibition of fungal spore germination and decay of artificial inoculations	[61]
	Mango	Freeze drying (−45 °C, 94 h) Particle size and cv information NA	MetOH 45 °C 30 min + Bath US + evaporator + water dilution	Postharvest. Chitosan (2%) in 0.5% citric acid solution + Pullulan (2%) in water (50:50 ratios). During stiring: 1% glycerol + 5% of pomegranate peel extract (0.02 g/mL). Dipping for 2 min	Increase of firmness, TPC and AOX. Prolonged the shelf life	[63]
	Apricot	Drier (60 °C, 48 h) Particle size < 0.251 mm cv	80% EtOH 25 °C + evaporator	Postharvest. Chitosan coating solution (1% chitosan in glacial acetic 1% + 0.8% glycerol + Tween	Reduction of % decay and weight loss. Maintenance of DPPH radical scavenging	[64]

	Matrix	Pomegranate Peel Byproduct	Extraction	Incorporation Method	Benefit	Ref.
		information NA		80 + 0.50, 0.75, and 1% pomegranate peel extract)	activity, ascorbic acid content, titratable acidity and firmness.	
	Figs	Air dried few days (more information NA) Pulverized (more information NA) cv information NA	Alcoholic buffer (EtOH 50%)	Postharvest. Alginic acid: agar (70:30) + 0.25 and 0.5% pomegranate peel extract Dipping in the coating solution + coating gelation	Prolonged the shelf life	[65]
	Dates	Drier (48 °C, 52 h) Ground peels (more information NA)cv information NA	EtOH 70% + evaporator + Water dilution	Postharvest. 1% Chitosan, 1% nanochitosan or 1% pomegranate peel extract in 1% glacial acetic	Growth inhibition of any fungal spore after 48 h of coating.	[66]
	Citrus	Hot air drier (50 °C, 48 h) Particle size 0.250 mm cv information NA	2.5:10 Solid–liquid ratio (Ac, EtOH, MetOH, H_2O, DMSO) + shaking (6 h) + re-extracted with water evaporation	Postharvest. Immersion of wounded lemons (2 × 1 mm long and wide tip) in pomegranate peel extract (pre-infection and post-infection with *P. digitatum*) + air drying	Prevention and control of *P. digitatum*	[67]
Fresh whole F&V (pre- and postharvest)	Grapefruit	Oven drier (40 °C) Particle size information NA Mollar de Elche cv	EtOH solvent (50 and 80%) + 1% citric acid evaporator + water dilution	Postharvest. Wounds treated with 10 μL of pomegranate peel extract (12, 1.2 or 0.12 g/L) + inoculation 10 μL *P.*	Inhibition of all fungal spore germination and decay of artificial inoculations	[68]

Matrix	Pomegranate Peel Byproduct	Extraction	Incorporation Method	Benefit	Ref.
			digitatum and *P. italicum*		
Lemon	Oven drier (40 °C) Particle size information NA Mollar de Elche cv	EtOH solvent (50 and 80%) + 1% citric acid + evaporator + water dilution	Postharvest. Wounds treated with 10 µL of pomegranate peel extract (12, 1.2 or 0.12 g/L) + inoculation 10 µL *P. digitatum* and *P. italicum*	Inhibition of all fungal spore germination and decay of artificial inoculations	[61] [68]
Mandarin	Drier (70 °C, 48 h) Ground peels (more information NA) Shirine Shahvar cv	0.25:10 solid–liquid ratio (60% EtOH + 0.1% citric acid)	Postharvest. Wounded (1 × 2 mm φ and depth) + dipping 1 min in pomegranate peel extract concentrations (25, 50, 75, 100%) + inoculation (*P. italicum* and *P. digitatum*) + drying	Reduction of % infected wound and lesion φ (75% or/and 100% extract). Increase of TPC, TFC, and PAL activity (75% or/and 100% extract)	[69]
Orange	Drier (35 °C, 2 days) Particle size NA Gabsi cv	1:10, 0.6:10, 0.3:10 solid–liquid ratio (MetOH or Water) + evaporated + drying (40 °C or freeze-drying) + re-dissolved in water	Postharvest. Chitosan coating solution (1% chitosan in glacial acetic 1% + 0.5% Locust bean gum + 20% glycerol + 7, 18, and 36% dry waster/MetOH pomegranate peel extract). Wounded oranges (4 times: 3 × 3 mm φ × deep) + Inoculation (20 µL of a *P. digitatum)* + drying + dipping in different coating solutions (2 min)	Controlled growth of *Penicillium digitatum* Reduction of postharvest decay	[70]
Orange	Oven drier (40 °C) Particle size	EtOH solvent (50 and 80%) + 1% citric	Postharvest. Wounded oranges (3 times 2 × 2 mm	Enhanced defense pathways	[71]

	Matrix	Pomegranate Peel Byproduct	Extraction	Incorporation Method	Benefit	Ref.
		NA Mollar de Elche cv	acid + evaporator + water dilution	φ and deep) + 20 μL pomegranate peel extract (12 g/L) + Inoculation (20 μL of a *P. digitatum)* + 1% citric acid + drying	(antibiotic biosynthesis)	
	Guava	Drier (60 °C, 72 h) Particle size 0.420 mm Bhagwa cv	1:10 solid–liquid ratio (80% EtOH) + evaporation	Postharvest. Chitosan (1% chitosan in glacial acetic 1% + 0.75% glycerol) and alginate solution (2% alginate + 10% glycerol + 2% calcium chloride) with 1% pomegranate peel extract	Preserved quality for 20 d under refrigeration	[72]
Fresh whole F&V (pre- and postharvest)	Capsicum	Drier (60 °C, 72 h) Particle size 0.420 mm Bhagwa cv	1:10 solid–liquid ratio (80% EtOH) + evaporation	Postharvest. Chitosan (1% chitosan in glacial acetic 1% + 0.75% glycerol) and alginate solution (2% alginate + 10% glycerol + 2% calcium chloride) with 1% pomegranate peel extract	Inhibition of microbial growth. Preserved sensory quality. Extension of shelf life up to 25 d at 10 °C	[73]
	Pear	Drier (60 °C, 72 h) Particle size 0.420 mm Bhagwa cv	1:10 solid–liquid ratio (80% EtOH) + evaporation	Postharvest. Chitosan (1% chitosan in glacial acetic 1% + 0.75% glycerol) and alginate solution (2% alginate + 10% glycerol + 2% calcium chloride) with 2% pomegranate peel extract	Lowered the cell wall degrading enzymes activity (firmness preservation)	[74]
Fresh-cut/Minimally	Fruit salad:	Oven drier (38 °C, 48 h)	Powder	2.5–5% (*w*/*v*) of pomegranate peel	Inhibition of mesophilic	[75]

	Matrix	Pomegranate Peel Byproduct	Extraction	Incorporation Method	Benefit	Ref.
processed F&V	nectarine and pineapple in cubes covered with fructose syrup	Particle size 500 mm Wonderful cv		powder at the container bottom	bacteria, total psychrotrophic microorganisms, yeasts, and lactic acid bacteria No negative effect on sensory characteristics	
	Fresh-cut pear, apple and melon (plugs)	Oven drier (40 °C) Particle size NA Mollar de Elche cv	EtOH solvent (50 and 80%) + 1% citric acid + evaporator + water dilution	Inoculated plugs were dipped (10 min, 150 rpm) + dried (25 °C 30 min)	Reduction of *Listeria monocytogenes*	[76]
	Fresh-cut Golden apple wedges: thickness 30-mm and 30 g	Drying and particle size information NA Dente di cavallo cv	Pulsed UAE (10 min, <50 °C, 1:40, 26 kHz, 200 W, 40% A, 50% duty cycle) + encapsulation with pectin from citrus peel by spray drying	Enrichment with microencapsulates reconstituted in water 1:1	Reduction of enzymatic browning. Color preservation	[77]
Beverages	Carrot juice	Oven drier (40 °C) Grounded in a colloid mill (more information NA) cv information NA	High pressure-assisted extraction	5 mg pomegranate peel extract per mL of carrot juice	Improvement of microbiological safety and AOX during storage. Color preservation	[78] [79]
Beverages	Apple juice	Oven drier (55 °C, 12 h) Particle size and cv information NA	Maceration extraction (1:50, 80% EtOH 1 h shaking)	Different% of pomegranate peel extract (0–2%)	Enhancing sensory quality and AOX. Low toxicity with 1% of pomegranate peel extract	[80]

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	Matrix	Pomegranate Peel Byproduct	Extraction	Incorporation Method	Benefit	Ref.
	Kiwi juice	Information NA	Commercial pomegranate extract (PureBulk, Roseburg)	Extract incorporation (180 µg/mL kiwi juice) + US bath (40 kHz, 180 W, 20 °C, 10–30 min)	US and pomegranate extract combined treatment: higher reductions on yeast and molds	[81]
	Red wine	Green decoction: Boiled in water 60 min (1:40) Freeze-drying of the extract Wonderful cv	Powder	Purification to obtain the tannins. 8 analyzed tannins (1 g L^{-1} wine solution)	Increase of protein stability Increase of color stability Reduction of sulfites	[82]
	Symbiotic drink powder	Hot oven (40 °C, 48 h) Particle size Kitchen-miller (more information NA) cv information NA	Ethanolic extract (80%; 1:15) + evaporator + Freeze-drier	Formulation: beetroot peel extract powder (3%), pomegranate peel extract powder (1%), grape pomace extract powder (1.5%), quince seed gum (0.5%), stevia (4%), mint (0.1%) and water (89.9%). Pasteurization: 72 °C, 90 s	Maintenance of *L. casei* viability of the recommended level of 10^{-7} CFU/g	[83]

NA: Data no available; A: amplitude; cv: cultivar; TPC: total polyphenolic content; TFC: total flavonoid content; AOX: total antioxidant capacity; TAC: total anthocyanin content; PAL: phenylalanine ammonia-lyase.

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