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REVIEW ARTICLE

Valorization of by-products Derived from Onions and Potato: Extraction Optimization, Metabolic Profile, Outstanding Bioactivities, and Industrial Applications

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Abstract

Huge quantities of vegetables and fruits by-products are discarded annually worldwide following the industrial food processing techniques. These biowastes were found to cause further environmental hazards. However, they could represent rich sources of numerous bioactive metabolites and substrates for high valued products. Specifically, onion (*Allium cepa* L.) and potato (*Solanum tuberosum* L.) are of economic importance since they are cultivated and found as chief components of most food recipes worldwide. Nevertheless, potato peels and the outer onion scaly leaves are major non-edible by-products. Both biowastes are rich in bioactive phenolic compounds, whereas potato peels are rich in chlorogenic acids and onion solid wastes in flavonoids, particularly flavonols (quercetin derivatives). Also, they are good sources of dietary fibers, fatty acids, starches, sugars and proteins. In addition, they are potential candidates for biofuels production. Hence, with the recent advances of bio-refinery concepts valorization of such treasures is highly recommended. The current review highlighted the major metabolic classes of onion and potato agro-industrial wastes and how we can utilize the available possibilities to maximize the recovery and benefits of metabolites found in these wastes.

Keywords Potato · Onion · Bioactive metabolites · Biotechnology · Extraction · Valorization

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Novelty Statement

The current review highlights two of the most discarded vegetable agro-industrial biowastes, i.e., onion and potato peels, comprehensively. Both biowastes are discussed in a comparative approach showing the potential phytoconstituents, including bioactive phenolic compounds, whereas potato peels are rich in chlorogenic acidsand onion solid wastes in flavonoids, particularly flavonols. In addition, they are potential candidates for biofuels production. Hence, with the recent advances of biorefinery concept, valorization of such treasures is highly recommended. The manuscript is the original work of the authors and the novelty in results is given.

Introduction

The state-of-the-art biorefinery has been evolved in the past few decades as a platform to integrate the industrial processes optimizing the utilization of terrestrial and marine raw biomasses rich in cellulose, hemicellulose, and lignocellulose contents, for production of high valued fine chemicals and biofuels [1]. The application of this concept has provided sustainable resources for diverse industrial sectors through the combination of various biotechnological with chemical conversion strategies [2]. For instance, production of lactic acid, succinic acid, and itaconic acid were possible from beech wood via chemo-catalytic biomass fractionation followed by fermentation with microorganisms, including *Aspergillus terreus* and *Ustilago maydis* using the produced glucose from cellulose hydrolysis as carbon source [3]. In addition, bio-butanol was reported as an important product upon fermentation with *Clostridium acetobutylicum* [4].

With the same concept, valorization of agricultural biowastes was applied in eco-friendly ways to produce valuable products for various foods, medical, and industrial applications [5]. As a result of increasing the global population and post-harvesting agro-processing and food industries, the Food and Agriculture Organization (FAO) has recently estimated the discarded biowastes at approximately 1.3 billion tons/year [6]. Such non-edible by-products have demonstrated their richness in wide spectrum of phytochemical classes, including fatty acids, phytosterols and tocopherols in *Citrus* seeds [7], dietary fibers in pomegranate peels [8], and phenolic compounds and sesquiterpene lactones in artichoke bracts, exterior leaves, and stalks [9, 10].

Specifically, onion (*Allium cepa* L.) and potato (*Solanum tuberosum* L.) are of economic importance grown worldwide, where they are chief components of diverse dishes [11, 12]. Onions are highly consumed leading to the production of massive quantity of onion solid wastes; outer fleshy scales, roots top, bottom bulb part, onion skins, and undersized onion bulbs [13, 14]. In addition, potato is recognized as the fourth cultivated crop after wheat, corn, and rice in more than 158 countries feeding over a billion people worldwide with also various kinds of biowastes [15–17]. It is also noteworthy to mention that potatoes biodiversity is vast of about 4000 varieties with 200 wild species and 10 cultivated species [18].

Both biowastes are rich in prolific metabolites, including dietary fibers and polyphenolics mainly flavonoids and phenolic acids [15, 18, 19]. In addition to the richness of potato by-products in steroidal glycoalkaloids, including α-chaconine and α-solanine [20, 21] that pose them potential candidates for production of valuable products beneficial for different medical, food, and pharmaceutical sectors [22–24]. Peeling leads to losses in dietary fiber and several bioactive constituents [9]. Giving the aforementioned points, classical and non-conventional extraction methods have been optimized to maximize the recovered yields of their metabolites, as the use of microwave-assisted extraction (MAE) for anthocyanin from onion peels [22] and conventional ethanol extraction of phenolics (e.g., flavonoids) from potato peels and with the aid of surface response methodology [23].

Targeting molecules with health-promoting properties are the most interesting trend nowadays. The aim of this work was to support a systematic review of onion and potato wastes as functional foods for their interesting and rich phytochemical constituents with biomedical potentials. The advantage of these wastes is owed to their low initial costs value, non-competitiveness to food, abundance, renewability, and availability. Therefore, the current review highlighted different aspects for the valorization of such biowastes. The phytochemical composition, extraction optimization, health benefits, and industrial applications are discussed, which could aid in the rediscovery of new drug candidates and nutraceuticals from well-known vegetable wastes.

Phytochemical Composition

Vegetable wastes have a great potential as residual sources of many bioactive components. Onion wastes were reported to have significant amount of numerous dietary compounds and bioactive phytonutrients, including phenolics, anthocyanins, flavonoids (e.g., quercetin and quercetin glucosides), sugars, minerals (e.g., chromium, manganese, molybdenum, folates, iron, zinc, potassium, magnesium, calcium, and copper), fibers, and vitamins. Red onions have the highest contents of flavonols and anthocyanins, then the yellow onions. Potato

peels are rich source of nutritional compounds, *i.e.*, phenolics especially chlorogenic acid, glycoalkaloids, starches and fatty acids, which enhance foods' nutritional benefit. The determination of the total phenolic compounds in peel extracts is commonly estimated using the Folin-Ciocalteu method. Where, for the identification and quantification of individual compounds present in the tested extracts, techniques such as High-Performance Liquid Chromatography (HPLC), using different detectors, as the DAD (Diode Array Detector) and the ESI–MS (Electrospray Ionization and Mass Spectrometer) are widely used as their high efficiency [24].

In the next subsections, the major phytochemicals in both biowastes are discussed in detail. In addition, the chemical structures of important compounds are traced in Table 1.

Polyphenols

The non-edible parts of the onion bulb contain polyphenols (Table 1) which are not present in the edible bulbs.

Onion Peels

Flavonols are the major class detected in the onion extracts, where quercetin derivatives being the most common ones exclusively with glucose linked to the 4′, 3, and/or 7-positions. Quercetin-4′-glucoside and quercetin 3,4′-diglucoside have been found in almost previous works as the main ones. Whereas kaempferol and isorhamnetin derivatives were reported as minor flavonols. In a comparison between 75 onion cultivars grown in Texas, the soil type, location, and growth stage affected the total flavonoids content. Where, quercetin aglycone was identified as the major flavanols of the cultivars. Flavonoids were present in the edible portions of *Allium* species in a range of < 0.03 to > 1 g/kg where onion wastes had higher amounts than edible parts of about 2 to 10 g/ kg [25]. Despite the importance of these flavonoids in onion wastes, they almost stay unused when processing. The identified compounds were summarized in Table 1.

Furthermore, nine phenolics were detected using HPLC analysis in the methanolic extract of onion as 2-(3,4-dihydroxybenzoyl)-2,4,6-trihydroxy-3(2*H*)-benzofuranone, with compounds 8, 57, 80, 81, 82, and 83 as shown in Table 1 [26]. In addition to compounds 20, 21, 22, 29, 33, 45, and 46 (Table 1) were also reported as minor constituents. Anthocyanidins and phenolic acids were identified by reverse-phase HPLC using retention times and UV–visible absorption spectra.

Additionally, compounds 24, 25, 27 and 29 (Table 1) were detected using HPLC analysis as the major constituents in onion grown in Canada and the USA while, compounds 26, 42, 45 and 37 (Table 1) were the minors [27]. In another study, the following compounds were isolated; compounds 36, 38, 39, 40, 46 and 48 (Table 1) from methanolic extracts of the dry outer scales of red onion [28]. The structures were established mainly by extensive use of 2D NMR spectroscopy and electrospray LC–MS.

Moreover, compounds 24, 27, 30, and 35 (Table 1) were detected in red onions using HPLC-analysis, and spectral measurements were made over the wavelength range 210–600 nm in steps of 2 nm. Two pelargonidin derivatives, compounds 34, and 41 (Table 1) were also reported in traces in three red onion cultivars, top onion (*A. cepa* var. Vivi-parum), *A. altaicum* and Chive (*A. schoenoprasum*) [29]. Where, the brown skin of red onion cultivars, cvs Recas and Figueres, from commercial production in Spain, showed the presence of compounds 55, 56, 57, 60, 72, and 74 (Table 1) by HPLC analysis. Quercetin 4′-glucoside was the main flavonol in whole onion, the top–bottom and brown skin, where quercetin 3,4′-diglucoside was the main in inner and outer scales [30].

In another study, the authors investigated the stability of the detected flavonols in onion wastes, and documented that the glycosides undergo hydrolysis firstly, while β-glycosidase, peroxidase and oxidative cleavage were responsible for quercetin degradation. Where the release of quercetin from its glycosides by hydrolysis progresses faster than quercetin decomposition [31].

Pearl, Red, Yellow, and White varieties of onions purchased from a local market in Canada were investigated using HPLC also and the data revealed the presence of compounds 53, 55, and 66 (Table 1) as the main polyphenolics in all tested extracts [32]. HPLC analysis was performed to quantify the levels of phenolic acids and flavonoids in Yellow onion peel (Gyeongsangnam-do, Korea) alcoholic extract, revealing morin, vanillic acid (compound 12), epicatechin, and *p*-coumaric acid (compound 9) as the richest antioxidant compounds present in onion peel extract [33]. They were in concentration of 583.2 ± 9.4, 245.0 ± 3.5, 275.0 ± 3.3, and 158.7 ± 5.7 µg/g of onion peel dry weight basis.

Phenolics were also detected in onion skin powder of the Red variety purchased from an Egyptian local market, using HPLC, among which coumarin, pyrogallol, compounds 1, 2, 4, 6, 7, 8, 9, 10, 13, 15, 17, and 19, 7-hydroxyflavon, naringin, compound 84, catechol, compound 85, compound 54, compound 65, compound 61, epicatechin, caffein, compound 77, hesperetin, compound 55, and compound 66 were detected as major components [34]. Furthermore, onion solid wastes, purchased from a local grocery store (Myrina, Lemnos), were investigated for their polyphenolics using LC–DAD–MS analysis, revealing 13 compounds; 2-(3,4-dihydroxybenzoyl)-2,4,6-trihydroxybenzofuran-3(2 H)-one, compounds 7, 55, 56, 57, 23, 59, 25, 73, quercetin 4`-*O*-glucoside/quercetin dehydrate adduct, quercetin 4'-O-glucoside/quercetin adduct,

Table 1 Phytoconstituents reported in onion and potato peels

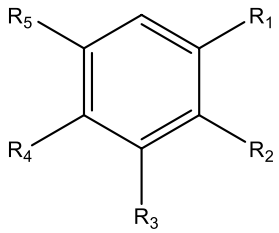
No	Compound	Structure					References
	Phenolic acids						
1.	Benzoic acid	R1 = COOH	R2 = H	R3 = H	R4 = H	R5 = H	Onion [34, 37]
2.	Cinnamic acid	R1 = $CHCH_2COOH$	R2 = H	R3 = H	R4 = H	R5 = H	Onion [34]
3.	Hydroxycinnamic acid	R1 = CHCHOHCOOH	R2 = H	R3 = H	R4 = H	R5 = H	Potato [62, 84]
4.	Gentisic acid	R1 = COOH	R2 = OH	R3 = H	R4 = H	R5 = OH	Potato [73]
5.	*p*-hydroxy benzoic acid	R1 = COOH	R2 = H	R3 = H	R4 = OH	R5 = H	Onion [34, 38]
							Potato [52, 62, 65, 83, 84]
6.	Salicylic acid	R1 = COOH	R2 = OH	R3 = H	R4 = H	R5 = H	Potato [62, 76]
7.	Caffeic acid	R1 = $CHCH_2COOH$	R2 = H	R3 = H	R4 = OH	R5 = OH	Onion [34]
							Potato [49, 52, 53, 58, 61, 62, 64, 65, 67, 73, 75–77, 79, 82–84]
8.	Protocatechuic acid	R1 = COOH	R2 = H	R3 = H	R4 = OH	R5 = OH	Onion [26, 31, 34, 39, 40, 46]
							Potato [49, 62, 65, 83]
9.	*p*-Coumaric acid	R1 = $CHCH_2COOH$	R2 = H	R3 = H	R4 = OH	R5 = H	Onion [33, 68]
							Potato [58, 65, 71, 83]
10.	Sinapic acid	R1 = $CHCH_2COOH$	R2 = H	R3 = OCH_3	R4 = OH	R5 = OCH_3	Potato [73]
11.	Gallic acid	R1 = COOH	R2 = H	R3 = OH	R4 = OH	R5 = OH	Onion [34]
							Potato [49, 62, 65, 83]
12.	Vanillic acid	R1 = COOH	R2 = H	R3 = H	R4 = OH	R5 = OCH_3	Potato [37, 62, 83]
13.	Ferulic acid	R1 = $CHCH_2COOH$	R2 = H	R3 = H	R4 = OH	R5 = OCH_3	Onion [34, 37, 38]
							Potato [58, 61, 62, 65, 75]

Table 1 (continued)

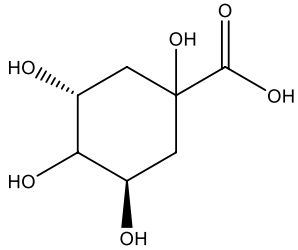
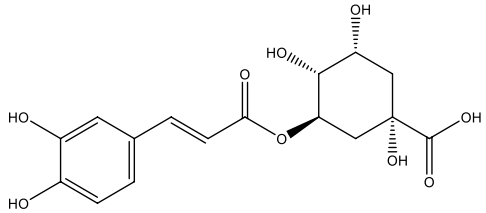
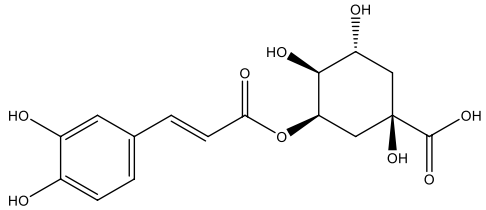
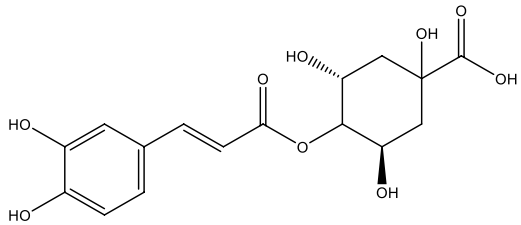
No	Compound	Structure	References
14.	Quinic acid		Potato [67]
15.	Chlorogenic acid		Onion [34] Potato [62, 77, 85]
16.	Neochlorogenic		Potato [77, 85]
17.	Cryptochlorogenic acid		Potato [77, 85]

Table 1 (continued)

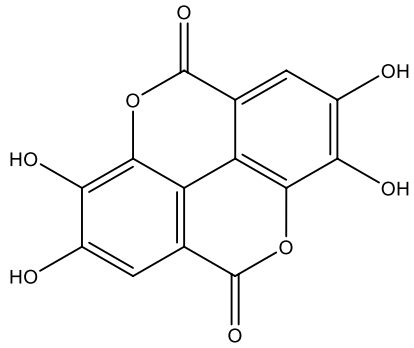
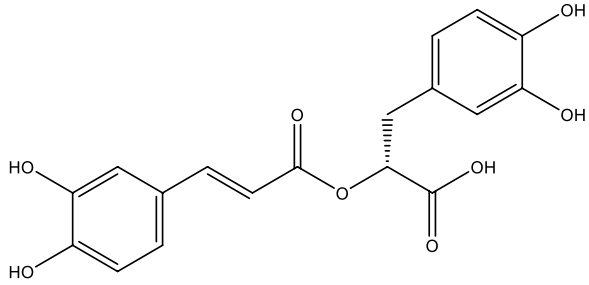
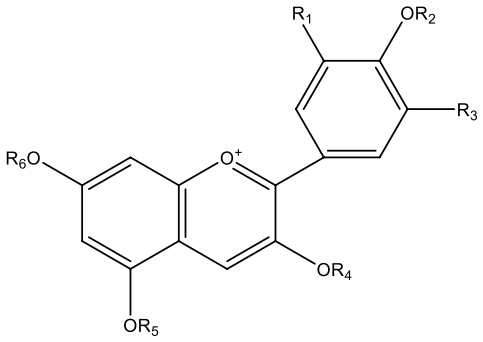
No	Compound	Structure	References
18.	Ellagic acid		Onion [34, 39]
19.	Rosmarinic acid		Onion [34]
	Anthocyanins		

Table 1 (continued)

No	Compound	Structure						References
20.	Pelargonidin	R1 = H	R2 = H	R3 = H	R4 = H	R5 = H	R6 = H	Potato [74, 79, 80]
21.	Pelargonidin 3-glucoside	R1 = H	R2 = H	R3 = H	R4 = Glucose	R5 = H	R6 = H	Potato [57, 64]
22.	Pelargonidin 3-rutinoside	R1 = H	R2 = H	R3 = H	R4 = Rutinose	R5 = H	R6 = H	Potato [57, 64]
23.	Cyanidin	R1 = OH	R2 = H	R3 = H	R4 = H	R5 = H	R6 = H	Potato [74, 80]
24.	Cyanidin 3-glucoside	R1 = OH	R2 = H	R3 = H	R4 = Glucose	R5 = H	R6 = H	Onion [27, 29, 46, 116]
25.	Cyanidin 3-laminariobioside	R1 = OH	R2 = H	R3 = H	R4 = laminariobioside	R5 = H	R6 = H	Onion [25, 27, 42]
26.	Cyanidin 3-(3″-malonylglucoside)	R1 = OH	R2 = H	R3 = H	R4 = 3``malonyl glucoside	R5 = H	R6 = H	Onion [25, 27, 29, 116]
27.	Cyanidin 3-(6″-malonylglucoside)	R1 = OH	R2 = H	R3 = H	R4 = 6``malonyl glucoside	R5 = H	R6 = H	Onion [25, 27, 29, 43, 116]
28.	Cyanidin 3-(3″-glucosyl-6″-malonylglucoside)	R1 = OH	R2 = H	R3 = H	R4 = 6``malonyl laminariobioside	R5 = H	R6 = H	Onion [25, 27–29, 35, 41, 46, 116]
29.	cyanidin 3-(6″-malonyllaminaribiosid)	R1 = OH	R2 = H	R3 = H	R4 = 6``malonyl laminaribioside	R5 = H	R6 = H	Onion [25, 27, 29, 43, 116]
30.	Cyanidin 3-(3″,6″-dimalonylglucoside)	R1 = OH	R2 = H	R3 = H	R4 = 3``, 6`` di malonyl glucoside	R5 = H	R6 = H	Onion [25, 27–29, 35, 41, 46, 116]
31.	Cyanidin 3-(dimalonyl)laminariobioside	R1 = OH	R2 = H	R3 = H	R4 = 3``, 6`` di malonyl laminariobioside	R5 = H	R6 = H	Onion [25, 27–29, 35, 41, 46, 116]
32.	Cyanidin 3-(3″-acetylglucoside)	R1 = OH	R2 = H	R3 = H	R4 = 3``acetoyl glucoside	R5 = H	R6 = H	Onion [25, 27–29, 35, 41, 46, 116]
33.	Cyanidin 3-(malonyl)(acetyl)glucoside	R1 = OH	R2 = H	R3 = H	R4 = malony-acetoyl glucoside	R5 = H	R6 = H	Onion [25, 27–29, 35, 41, 46, 116]
34.	Cyanidin 3,5-diglucoside	R1 = OH	R2 = H	R3 = H	R4 = Glucose	R5 = Glucose	R6 = H	Onion [25, 27–29, 35, 41, 46, 116]
35.	Cyanidin 3-(6′-malonyl-3′-glucosylglucoside)	R1 = OH	R2 = H	R3 = H	R4 = 6′-malonyl-3′-glucosylglucoside	R5 = H	R6 = H	Onion [25, 27–29, 35, 41, 46, 116]
36.	Cyanidin 4′-glucoside	R1 = OH	R2 = Glucose	R3 = H	R4 = H	R5 = H	R6 = H	Onion [25, 27–29, 35, 41, 43, 46, 116]
37.	Cyanidin 3,4′-diglucoside	R1 = OH	R2 = Glucose	R3 = H	R4 = Glucose	R5 = H	R6 = H	Onion [25, 27–29, 35, 41, 46, 116]
38.	Cyanidin 3-(3″-glucosyl-6″-malonylglucoside)-4′-glucoside	R1 = OH	R2 = Glucose	R3 = H	R4 = 6``malonyl laminariobioside	R5 = H	R6 = H	Onion [25, 27–29, 35, 41, 46, 116]
39.	Cyanidin 7-(3″-glucosyl-6″-malonylglucoside)-4′-glucoside	R1 = OH	R2 = Glucose	R3 = H	R4 = H	R5 = H	R6 = 6`` malonyl laminariobioside	Onion [25, 27–29, 35, 41, 46, 116]

Table 1 (continued)

No	Compound	Structure						References
40.	Malvidin	R1 = OCH_3	R2 = H	R3 = OCH_3	R4 = H	R5 = H	R6 = H	Onion [42] Potato [74, 79, 80]
41.	Peonidin	R1 = OCH_3	R2 = H	R3 = H	R4 = H	R5 = H	R6 = H	Potato [74, 80]
42.	Peonidin 3-glucoside	R1 = OCH_3	R2 = H	R3 = H	R4 = Glucose	R5 = H	R6 = H	Onion [25, 27–29, 29, 41, 42] Potato [57, 64]
43.	Peonidin 3-rutinoside	R1 = OCH_3	R2 = H	R3 = H	R4 = Rutinose	R5 = H	R6 = H	Onion [25, 27–29, 41, 42]
44.	Peonidin-3-(p-coumaroyl-rutinoside)-5-glucoside	R1 = OCH_3	R2 = H	R3 = H	R4 = *p*-coumaroyl-rutinosid-glucoside	R5 = H	R6 = H	Potato [57, 64]
45.	Peonidin 3-(6″-malonylglucoside)	R1 = OCH_3	R2 = H	R3 = H	R4 = 6``malonyl glucoside	R5 = H	R6 = H	Onion [25, 27–29, 41, 42]
46.	Peonidin 3,5-diglucoside	R1 = OCH_3	R2 = H	R3 = H	R4 = Glucose	R5 = Glucose	R6 = H	Potato [57, 64]
47.	Peonidin 3-(6″-malonylglucoside)-5-glucoside	R1 = OCH_3	R2 = H	R3 = H	R4 = 6``malonyl glucoside	R5 = Glucose	R6 = H	Onion [25, 27–29, 41, 42]
48.	Delphinidin	R1 = OH	R2 = H	R3 = OH	R4 = H	R5 = H	R6 = H	Potato [74, 80]
49.	Delphinidin 3-glucoside	R1 = OH	R2 = H	R3 = OH	R4 = Glucose	R5 = H	R6 = H	Onion [25, 42]
50.	Delphinidin 3-glucosylglucoside	R1 = OH	R2 = H	R3 = OH	R4 = 6``malonyl laminariobioside	R5 = H	R6 = H	Onion [25]
51.	Petunidin	R1 = OCH_3	R2 = H	R3 = OH	R4 = H	R5 = H	R6 = H	Potato [74, 80]
52.	Petunidin glucoside	R1 = OCH_3	R2 = H	R3 = OH	R4 = Glucose	R5 = H	R6 = H	Onion [42]
53.	Petunidin (glucosylglucoside)	R1 = OCH_3	R2 = H	R3 = OH	R4 = di glucoside	R5 = H	R6 = H	Onion [25]
54.	Petunidin-3-(*p*-coumaroyl)-rutinoside-5-glucoside	R1 = OCH_3	R2 = H	R3 = OH	R4 = *p*-coumaroyl-rutinosid-glucoside	R5 = H	R6 = H	Potato [64]

Flavonoids

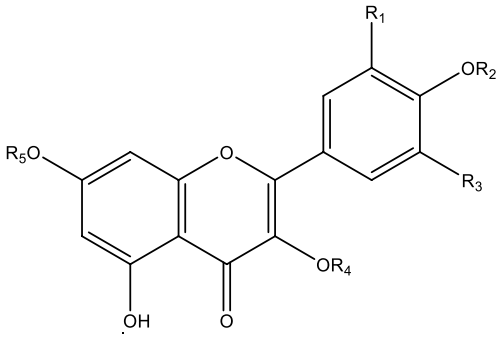


Table 1 (continued)

No	Compound	Structure					References
55.	Apigenin	R1 = H	R2 = H	R3 = H	R4 = H	R5 = H	Onion [34]
							Potato [73]
56.	Quercetin	R1 = OH	R2 = H	R3 = H	R4 = H	R5 = H	Onion [26, 30, 31, 33–37, 39–46, 68]
							Potato [73, 75, 76]
57.	Quercetin 4′-glucoside	R1 = OH	R2 = Glucose	R3 = H	R4 = H	R5 = H	Onion [25, 30, 31, 40, 44, 46]
58.	Quercetin 3,4′-diglucoside	R1 = OH	R2 = Glucose	R3 = H	R4 = Glucose	R5 = H	Onion [25, 30, 31, 40, 44, 46]
59.	Quercetin 7-glucoside	R1 = OH	R2 = H	R3 = H	R4 = H	R5 = Glucose	Onion [25]
60.	Quercetin 7,4′-diglucoside	R1 = OH	R2 = Glucose	R3 = H	R4 = H	R5 = Glucose	Onion [35, 37, 39, 40]
61.	Quercetin 3-glucoside	R1 = OH	R2 = H	R3 = H	R4 = Glucose	R5 = H	Onion [25, 30, 39, 44]
62.	Quercetin 3′-glucoside	R1 = O Glucose	R2 = H	R3 = H	R4 = H	R5 = H	Onion [25]
63.	Quercetin 3,7-diglucoside	R1 = OH	R2 = H	R3 = H	R4 = Glucose	R5 = Glucose	Onion [25]
64.	Quercetin 3,7,4′-triglucoside	R1 = OH	R2 = Glucose	R3 = H	R4 = Glucose	R5 = Glucose	Onion [25, 37]
65.	Quercetin 3-rhamnoside	R1 = OH	R2 = H	R3 = H	R4 = Rhamnose	R5 = H	Onion [25]
66.	Quercetin 3-rutinoside	R1 = OH	R2 = H	R3 = H	R4 = Rutinose	R5 = H	Onion [25, 34]
							Potato [73, 75]
67.	Kaempferol	R1 = H	R2 = H	R3 = H	R4 = H	R5 = H	Onion [33, 34, 37, 40, 42, 46, 68]
68.	Kaempferol 4′-glucoside	R1 = H	R2 = Glucose	R3 = H	R4 = H	R5 = H	Onion [25, 37]
69.	Kaempferol 3-glucoside	R1 = H	R2 = H	R3 = H	R4 = Glucose	R5 = H	Onion [25]
70.	Kaempferol 7,4′-diglucoside	R1 = H	R2 = Glucose	R3 = H	R4 = H	R5 = Glucose	Onion [25]
71.	Kaempferol 3,4′-diglucoside	R1 = H	R2 = Glucose	R3 = H	R4 = Glucose	R5 = H	Onion [25]
72.	Kaempferol 3- rutinoside	R1 = H	R2 = H	R3 = H	R4 = Rutinose	R5 = H	Onion [25]
							Potato [55, 57]
73.	Isorhamnetin 4′-glucoside	R1 = OCH_3	R2 = Glucose	R3 = H	R4 = H	R5 = H	Onion [30, 35, 36, 38–40, 46, 117, 118]
74.	Isorhamnetin 3-glucoside	R1 = OCH_3	R2 = H	R3 = H	R4 = Glucose	R5 = H	Onion [30, 35–40, 46, 117, 118]

Table 1 (continued)

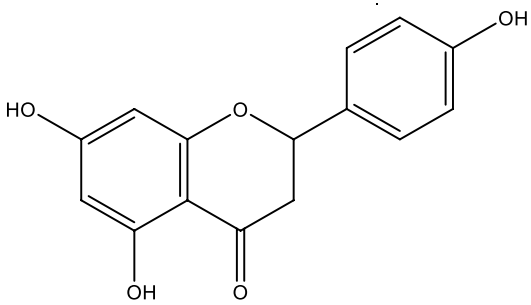
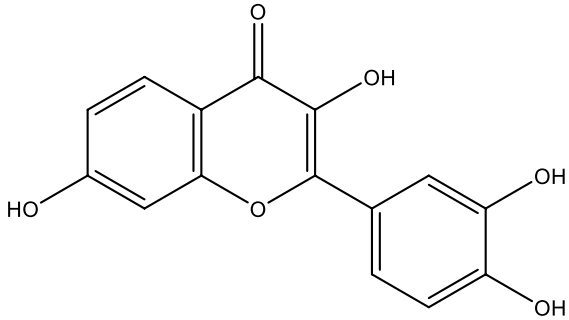
No	Compound	Structure					References
75.	Isorhamnetin 3,4′-diglucoside	R1 = OCH_3	R2 = Glucose	R3 = H	R4 = Glucose	R5 = H	Onion [30, 35, 36, 38–40, 46, 117, 118]
76.	Isorhamnetin	R1 = OCH_3	R2 = H	R3 = H	R4 = H	R5 = H	Onion [39, 117]
77.	Myricetin	R1 = OH	R2 = H	R3 = OH	R4 = H	R5 = H	Potato [73]
78.	Naringenin						Onion [34] Potato [55, 57, 76]
79.	Fisetin						Potato [73]

Table 1 (continued)

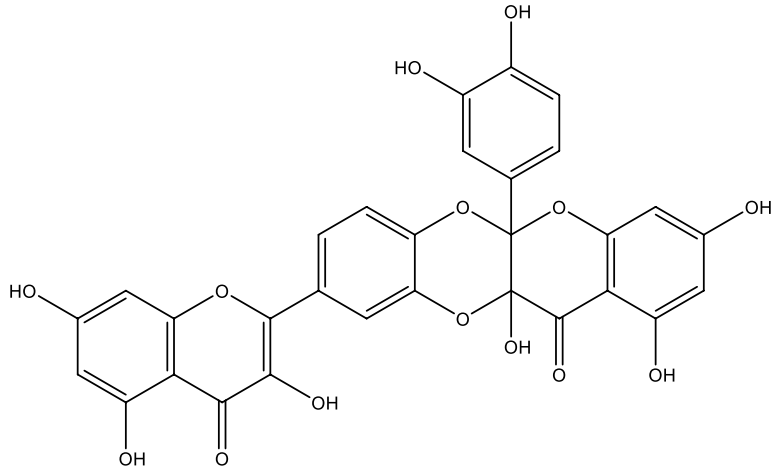
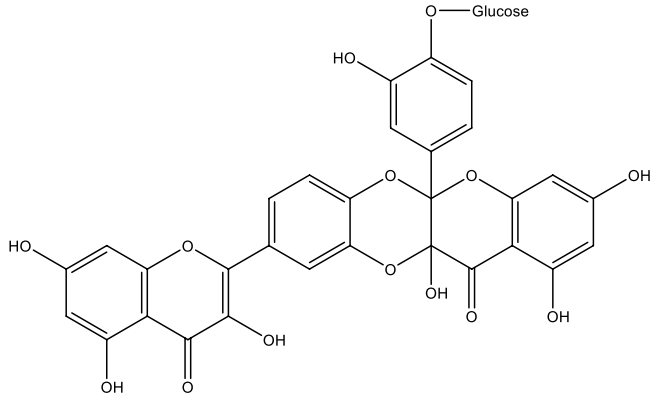
No	Compound	Structure	References
80.	Quercetin dimer		Onion [26, 40, 46]
81.	4′-Glucoside of quercetin dimer		Onion [45, 46, 50]

Table 1 (continued)

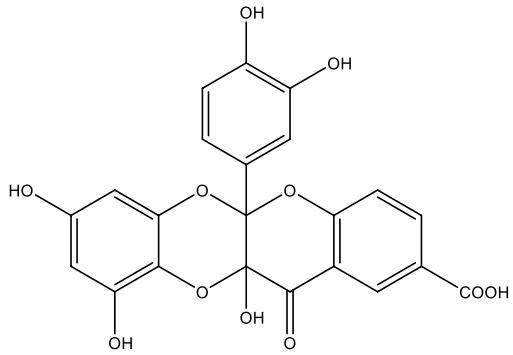
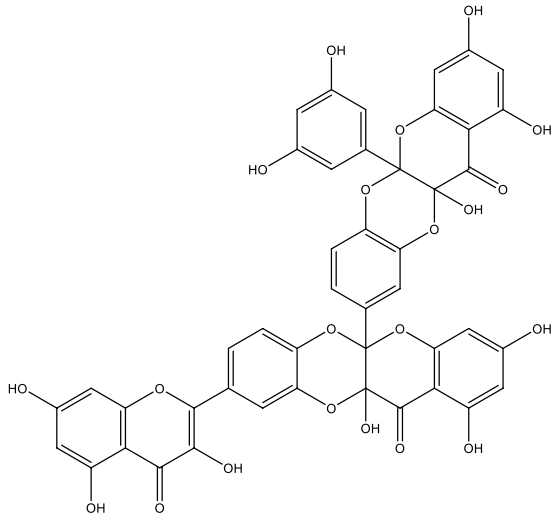
No	Compound	Structure	References
82.	condensation products of quercetin and protocatechuic acid		Onion [25]
83.	Quercetin trimer		Onion [26, 40, 46]

Table 1 (continued)

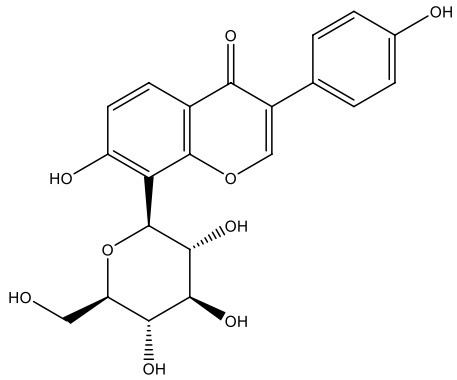
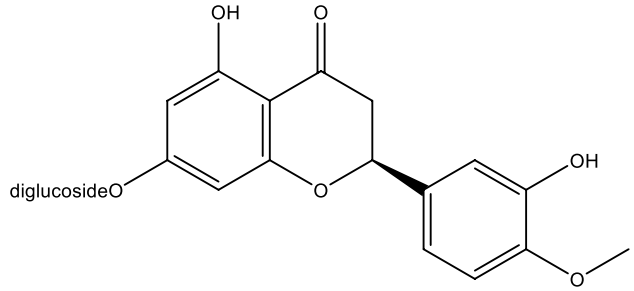
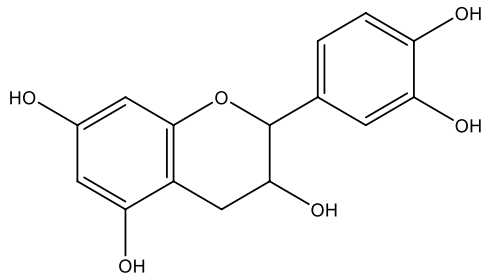
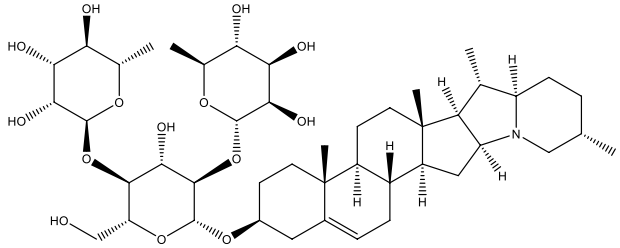
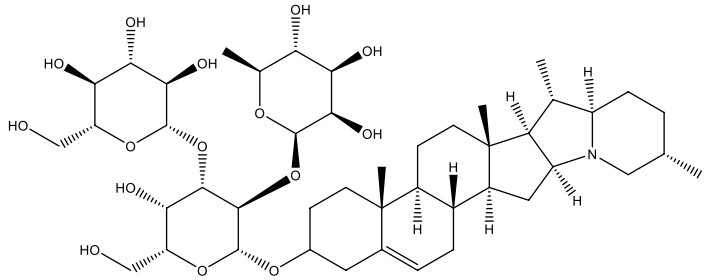
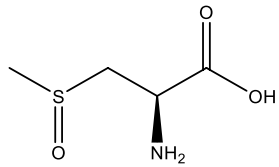
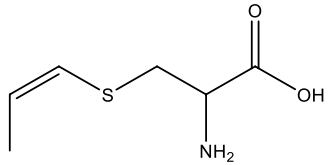
No	Compound	Structure	References
84.	Puerarin		Potato [73]
85.	Hesperidin		Onion [34]
86.	Catechin		Potato [73] Onion [34] Potato [55, 57, 76, 79, 84]

Table 1 (continued)

No	Compound	Structure	References
	Glycoalkaloids		
87.	Chaconine		Potato [11, 67, 69, 87, 88]
88.	Solanine		Potato [11, 67, 69, 87, 88]
	Organosulfur compounds		
89.	(+)-S-methyl-L-cysteine sulphoxide		Onion [13, 19, 20, 23, 68, 70, 71]
90.	trans-(+)-S-1-propenyl-L-cysteine sulphoxide		Onion [13, 19, 20, 23, 68, 70, 71]

quercetin dehydrodimer, and protocatechuic acid derivative [35].

The flavonol glycosides from onion solid waste, collected from the Nong Hyeop onion processing institute (Muan, Republic of Korea), were quantified using HPLC and the amount of quercetin-4`-*O*-monoglucoside was 254.85 mg/100 g dry weight, quercetin-3, 4`-*O*-diglucoside was 27 162.34 mg/100 g dry weight, quercetin was 60.44 mg/100 g dry weight, isorhamnetin-3-glucoside was 23.92 mg/100 g dry weight [36]. Also, onion peel and skin extracts were investigated using the HPLC–MS analysis, where phenolics and flavonoids were identified in both samples and summarized in Table 1 [37]. Additionally, quercetin-3,4'-*O*-diglucoside, quercetin-4'-*O*-monoglucoside, and quercetin were isolated from the tested wastes obtained from processed Yellow onion bulbs from Mokpo Experimental Station, National Institute of Crop Science, Muan (Republic of Korea) using HPLC/DAD and a Zorbax Eclipse XDB C18 column identified and identified using several spectroscopic methods [38].

The aqueous extract of dry onion skin waste from the Dorata di Parma cultivar was analyzed using HPLC–UV/DAD analysis of the onion water extract at 254 nm and the data showed the presence of phenolic acids with flavonols and were shown in Table 1 [39]. Moreover, the outer dry layers of onion cultivar (Ramata di Montoro) extracts obtained by ultrasound assisted and supercritical fluid extractions by UHPLC-UV-HRMS/MS analysis and led to identification of 15 compounds namely; 2-(3,4-dihydroxybenzoyl) – 2,4,6-trihydroxy-3(2H)-benzofuranone, quercetin, protocatecoyl quercetin, and other compounds were shown in Table 1 [40].

Red onions were reported to contain anthocyanins as compounds 22–28 (Table 1) and characterized using different spectral methods [41]. Furthermore, the peel waste extracts of triploid onion and diploid onion varieties were analyzed using HPLC and flavonols with anthocyanins were the significant metabolites identified. It was worth noting that their amounts were higher than present in onion bulb extracts. Five anthocyanins were present in the Red and Yellow varieties of *A. cepa*. Malvidin-3-*O*-glucoside, peonidin 3-*O*-glucoside, delphinidin 3-*O*-glucoside, cyanidin 3-*O*-glucoside, and petunidin 3-O-glucoside were the identified anthocyanins in both samples with their acetate form [42]. Peonidin-3-*O*-glucoside acetate and petunidin-3-*O*-glucoside acetate were in the Red variety of *A. cepa*, while peonidin and petunidin-3-*O*-glucoside were in the yellow variety. Also, eight anthocyanins were detected in the Red onion skins extract by HPLC/DAD, Japanese cultivar Kurenai showed the presence of several anthocyanins and were shown in Table 1 [43].

Additionally, red onion solid waste were investigated, where the major compounds were drawn in Table 1 [44]. In another study, the authors reported that onion peel had a concentrated amount of quercetin than the edible fleshy part [45]. Onion peel of Rossa di Tropea and Ramata di Montoro onion varieties from Italy were investigated also using UHPLC-HRMS analysis and a total of 22 phenolics and were summarized in Table 1 [46]. In another study, Red, Yellow and White onion varieties, and red shallots were investigated and also the authors proved that the waste fractions were more abundant in quercetin and showed higher antioxidant capacities, compared to their edible parts [47].

Potato Peels

Potatoes have higher content of phenolics than the other widespread fruits and vegetables. Phenolics reported in potatoes are phenolic acids and flavonoids (flavonols, flavanols, and anthocyanins) [48]. Phenolic compounds in potato peels are up to 10 times more than in potato flesh [21]. Singh and coauthors reported that the Purple- or Red-peel cultivars have 3 to 4 times more phenolics as compared to the White-peel cultivars, and these could be due to anthocyanins detected [21].

Phenolics in potato peels are different according to the genotype (variety of the potato cultivars), peel color, and geographical location. For example, the Yukon Gold variety was reported to have a total phenolics of 23.8 mg/100 g, while the Russet Norkotah variety had 52.7 mg/100 g dry matter [49]. Also, purple or pigmented peels have 3 to 4 times more phenolic acids as compared to the white ones [20]. Most of the phenolics (90%) in potatoes were reported in several works to be chlorogenic acid [50, 51]. Where, tubers of six varieties of potato, Kennebec, Norchip, Russet Burbank (brown-skinned), Red Norland, Red Pontiac, and Viking (red-skinned) were investigated. The peel extracts of red and brown varieties quantified using HPLC the presence of protocatechuic (216.0–256.0 mg/100 g dry matter), *p*-coumaric (41.8–45.6 /100 g dry matter), caffeic (278.0–296.0 mg/100 g dry matter), chlorogenic (753.0–821.3 mg/100 g dry matter), *p*-hydroxybenzoic (82.0–87.0 mg/100 g dry matter), ferulic (174.0–192.0 mg/100 g dry matter), gallic (58.6–63.0 mg/100 g dry matter), and vanillic (43.0–48.0 mg/100 g dry matter) acids. Where, Red skins had more total phenolics than the brown ones [52].

Phenolic compounds were extracted using methanol, where chlorogenic, gallic, protocatechuic, and caffeic acids were detected as the major compounds by HPLC analysis of potato peels [53]. The total phenolics was quantified by HPLC as 48 mg/100 g dry matter. The authors reported that chlorogenic acid was degraded to caffeic acid. Two studies investigated the peels of colored potato varieties and reported using analytical HPLC revealed the presence of catechin, epicatechin, eriodicytol, kaempferol 3-*O*-rutinoside, naringenin as the major components [54, 55]. The total

phenolics of 92 extracts from edible and nonedible medicinal plants were estimated using the Folin-Ciocalteu assay and calculated as gallic acid equivalents. The peels of potatoes are potential source of phenolics and could be used as a strong antioxidant agent. Where, the total phenolics of Rosamunda potato peels were 4.3 mg of gallic acid equivalents/g of dry potato peel and 2.5 mg of gallic acid equivalents/g of dry potato peel of Matilda cultivar [56].

Moreover, The anthocyanins in Skin of Desiree (Pink skin/ White flesh) cultivar from New Zealand were investigated as peonidin-3-(*p*-coumaroyl-rutinoside)-5-glucoside and pelargonidin-3-(*p*-coumaroyl-rutinoside)-5-glucoside as majors anthocyanin detected by HPLC, with pelargonidin-3-rutinoside, and pelargonidin-glycoside as minors [57]. Furthermore, potato peels (Kufri Chandromukhi) exhibited gallic acid, caffeic acid, chlorogenic acid and protocatechuic acid as the major phenolics present. The extract showed high phenolic content (70.82 mg of catechin equivalent/100 g dry matter), of that chlorogenic acid (27.56 mg/100 g dry matter) was the major phenolic acid [49]. Phenolics present in the skin were more than flesh tubers of potato. Although, the skin was the richest in the phenolics, which is discarded during the consumption of potato as analyzed by spectrophotometry and HPLC [56].

Additionally, quantitative estimation of free and bound forms of phenolic compounds in peels were 1.26 and 3.66 mg ferulic acid equivalents/g of dry weight, respectively [58].

Jansen and Flamme investigated 27 potato cultivars from Germany, and reported that the anthocyanins in the skin of the colored potato varieties was 2.5-fold higher than flesh using spectrophotometric analysis [59]. The results showed also that the colored skin variety had higher anthocyanins contents in their skin than other cultivars. Caffeic (38.6 ± 0.1 mg/ 100 g dry matter), and gallic (26.5 ± 0.2 mg/ 100 g dry matter), then protocatechuic (18.8 ± 0.1 µg/100 g dry matter) followed by chlorogenic acids (16.0 ± 0.2 mg/ 100 g dry matter) were the major phenolics identified in the peels of potato by HPLC [60]. The total polyphenolics in potato peel extract was 3.93 mg/g powder as quantified by HPLC. The good quantity of these phenolics supports the fact that those peels showed a potent antioxidant activity. The total phenolic content in six varieties of potatoes (Siècle, Vivaldi, Yukon Gold, Purple Majesty, FL 1533 and Dakota Pearl), obtained from Canada, including Purple and Yellow potatoes, ranged from 1.51 to 3.32 mg gallic acid equivalent/g dry potato peel powder, the highest were found in the peel extracts from red-color potato varieties, Siècle and Purple Majesty, may be due to the anthocyanins detected in these varieties of potatoes [61]. Chlorogenic acid was present as the major one (62.4–85.6 mg/ 100 g dry matter) then caffeic acid in all tested extracts (14.4–37.6 mg/100 g dry matter). Others as *p*-coumaric and ferulic acids were present as minors. Phenolics present in potato peels as quantified by UPLC–ESI-MS were summarized in Table 1 [62]. However, potato peel extracts obtained from a local potato chip manufacturer (Egypt) had 1.08 to 2.91 mg gallic acid equivalent/g dry matter as total phenolic content, where total flavonoids were 0.51–0.96 mg quercitin equivalent/g dry matter [63].

Mori and coworkers investigated a red potato cultivar Kintoki-Imo and other colored cultivars grown in Hokkaido, Japan, for their anthocyanins using DAD-HPLC and ESI-TOF/MS. The results revealed that pelargonidin 3-rutinoside, 5-glucoside (7%), peonidin 3-rutinoside 5-glucoside (6%), petunidin 3-*p*-coumaroylrutinoside, 5-glucoside (11%), peonidin 3-caffeoylrutinoside 5-glucoside (8%), pelargonidin 3-*p*-coumaroylrutinoside 5-glucoside (23%), peonidin 3-*p*-coumaroylrutinoside 5-glucoside (12%), pelargonidin 3-feruloylrutinoside, 5-glucoside (22%), and peonidin feruloylrutinoside, 5-glucoside (12%). The content of anthocyanins was 2–816 mg/100 g flesh tubers [64]. Another study investigated the extraction of eight phenolics (gallic, chlorogenic, caffeic, protocatechuic, syringic, *p*-hydroxyl benzoic, ferulic, and coumaric acids) from potato peel varieties. Where, the bound phenolics were the most abundant in Innovator and Russet varieties. Free and esterified compounds were the most abundant in Purple and Yellow varieties [65]. Additionally, the content of phenolics of potato peel using five different solvents (methanol, water, acetone, ethanol, and hexane) and two methods (solvent and ultrasound-assisted) were estimated spectrometrically using the Folin-Ciocalteu method. Where, the total phenolics in the different of potato peel extracts were as 155.6 to 593.3 µg gallic acid equivalent/g dry matter [66]. These results also supported the potent antioxidant of the extracts. Furthermore, potato peels (Wulanchabumeng, Inner Mongolia, China), were investigated and quinic, chlorogenic, caffeic acids, and methyl caffeate were isolated where the potato peels had a higher amount of phenolics than the flesh. Quinic acid was present, as quantified by UPLC–ESIMS, in the range of 0.63–0.71 mg/g dry weight [67].

Albishi and co-workers investigated the peels of potatoes of four common varieties (Yellow, Purple, Innovator, and Russet), obtained from local markets in Canada, where phenolic acids were the most abundant phenolics then anthocyanins analysed using ultrafast liquid chromatography [68]. Chlorogenic, caffeic, *p*-coumaric and ferulic acids were the predominant components in the peels. Peels of the Purple-fleshed cultivar showed the highest amount of free and esterified phenolics in all the four studied varieties, then Innovator potato peel, Russet potato peel, and Yellow potato peel. The phenolics were mainly present in the bound form in peels of the Innovator and Russet though the free and esterified phenolics were the main in the Purple and Yellow potatoes. The total anthocyanins, presented as mg cyanidin-3-*O*- glucoside equivalents, in peels of Purple, Russet,

Yellow and Innovator varieties were reported as 6.84, 0.40, 0.27 and 0.24 mg /100 g dry matter, respectively [68]. In the purple cultivar, anthocyanins were almost present in the peel and the outer cortices of tubers, where the content of anthocyanins in the peel 10.69 times more than in the flesh. Neochlorogenic, caffeic, chlorogenic acids were detected at levels of 0.48, 7.76, and 1.33 mg/100 g dry matter, respectively in peels of the Russet cultivar (Canada), where caffeic acid was the most abundant phenolic acid using an Agilent 1200 series HPLC [69]. The samples were studied using ultrafast liquid chromatography mass spectrometry technique. These compounds were responsible for their antioxidant and antibacterial activities.

The total phenolics were estimated using the Folin-Ciocalteu method and gallic acid as a standard, which was expressed as 3.2–10.3 mg gallic acid equivalent/100 g dry matter. Ferulic and chlorogenic acids were the two most abundant phenolic acids detected in the peels of Agria variety (Spain) ethanolic extract [23]. Folin–Ciocalteu method was used to estimate the quantity of phenolics in potato peel extracts. Where, total phenolics of 6.74 and 20.21 mg gallic acid equivalent/ g dry matter was stated in the tested extract using solid–liquid batch and pressurized liquid extractions, respectively [70].

Chlorogenic, neochlorogenic, cryptochlorogenic, coffeic, ferulic, and *p*-coumaric acids in one yellow-fleshed potato variety and four blue-fleshed potatoes varieties (Valfi, Blaue Elise, Bore Volley and Blue Congo), where coffeic acid was the major detected component [71].

Potatoes peels were fractionated using hexane, ethyl acetate followed by methanol. Where, the ethyl acetate fractions had the highest phenolics. Total phenolic contents was estimated using Folin-Ciocalteu method of 83.2 and 44.14 mg gallic acid equivalent/g dry matter, respectively were estimated in the ethyl acetate fractions of young and mature [72]. High content of phenolics in Red-coloured varieties (Siècle and Purple Majesty) of potato were reported as compared to the other varieties (Yukon Gold, Dakota pearl, Vivaldi, FL 1533). Total phenolic acid content in dry peels was 0.863 mg gallic acid equivalent/100 g. The total content of flavonoids in dry peels was 2.75 mg catechin equivalent/100 g dry matter. The flavonoids identified in the extract of dry potato peels were quercetin (0.42/100 g dry matter), myricetin (0.29/100 g dry matter), apigenin (0.19/100 g dry matter), catechin (0.09/100 g dry matter), puerarin (0.08/100 g dry matter), fisetin (0.05/100 g dry matter), hesperidin (0.03/100 g dry matter), naringin (0.02/100 g dry matter) and rutin (0.02/100 g dry matter), quantified using HPLC/DAD [73].

Yin et al. investigated the peel and flesh of ten colored potato varieties from China (Purple Cloud No. 1, Red Cloud No. 1, Yunnan Potato 303, Yunnan Potato 603, S03-2677, S03-2685, S03-2796, S05-603, S06-277 and S06-1693) [74]. The total anthocyanin content in peel was 15.34 times more than of its respective flesh using HPLC analysis. Additionally, the total phenolics were 7.28 times more than in peels as compared to their respective flesh. Types and contents of anthocyanidins in the peel were higher than in the respective flesh, but with the same dominant compounds. Six anthocyanins were detected: delphinidin, peonidin, petunidin, malvidin, cyanidin, and pelargonidin.

It was also reported that gallic, chlorogenic, caffeic, and ferulic acids with two flavonoids (rutin and quercetin) were the major phenolics detected by HPLC in potato peels of the Fianna variety, obtained from Yaqui valley, Sonora, México. Where, chlorogenic, caffeic, and gallic acids were the predominant compounds. The total flavonoids were 1.016–3.310 mg quercetin equivalent/g dry matter and the total phenolics were 4.160–14.031 mg gallic acid equivalent/g dry matter [75].

Akyol and coauthors reported that chlorogenic acid was the main phenolic component in potato peels and constitutes up to 90% of the total phenolics, in the form of 3 isomers, chlorogenic acid (5-*O*-caffeoylquinic acid), neochlorogenic acid (3-*O*-caffeoylquinic acid), and cryptochlorogenic acid (4-*O*-caffeoylquinic acid) [76]. Chlorogenic (50.31%), gallic (41.67%), protocatechuic (7.815%), and caffeic acids (0.21%) were reported as the major phenolic acids detected in several works. Where, ferulic acid, vanillic acid, and salicylic acids were present in traces. Also, they reported that the flavonoids detected in the potato skin are quercetin, naringenin, catechin, and epicatechin. In another study, the authors investigated the peels of six potato varieties from organic and non-organic commercial gold, Russet and Red potatoes, where they detected the presence of three phenolic acids as shown in Table 1. Chlorogenic acid was in the range of 1094–7810 µg/g dry matter in peels of six potato varieties. Total phenolics and flavonoids, determined by colorimetry methods, were in the range 11.0–34.4 and 7.8–29.7 mg/g dry matter, respectively [77].

Phenolic compounds of selected colored potato varieties were investigated by HPLC–DAD for their composition and concentration. Among the identified phenolics; 4-aminobenzoic acid, neochlorogenic acid, chlorogenic acid, *p*-hydroxybenzoic acid, cryptochlorogenic acid, fraxin, daphnetin, caffeic acid, vanillic acid, 2,4-dihydroxy-benzoic acid, quercetin 3,4-rutinoside, *p*-coumaric acid, coniferyl alcohol, vanillin, rutin, quercetin 3-glucoside, ferulic acid, scopoletin, sinapic acid, kaempferol 3-rutinoside, isorhamnetin 3-rutinoside, 1,5-dicaffeoylquinic acid, kaempferol 3-glucoside, quercetin 3-rhamnoside, isorhamnetin 3-glucoside, coniferyl aldehyde, dihydrokaempferol, phlorizin, luteolin, cinnamic acid, and kaempferol. Where, caffeic acid, coniferyl alcohol, coniferyl aldehyde, vanillin, vanillic acid, ferulic acid and *p*-coumaric acid were present in tuber peel and rarely or not detected in flesh [78]. Caffeic acid and

chlorogenic acid isomers, were present as the main while quercetin derivatives as well as cinnamic acid were present as minors in in all samples. Where, remaining metabolites showed different specificities. LC/UV/MS analysis was used in detection of anthocyanin and polyphenol profiles of 57 potatoes cultivars, where the red tuber tissue has mainly pelargonidin derivatives, where blue/purple tuber tissue has almost derivatives of malvidin and petunidin [78].

Moreover, Andean potato varieties were investigated, where the quantity of all phenolics were higher in peels than in flesh. Phenolic acids were the main class, followed by anthocyanins and flavan-3-ols. Chlorogenic acid, and caffeic acid were the major phenolic acids, where catechin and epicatechin were the major flavan-3-ols and delphinidin, cyanidin, petunidin, pelargonidin, peonidin and malvidin were the major anthocyanidins quantified by HPLC–DAD. Major anthocyanidins found in red fleshed/skinned tubers were pelargonidin, followed by peonidin, whereas purple potatoes contained petunidin followed by malvidin [79]**.** The Red and Purple colors of potatoes' peels are originated from anthocyanins. The most common anthocyanidins were shown in Table 1 [80].

Chlorogenic acid and its isomers were the major phenolics determined by HPLC-DAD-ESI-MS analysis in five potato varieties (Bintje, Challenger, Daisy, Innovator and Fontane) from Italy [81]. Elkahoui et al. investigated the content of the phenolic acids (chlorogenic and caffeic acids) of organic and non-organic potato peels of the Russet variety, and found that there was a wide range of these compounds in the tested samples: a nearly sixfold difference in the chlorogenic acid, where caffeic acid levels were more consistent between samples [82]. The highest contents in peels from the non-organic of the Russet variety. Additionally, Javed and coworkers reported the presence of several phenolic acids in the potato peel extract as caffeic acid (278.0–296.0 mg/100 g dry matter), protocatechuic acid (216.0–256.0 mg/100 g dry matter), gallic acid (58.6–63.0 mg/100 g dry matter), vanillic acid (43.0–48.0 mg/100 g dry matter), chlorogenic acid (753.0–821.3 mg/100 g dry matter), *p*-coumaric acid (41.8–45.6 mg/100 g dry matter), and *p*-hydroxybenzoic acid (82.0–87.0 mg/100 g dry matter) [83]. The most abundant phenolic acid reported in peels is chlorogenic acid (5-*O*-caffeoylquinic acid), in addition to other isomers (3,4-dicaffeoylquinic acid, 3,5-dicaffeoylquinic acid, and 4,5-dicaffeoylquinic acid). Chlorogenic acid was of about 2115 µg/g dry weight in peel, decreasing in the neighboring tissues (cortex) to 276 µg/g dry weight. Catechin, hydroxycinnamic and hydroxybenzoic acids are present only in trace, but caffeic acid is present in good quantity [84]. Potato peel extracts, obtained from "Roquette Frères" Company, Lestrem, France, were analyzed using HPLC for their phenolics profile, with the total phenolics that was assessed using spectrophotometric analysis. The greatest amount of phenolic acid was 5-caffeoylquinic acid isomers, mainly the 5-caffeoylquinic acid or chlorogenic acid (870 ± 39.7 mg/100 g dry matter) [85].

Red- and purple-skinned potato tubers of ten genotypes (Red-skinned: Rosemary, Red Emmalie, Red Cardinal; Purple-skinned: Purple, Violetta, Kefermarkter Blaue, Salad Blue, Blaue aus Finnland, UACH 0917 and Shetland Black) from five different countries of origin (Chile, Germany, Austria, United Kingdom, and Finland) were investigated. 4-*O*-Caffeoylquinic acid, caffeic acid, salvianolic acid, kaempferol-*O*-hexoside-deoxyhexoside-hexoside, kaempferol-*O*-deoxyhexoside-hexoside, bis(dihydrocaffeoyl) spermidine, and kaempferol-3-*O*-rutinoside were identified as non-anthocyanin phenolics from the studied peels. Caffeic and caffeoylquinic acid were detected as the majors in all the samples, also *O*-glycosylated flavonoid derivatives and polyamine derivatives were present [86].

Glycoalkaloids and Amides

Potatoes contain toxic glycoalkaloids, which protect the tuber from pathogens, and insects, but can cause diarrhea, nausea, abdominal cramping, or vomiting to consumers. Removing the sprouts and peeling of the skin before processing eliminates mostly the glycoalkaloids [11]. It was reported that that 95% of potato glycoalkaloids consist of α-solanine and α-chaconine (Table 1) [82, 87, 88]. This was consistent with another report which showed that total contents of α-solanine and α-chaconine were in range of 0.64 and 0.3526 mg/100 g dry matter in flesh, peels, and whole potatoes [62].

Samples for measurement of glycoalkaloids were taken from of all 31 coloured cultivars, the analyses were confined to the most common reported two types of glycoalkaloids (α-solanine and α-chaconine), where results revealed that the highest level was found in skin samples (1.72 mg/100 g dry weight), while in samples taken from whole tubers (0.44 mg/100 g dry weight) and flesh (0.23 mg/100 g dry weight), the glycoalkaloid content was significantly lower than skin samples [59]. The genotypes concerned in this test series differed significantly from the skin. The highest amount of glycoalkaloids was found in Violettfleischige (3.68 mg/100 g dry weight), while the Blaue Utwill had the lowest value (0.63 mg/100 g dry weight). It was also shown that α-chaconine, α-solanine and solanidine accounted for 1.70, 0.71 and 0.01 mg/100 g of potato peel dry weight, respectively [89]. In another study the authors isolated and characterized 2-hydroxy-3-phenyl-propionamide, and (*cis*-N-feruloyloctopamine) as amides, with the two major glycoalkaloids in potato from the peels [67].

The main glycoalkaloids detected in the selected Pakistani potato cultivars were α-solanine and α-chaconine. They were 3 to 10 times greater in the peel than in the flesh

[77, 90]. In another study, the authors investigated the levels of glycoalkaloids in potato peels which was as follow; α-chaconine (1.17 mg/100 g of potato peel dry weight), α-solanine (0.71 mg/100 g of potato peel dry weight), and solanidine (0.01 mg/100 g of potato peel dry weight) [69].

Further, Hossain et al. reported that the dried peels of Lady Claire showed the presence of α-solanine, α-chaconine, solanidine and demissidine at the levels of 597, 873, 374 and 75 µg/g dried potato peel, respectively using pressurized liquid extraction and in lower amounts in solid liquid extraction [91]. Additionally, Friedman and coworkers investigated the α-chaconine content ranged from 424 to 2830 mg/100 g dry matter and the content of α-solanine ranged from 215 to 750 mg/100 g dry matter in peels of six potatoes cultivars using HPLC analysis [77]. The peels derived from the organic-grown gold and Russet varieties had a higher glycoalkaloids contents estimated as 3580 and 1550 µg/g dry weight, respectively where to the non-organic samples had glycoalkaloids contents of 920 and 639 µg/g dry weight, respectively. Organic samples of the red one had lower content of glycoalkaloids (850 µg/g dry weight) in compared to the conventionally grown ones (1709 µg/g dry weight). Also, Elkahoui et al. investigated the content of the glycoalkaloids α-chaconine and α-solanine on of organic and non-organic potato peels of the Russet variety, and found that there was a wide range of these compounds in the tested samples: a 2 − threefold difference in the glycoalkaloid levels, where the contents in peels from the conventionally grown red variety were the highest (2180 µg/g dry weight) [82].

Organosulfur Compounds

The sulfur compounds in onion come from the non-volatile precursor sulphuric compounds namely aliin or *S*-alk(en)yl-$_L$-cystein sulfoxides (ACSOs). Many compounds were identified which are responsible for the aroma of onion namely metiin, propiin, and izoaliin. Izoaliin are the most dominant with about 80% of organosulfur compounds in onion, and responsible for onion aroma [92–94]. ACSOs are the precursors for flavoring and aroma of onion, where the enzyme namely alliinase with responsible for their cleavage. *Trans*-(+)-*S*-1-propenyl-$_L$-cysteine sulphoxide found as major constituent and has a lachrymatory effects, (+)-*S*-methyl-$_L$-cysteine sulphoxide and (+)-*S*-propyl-$_L$-cysteine sulphoxide (Table 1), detected as minors [95, 96].

Two cultivars, cvs Recas and Figueres, that are common in commercial production in Spain, were investigated for the total sulphur content using an elemental analyzer. The highest content was in the inner scales and the lowest was present in brown skin. Total ACSOs were 19% of total content in onion and of about 15–35% in onion wastes, was there higher in the inner scales and brown skin. Two ACSOc were identified as (+)-*S*-methyl-cysteine sulphoxide and *trans*-(+)-*S*-1-propenyl-$_L$-cysteine sulphoxide. The latter was the main flavor precursor in the whole bulb and onion wastes, of about 52–71% of total precursors. Alliinase cleaved ACSOs into 1-propenylsulfenic acid, ammonia, and pyruvate [30]. Additionally, Sharma et al. reported that the inner scales of onion were an important source of ACSOs. Also they detected low molecular weight sulfur compounds in onions as thiol compounds, where they were reports as very active components in several health problems [13].

Other Miscellaneous Phytonutrients

Six onion cultivars: five were traditional cultivars from Tenerife (Guayonje, San Juan de la Rambla, Carrizal Alto, Carrizal Bajo and Masca) and the other was a foreign cultivar (Texas Early Grano 502) were selected for screening. Phosphorus, potassium, calcium, sodium, selenium, magnesium, iron, copper, zinc, and manganese were determined. Onion wastes had higher contents of calcium, magnesium, iron, sodium, copper, and selenium than those found in other studies for onion bulbs. Whereas potassium, manganese and zinc contents were lower. Consumption of 100 g accounts for 5.6% of the recommended intake for phosphorus (for adults). Additionally, manganese, magnesium, and potassium intake for a serving of onions accounts for 2–5% of the recommended dietary allowances of these elements for adults. The Na/K ratios were very low (0.05–0.09), which is remarkable for cardiovascular diseases prevention or treatment [97]. Further, brown skin of onion had a high content of calcium, and top–bottom had high content of magnesium, iron, zinc and manganese. Proteins increased towards inner scales and growing apex. Magnesium, iron, zinc, and manganese was found in top–bottom in highest concentration, as this waste encompassed the plant roots, where the nutrient uptake happens, where the highest amounts of potassium and selenium were in the inner scales, but selenium was high similar to inner scales in brown skin. Similarly, calcium was found in brown skin in high amounts [30]. Brown skin had a high concentration of calcium, where top–bottom were reported to have high concentration of minerals.

Additionally, the proximate analysis of Yellow variant of onion bulbs from Nigeria and showed that protein (8.76 mg/100 g dry matter), ash (11.46 mg/100 g dry matter), carbohydrate (66.12 mg/100 g dry matter), fat (15.71 mg/100 g dry matter) and fiber (26.84 mg/100 g dry matter). Protein and carbohydrate were concentrated in top–bottom part, fats, and fibers in outer scale part while moisture content was in top–bottom part. The outer scale showed high level of calcium (3.05 mg/100 g dry matter) then the onion bulb (2.98 mg/100 g dry matter) and in the top–bottom part (2.08 mg/100 g dry matter). GC/MS of oil revealed that the outer scale with the following profile; linoleic acid (52.87%), where 12 fatty acids were totally

identified of about 21.42% was saturated and 76.79% was unsaturated; C12:0 (0.94%), C14:0 (1.28%), C16:0 (9.80%), C16:1 (2.84%), C18:0 (8.81%), C18:1 (17.57%), C18:2 (52.87%), C18:3 (2.88%), C20:0 (0.59%), C22:0 (1.23%), C22:1 (0.63%), C24:0 (0.54%) [98]. further, onion skins of a Red onion variety, from an Egyptian local market, were analyzed for its mineral contents revealing the presence of calcium (39.251 mg/ 100 g dry matter), potassium (4.365 mg/100 g dry matter), magnesium (1.495 mg/100 g dry matter), manganese (1.077 mg/100 g dry matter) with iron (0.818 mg/100 g dry matter); the high amounts of iron and zinc was in top–bottom waste as this organ contain the plant roots where the nutrient uptake happens [34].

Wastes showed a high mineral content, as most of it contains top–bottom and plant roots, where nutrient uptake happens. Distribution of them is related to the mobility of the minerals, the low mobility elements (iron, calcium and magnesium) were concentrated predominantly in the outer sections of the bulb. In contrast, high mobility elements showed no remarkable difference found. Magnesium, iron, zinc and manganese are found in top–bottom in high concentration, where the highest concentrations of potassium and selenium are found in inner scales. Likewise, the high amount of calcium was in the brown skin. They had many transition metals (e.g., manganese, iron, nickel, titanium, and chromium). These elements are classified as a food ingredient to enhance digestion and metabolic activity in our body. Chromium was detected only in the top–bottom waste, nickel was detected only in the outer scale, and the manganese content was high for top–bottom waste [13]. In the same previous study, the authors documented that onion showed both saturated and unsaturated fatty acids in its chemical profile. The saturated fatty acids were great in the onion bulb, where saturated fatty acids were main in the top–bottom waste. The unsaturated fatty acids were detected in higher amounts in the outer scales as 76.79% of the total content. The top and bottom had the highest percentage of oleic acid, but the outer scale had the lowest. Oleic acid (omega 9) is one of the important fatty acids in onion oil. Linoleic acid and linolenic acid were detected in the onion oil. The outer scale which was unused had 52.87% of linoleic acid (omega 6) and so it is an important dietary supplement [13]. In another study, onion wastes were found rich in crude fiber, protein, sugars, fats, and minerals. Calcium, potassium, magnesium, zinc, and manganese were found to satisfy the recommended dietary intake of adults. They showed a good percentage of unsaturated fatty acids as oleic and linoleic acids. Glucose was the most abundant sugar followed by fructose. This work highlighted the onion waste as a potential source for many food applications [99].

Peels were found to contain notable amounts of unsaturated fatty acids such as omega-6 and omega-3 fatty acids, which is rarely found in plants. Also, they are highly reported for their protein content, where the most common protein contained in potato skins is known as patatin [100]. Peels of potato (Egypt) contained 65.5 µg/100 g dry matter moisture, 84.6 µg/100 g dry matter crude fat, 138.5 µg/100 g dry matter crude protein, 84.8 µg/100 g dry matter ash, 129.8 µg/100 g dry matter crude fiber and 562.3 µg 100 g dry matter carbohydrate [63]. The peels of the studied varieties had similar fatty acid composition; myristoleate, palmitate, palmitoleate, stearate, oleate, linoleate, linolenate, and arachidate, with higher amounts of polyunsaturated fatty acids. Differences of their proportions were influenced by the color of the peels. The brown peels had myristoleic and arachidic acids, 2.3–4.2% and 7.0–7.4%, respectively, whereas these were detected only in trace quantities in the red ones. Where, the red peels contained higher amounts of oleic and linoleic acids and less of linolenic acid than the brown ones [52]. Chemical composition of potato peel extract from Greece was as follow total carbohydrates (68.7% of dry weight), soluble sugar (1% of dry weight), reducing sugar (0.6% of dry weight) and starch (52% of dry weight), protein (8% of dry weight), fats (2.6% of dry weight). So, potato peel waste had a high starch content [101]. Ascorbic acid or vitamin C in potato peels was detected (1.44 ± 0.5 mg/g dry weight) in the Russet Burbank Canadian cultivar [102].

An omega-6 fatty acid [9,10,11-trihydroxy-12(*Z*)-octadecenoic acid] and omega-3 fatty acid [9,10,11-trihydroxy-12(Z), 15(*Z*)-octadecadienoic acid] were isolated and characterized from the potato peels [67]. Previous work also reported 17 fatty acids in potato peel extract, where linoleic (39%), palmitic (18%), and linolenic (16%) acids were the main with minor lauric, myristic, pentadecanoic, heptadecenoic, stearic, eicosanoic, heneicosanoic, docosanoic, tricosanoic, tetracosanoic, hexacosanoic, montanic, nonacosylic, and melissic acids [103]. Moreover, Javed and coworkers reported the presence of non-starch polysaccharide (30%), starch (25%), acid-soluble and acid-insoluble lignin (20%), ash (6%), protein (18%), and lipids (1%) on dry basis in potato peels. They also reported that the potato peels as a potential source of dietary fibres [83]. Previous reports also highlighted the importance of potato peels as a rich source of dietary fibres, with several benefits to human health [104, 105].

Choi et al. investigated the nutritional protein composition of potato peels, where they reported that the potato peels were important macronutrient source [106]. The result revealed that the total crude protein concentration of 9.52–10.58 g/100 g dry weight, an essential amino acids content of 429–666 mg/100 g dry weight, a total free amino acid level of 1383–2077 mg/100 g dry weight, and asparagine in level of 90.4–115.8 mg/g dry weight. Total dietary fibre content of potato peels from the Lady Claire variety was reported to be 51% [107] and in another study [82] were reported to be 21.4% and 22.39% dry weight of organic and

non-organic of the Russet variety, respectively. The presence of calcium (1%), iron (6%), magnesium (6%), manganese (7%), phosphorus (8%), potassium (9%), and zinc (3%) as minerals in addition to some vitamins: B1, B2, B3, B5, B6, C, K, and folate (B9) together carbohydrate, dietary fibres, starches, fats, and proteins were found mostly in the thick periderm of the potato skin [108]. The levels of minerals were present in greater amounts in the skin than in the flesh of the tuber. Additionally, this report also highlighted the great importance of peels for their content of dietary fiber. Approximately 50% of potato peels (w/w) is dietary fibers such as cellulose, hemicelluloses, lignins, pectins, and gums.

Dietary fiber is a major element of foods that has just got attention for its health advantages including polysaccharides, oligosaccharides, lignin, and associated plant substances. The ratio between soluble and insoluble dietary fiber is highly important for health conditions and technological features; 30–50% of soluble dietary fiber and 70–50% of insoluble dietary fiber is considered a good-balanced proportion [109, 110]. The insoluble and soluble dietary fiber contents in onion by-products depend on the variety; Recas, Paste and Bagasse were the onion by-products with higher in the content. Onion Bagasse could be considered a good source of insoluble fiber. The ratio of soluble dietary fiber to insoluble dietary fiber was 1:3 in Purée, Bagasse, and Figueres, which was considered a good ratio supplying a reasonable amount to about 30% of soluble dietary fiber, so onion by-products could be utilized as a good source of soluble dietary fiber [111–113].

Insoluble and soluble dietary fibers were exposed to acid hydrolysis, uronic acids, neutral sugars, and Klason lignin were detected and quantified. Brown skin showed total dietary fiber content (65.8%) on a dry weigh basis, then top (48.5%) and bottom (38.6%), insoluble dietary fibers were the main fraction found. The soluble to insoluble ratio reduced from inner to outer tissues. Brown skin and outer leaves by-products seem to be the important sources of dietary fiber used in natural product supplements. Cellulose and pectic polysaccharides were the major parts of onion dietary fiber in all tissues, with some differences. Uronic acids/neutral sugars ratio showed slight increases from inner to outer tissues, because of the galactan side chain has a dietary fiber solubilization responsibility [112]. Additionally, onions contain soluble and insoluble dietary fiber, and the ratio of soluble/insoluble dietary fiber is better than other vegetables. Brown skin has the highest content of dietary fiber, followed by top–bottom. Of about 65% or more of the dry weight could be in the form of non-structural carbohydrates including glucose, fructo-oligosaccharides, fructose, and sucrose [112]. Moreover, onion wastes soluble dietary fibers were mainly glucose, uronic acids, and galactose accounting for more than 70% of the total sugars, where xylose, mannose and arabinose occurred in lesser quantities. Cellulose and polyuronides were the main polysaccharides of onion dietary fibers. They also contain non-structural carbohydrates like fructans and fructooligosaccharides, and flavour compounds [112, 113].

Brown skin of two onions cultivars (cv. Figueres and cv. Recas) had the highest amount of total dietary fiber, then top–bottom suggesting that a decrease in it from outer bulb to the inner. So, brown skin and top–bottom could be possibly used as functional components rich in dietary fiber, mostly in insoluble fraction. Outer scales could be used as source of dietary fiber. Though, inner scales with a potential source of fructans and alk(en)yl cystein sulphoxides [111]. Glucose was the main non soluble carbohydrates component of whole onion and the minor was fructans [30]. Further, Onion skin powder had significant content of dietary fiber (7.78%), moisture content (8.08%), ash content (5.93%), crude fats (1.08%), protein content (3.06%), and total carbohydrates (82.15%). Onion skins also showed a considerable amount of dietary fiber, suggested the possibility of them as a potential functional food [34]. Onion peels showed contents of carbohydrate (88.56%); protein (0.88%), ash (0.39%) and crude fiber (0.15%), highlighting the peels as a good source of carbohydrates [114]. Onion skin powder showed a lower protein content (2.58–3.06%), with lower crude fat content (0.71–0.77%) and high content of total dietary fiber (7.78–62.09%) of about 54.71% were insoluble with 7.38% soluble dietary fibers, and ash (5.50–5.93%) [115].

Extraction Optimization

Extraction is the process of metabolites recovery from plant tissues in solvents. It acts through affecting the cell wall integrity, and then, disruption letting the solvents capture the plant cell metabolites. Since solubility of plant products is a pre-requisite for the extraction process, the choice of the solvent polarity is critical issue [119, 120]. In addition, different parameters, including temperature, time, solvent-to-solid ratio, costs, safety, energy input and others are involved. So, optimization of these factors should be conducted with aid of statistical calculations, including factorial design and response surface Box-Behnken design, to guarantee effective extraction and improved yields of desired metabolites [40, 119, 121].

Extraction methods can be classified into conventional solvent extraction and non-conventional methods [122]. Despite of the common use of solid/liquid extraction (SLE) methods for the recovery of bioactive compounds, including polyphenols from potato and onion peels, modern green technologies have been preferred nowadays, including microwave- and ultrasound-assisted extraction [123]. The mechanisms behind the different extraction mechanisms were discussed extensively and how they can disrupt the cell walls in previous literature [124]. Table 2

Table 2 Summary of used extraction techniques and the effect on the obtained yields from potato and onion biowastes

Potato by-products		
Extraction parameters	**Affected phytoconstituents**	**Ref**
1.1.**Conventional solvent extraction**		
--Solvent: ethanol (71.2% *v/v* for phenolic compounds and 38.6% for flavonoids), --Time: 34 min., and --Temperature: 89.9 °C	phenolic, *i.e.*, chlorogenic and ferulic acids, and flavonoid compounds	[23]
--Solvent: methanol, --Time: overnight in a shaker, and --Temperature: room temperature	phenolic compounds including flavonoids (2.91 mg gallic acid equivalent/g dry weight)	[63]
--Solvent: water, --Time: 10,000 × *g* for 10 min and then 5 min. with deionized water --Temperature: cold (5 °C), and --Sample to solvent ratio: 0.5 g/10 mL	phenolic acids (86.3 mg/100 g freeze dried sample) and flavonoids (27.5 mg/100 g freeze dried sample)	[117]
--Solvent: methanol:water (80%*v/v*), --Temperature: 40 °C, --Time: 30 min, and --Sample to solvent ratio: 1:10	phenolic compounds, *i.e.*, chlorogenic acids (4.78 mg chlorogenic acid/g)	[85]
--Solvent: ethanol 50%*v/v*)/acetic acid (0.5% *v/v*), and --Time: 1 h	glycoalkaloids, *i.e.*, solanidine, α-solanine, and α-chaconine	[126]
--Solvent: methanol under reflux then partitioned with EtOAc–H_2O	unsaturated fatty acids, amides, phenolic compounds, and glycoalkaloids	[67]
--Solvent: ethanol --Time: overnight, --Temperature: room temperature, and --Sample:solvent ratio: 1:10	Phenolic acids, *i.e.*, caffeic, chlorogenic, and neochlorogenic acids	[127]
--Solvent: ethanol (96%*v/v*), --Sample:solvent ratio: 1:10, --Temperature: 5 °C, and --Time: overnight	Phenolic compounds (70.8 mg of catechin equivalents/100 g of potato peel)	[128]
--Aqueous extraction, --Solvent:sample ratio: 1:20	phenolic acids, *i.e.*, chlorogenic, gallic, caffeic, and protocatechuic acids	[129]
2.2.**Non-conventional green methods**		
a.a.**Ultrasound-assisted extraction**		
--Solvent: ethanol/water 55/45 (% *v/v*), --Time: 35 min, --Temperature 35 °C, and --Sample to solvent ratio: 1:10	phenolic compounds, *i.e.*, chlorogenic acid accounted for a 49.3–61% of the total phenolics	[81]
--Solvent: methanol, --Time: 17 min, --Frequency: 20 kHz, and --Sample: solvent ratio: 1:10	steroidal alkaloids (1102 µg/g dried peel), *i.e.*, α-solanine (273 µg/g), α-chaconine (542 µg/g), solanidine (231 µg/g), and demissidine (55 µg/g)	[130]
--Solvent: water, --Temperature: 25 °C, --Frequency: 40 Hz, --Power: 49.5 W, --Liquid/solid ratio: 200:10, and --Time: 30 min	Total phenolic content 2.12 ± 0.22 mg GAE/g	[131]
b.b.**Microwave-assisted extraction**		
--Solvent: methanol (67.33%*v/v*), --Time: 15 min, and --Microwave power level: 14.67%	maximum phenolics content (3.94 mg/g dry weight (dw)), *i.e.*, ferulic acid, caffeic acid, and chlorogenic acid	[102]
c.c.**Pressurized liquid extraction**		
--Solvent: 89% methanol, and --Temperature: 80 °C	steroidal alkaloids (1.92 mg/g dried peels), *i.e.*, α-solanine, α-chaconine, solanidine, and demissidine	[91]

Table 2 (continued)

Potato by-products		
Extraction parameters	**Affected phytoconstituents**	**Ref**
--Solvent: ethanol in water acidified to pH 2.6, --Pressure: 100 bar, and --Temperature: 80 °C	anthocyanin	[132]
d.d.**Supercritical fluid extraction**		
--supercritical fluid extraction with pure CO_2 or with CO_2 and ethanol (5% *v/v*) as cosolvent --Pressure: low pressure (100 bar), and --Temperature: 65 °C	anthocyanin	[132]
Onion by-products		
1.1.**Conventional extraction methods**		
--Solvent: ethanol (50%*v/v*), --Solid:solvent ratio: 1:100, --Temperature: 25 °C, and --Time: 15 min	Flavonoid, *i.e.*, quercetin (7.96 mg/g dry weight)	[12]
--Solvent: mixture of ethanol (70%*v/v*) and 2 N hydrochloride acid, --pH: 1.0 --Time: 24 h for maceration, 8 h for percolation, and 2 h for reflux and Soxhlet method, and --Solid:liquid ratio: 1:10	Antioxidant content	[133]
--Solvent: water, --solvent:solid ratio: 1:50, --pH: 6 with phosphate buffer, --Temperature: 100 °C, and --Time: 30 min	total polyphenol (34.7 mg/g) and quercetin (13.5 mg/g dry weight)	[134]
--Solvent: ethanol (60%*v/v*), --Temperature: 50 °C, and --Time: 3 h	Quercetin (1 mg/10 mg dry weight)	[135]
--Solvent: ethanol (80%*v/v*), --Solid:solvent ratio: 1:1, --Time: 48 h, and --Temperature: 25 °C	4'-*O*-glucoside of quercetin (spiraeoside) (32.5 mg/g dry weight)	[119]
--Solvent: methanol (80%*v/v*), --Time: 48 h, --Temperature: 30 °C, and --Solid:solvent ratio: 1 g/5 mL --and then partitioned with 80% methanol, 80% ethanol, diethyl ether, ethyl acetate, and n-butanol	Flavonols, *i.e.*, quercetin-3,4′-*O*-diglucoside (1.6 mg/ g dry weight), quercetin-4′-*O*-monoglucoside (2.3), and quercetin (0.5) - Total phenolic content: methanol (415.3 mg GAE/g), ethanol (398.5 mg GAE/g) and ethyl acetate (305.9 mg GAE/g), n-butanol (115.6 mg GAE/g), diethyl ether (92.6 mg GAE/g) and water (30.5 mg GAE/g) extracts - Total flavonoid content: ethanol (120.6 QE/g), methanol (101.4 QE/g), ethyl acetate (98.2 QE/g), n-butanol (50.2 QE/g), diethyl ether (35.8 QE/g) and water (10.6 QE/g)	[38]
--Solvent: methanol (80%*v/v*), --Time: 48 h, --Temperature: 25 °C, and --Solid:solvent ratio: 50:1	Flavonols, *i.e.*, quercetin-3,4'-*O*-diglucoside, quercetin-3-*O*-glucoside, quercetin-4'-*O*-glucoside (spiraeoside), isorhamnetin-4'-glucoside, quercetin glycoside, and quercetin	[44]
--Solvent: methanol:water:HCl (70:29.5:0.5 *v/v/v*), --Temperature: 35 °C, and --Time: 90 min	quercetin 4'-glucoside and quercetin 3,4'-diglucoside - Total phenolics (52.7 mg GAE/g) - Total flavonoids (43.1 mg QE/g)	[30]
--Solvent: ethanol:water, --Temperature: 40 °C, and --Time: 60 min	- Total flavonoids (25.64 ± 1.40 mg QE /g dry weight) - Total anthocyanins (0.78 ± 0.01 mg cyanidin 3-glucoside /g dry weight)	[136]

Table 2 (continued)

Potato by-products		
Extraction parameters	**Affected phytoconstituents**	**Ref**
2.2.**Non-conventional extraction methods**		
a.a.**Ultrasound-assisted extraction**		
--Solvent: ethanol (59%*v/v*), --Temperature: 49 °C, --pH: 2, --Frequency: 40 Hz, --Power: 469 W, --Liquid/solid ratio: 60:1, and --Time: 35 min	Flavonoids, *i.e.*, quercetin (11.1 mg/g dry weight)	[137]
--Solvent: ethanol; water, --Temperature: 40 °C, --Frequency: 40 Hz, --Power: 469 W, --Liquid/solid ratio: 100:5, and --Time: 120 min	- Total flavonoids (23.12 ± 0.52 mg QE /g dry weight) Total anthocyanins (0.48 ± 0.02 mg cyanidin 3-glucoside /g dry weight)	[136]
b.b.**Microwave-assisted extraction**		
--Solvent: ethanol (69.7%*v/v*), --Time: 117 s, and --Power: 700 W irradiates at 10 s interval times	Quercetin (4.75 mg/g dry weight)	[138]
--Solvent: ethanol/water --Time: 15 min, and --Power: 250 W irradiates	- Total flavonoids (19.09 ± 0.45 mg QE /g dry weight) - Total anthocyanins (0.55 ± 0.05 mg cyanidin 3-glucoside /g dry weight)	[136]
c.c.**Subcritical water extraction**		
A semicontinuous extraction (2.5 mL/min; 105–180 °C; 5 MPa) --Time: < 30 min, and --Temperature: 145 °C	Flavonoids (27.4 mg/g dry weight), *i.e.*, quercetin (15.4 mg/g) and quercetin-4′-glucoside (8.4 mg/g) accounting for the 90% of the total flavonoids identified	[139]
d.d.**Deep eutectic solvent-based extraction**		
--Eutectic mixtures composed of choline chloride (ChCl) with hydrogen bond donor urea (1:2), --Temperature: 60 °C, --Time: 120 min, and --Solid:solvent ratio: 1:50	Phenolic compounds (222.97 mg gallic acid equivalent (GAE)/g dry weight), Flavonoids, *i.e.*, quercetin, kaempferol, and myricetin	[140]
--Eutectic mixtures composed of Glycerol/Trimethyl glycine (GA/TMG), Glycolic Acid/L-Proline (GA/L-Pro) and *p*-toluenesulfonic acid/benzyltrimethylammonium --methanesulfonate (pTSA/BZA) --Temperature: 70–80 °C, --Time: 10 min to 3 h, --Water dilutions: 0.1 to 5% w/w, --Solid:solvent ratio: 2/1, 3/1 molar ratio, respectively	The better extraction method of polyphenols (quercetin) from vegetal matrixes; onion skin waste. The quercetin concentration in the samples were over 3 times higher than methanol using HPLC (5.84 µg/mL with methanol, 18.56 µg/mL with GA/L-Pro and over 14 µg/mL for GA/TMG and pTSA/BZA) and more than 1.5 times higher by the water/methanol mixture (10.83 µg/mL)	[43]
e.e.**Microwave-assisted deep eutectic solvent extraction**		
--Solvent: ChCl:Urea:H_2O, --Microwave power: 100 W, --Time: 15.03 min, and --Liquid:solid ratio: 1:55	phenolic compounds (80.45 mg GAE/g dw)	[141]
f.f.**Others**		
--Enzymatic digestion of non-dietary fibers components	dietary fiber and fructooligosaccharides (FOS)	[30]

summarizes the applied extraction methods for both biowastes and how could improve the yields of different phytoconstituents.

Biological Activities

Several natural products and extracts captured the attention of researchers for discovering new therapeutic agents,

but this requires extensive investigations for their biological activity. Onion peel extract (OPE) and potato peel extract (PPE) demonstrated certain biological activity, which will be discussed below in details and summarized in Figs. 1 and 2.

Antioxidant Activity

It is well known that excessive production of free radicals, reactive oxygen species (ROS), has an important role in the pathogenesis and progression of several diseases [141]. There are numerous published articles that have referred to the antioxidant potential of several natural products from different botanical parts and origins [142–145]. Several studies have revealed that Onion peel extract and Potato peel extract also have a substantial antioxidant activity [146–148].

The antioxidant activity of Onion peel extract has been assayed in vitro via 2,2-diphenyl-1-picrylhydrazyl (DPPH), thiobarbituric acid (TBA), and ferric thiocyanate (FTC) methods. Several lines of evidence have suggested a powerful correlation between antioxidant activity and phenolic content of the natural product extracts [32, 149, 150]. Ethanol extraction of yellow OPE showed the highest DPPH scavenging activity compared to hot or subcritical water extraction. Lipid peroxidation inhibitory effect of ethanolic Onion peel extract was better than hot or subcritical aqueous extract. These findings could be explained by the high concentration of quercetin in the extracted peels by ethanol [151]. The antioxidant activity of most common flavanols; quercetin aglycone, quercetin 3,4'-diglucoside, and quercetin 4'-monoglucoside, in methanolic Onion peel extract was evaluated and found to be in the following descendant order: quercetin > quercetin diglucoside > quercetin monoglucoside [36, 38]. Despite the fact that the antioxidant activity is absolutely linked to total phenolic content [42], yellow

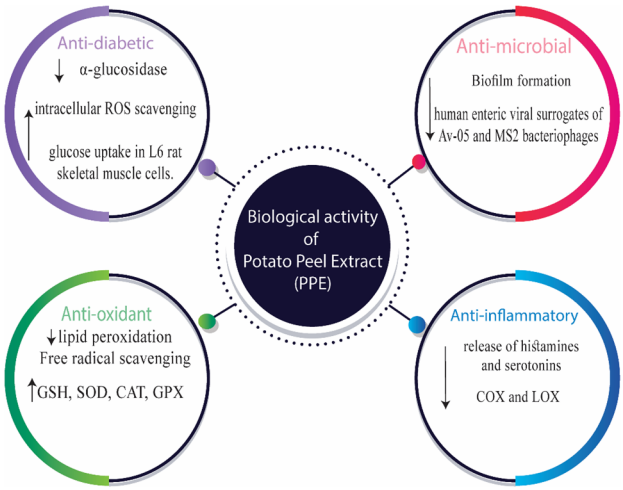


Fig. 2 Biological activities of Potato Peels Extract (PPE)

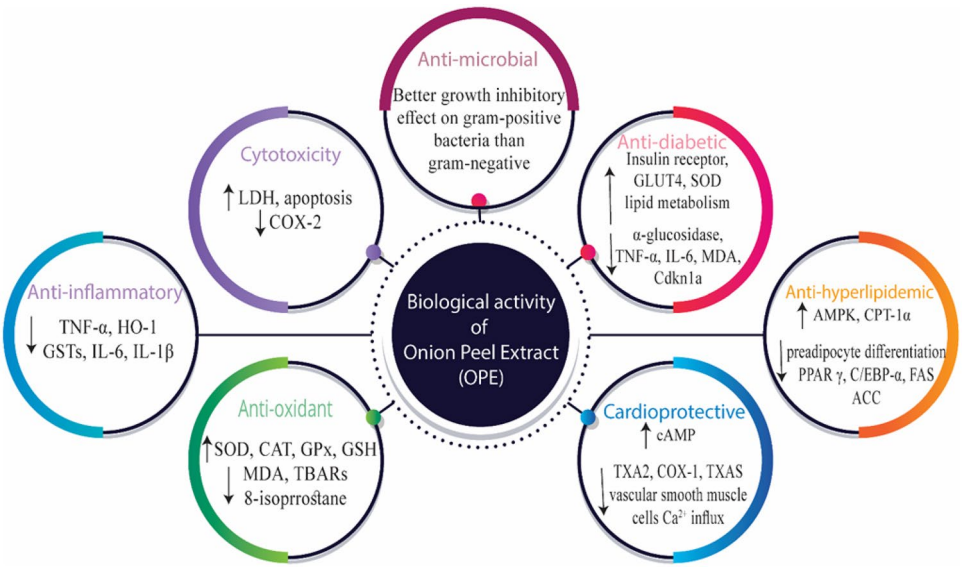


Fig. 1 Biological activity of onion peel extract and possible underlying mechanisms. *SOD* superoxide dismutase, *CAT* catalase, *GPx* glutathione peroxidase, *GSH* glutathione, *MDA* malondialdehyde, *TBARs* thiobarbituric acid reactive substances, *TNF-α* tumor necrosis factor- α, *HO-1* heme oxygenase-1, *GSTs* glutathione S-transferase, *IL-6* interleukin 6, *IL-1β* interleukin 1beta, *LDH* lactate dehydrogenase, *COX-2* cyclooxygenase-2, *GLUT4* glucose transporters 4, *Cdkn 1a* cyclin-dependent kinase Inhibitor 1a, *AMPK* AMP-activated protein kinase, *CPT-1α* carnitine palmitoyl transferase-1 α, *PPAR γ* peroxisome proliferator-activated receptor γ, *C/EBP-α* CCAAT/enhancer binding protein, *FAS* fatty acid synthase, *ACC* acetyl-CoA carboxylase, *cAMP* cyclic adenosine monophosphate, *TXA2* thromboxane A_2, *COX-1* cyclooxygenase-1, *TXAS* XA_2 synthase

Onion peel extract showed lower content of all identified flavones but higher antioxidant activity than the corresponding red peel extract. A possible explanation for this might be that yellow onion variety has a higher amount of anthocyanin cyanidin-3-glucoside, which is a potent antioxidant characterized owing to its hydroxyl group-rich structure [13, 152]. It is noteworthy that the antioxidant activity of the onion increased from the inner to the outer parts [30, 42, 117].

The protective effect of onion biowaste against oxidative stress and its molecular mechanism have been indicated in several studies [153, 154]. Onion skin extract protected *Saccharomyces cerevisiae* (yeast cells) from cadmium-induced oxidative stress through increasing the activity of antioxidant enzymes including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx). Additionally, the level of malondialdehyde (MDA) was decreased, whereas the level of glutathione (GSH) was increased in the yeast cells homogenate [153]. 2-(3,4-dihydroxybenzoyl)-2,4,6-trihydroxy-3(2*H*)-benzofuranone (BZF) is an oxidation-induced quercetin metabolite in onion peels and found to protect Caco-2 human colon adenocarcinoma cell line against oxidative stress at unprecedentedly low nanomolar concentrations [154, 155].

Regarding the pre-clinical in vivo studies, the antioxidant power of Onion peel extract has been also reported by some researchers. Supplementation with powdered dried or ethanolic extract of onion peel for three months improved the antioxidant status in aged rats as demonstrated by elevation of total plasma antioxidant status, decline of thiobarbituric acid reactive substances (TBARs) in hepatic tissues, and decreased level of 8-isoprrostane in brain tissues [156]. On the other hand, there was a clinical trial carried out by *Kim and Yim* to investigate the benefits of Onion peel extract at a dose of 100 mg/day for three months in obese women to avoid chronic diseases linked to the oxidative stress [146].

The phenolic content of the lyophilized water extract of potato peels were measured to be 3.93 mg/g powder using Folin–Ciocalteu method. HPLC analysis of the extract showed that its major phenolics are caffeic acid, gallic acid, protocatechuic and chlorogenic acid. The antioxidant activity of the extract was evaluated using $FeSO_4$ and ascorbic acid induced-lipid peroxidation in rat RBCs and human RBC membranes. The extract showed significant protection in both types of cells at 2.5 mg/mL, and also significantly prevents the peroxide-induced morphological alterations in the erythrocytes studied by scanning electron microscopy. In addition, the extract significantly protected the membrane proteins of human RBCs against ferrous–ascorbate induced oxidative damage [60].

Further, the antioxidant capacity of the oligosaccharide from potato peels variety spunta was evaluated using phosphomolybdate method, and it showed total antioxidant activity of 87.66 ± 9.38 α-tocopherol (µmol/mL) at 10 mg/mL. The oligosaccharide fraction also proved DPPH radical-scavenging capacity with IC_{50} = 2.5 mg/mL [128, 157], ferric reducing power (OD: 0.622 ± 0.032; concentration = 20 mg/mL) [128, 157], β-carotene bleaching inhibition activity of 45.335 ± 3.653% at 50 mg/mL [157], and also the ABTS radical scavenging activity of 14.835 ± 0.1% at 10 mg/mL [157].

Additionally, the extracts of potato peels of different varieties were assessed for the capacity to stop lipid peroxidation of porcine brain tissues (TBARS assay), the extract from peels of Rosemary tubers was the potent one, while that of Salad Blue showed the lowest results [86]. Concerning the haemolysis of sheep blood cells, the hydroethanolic extracts from the peels of *Violetta* and *Purple* showed the most prominent activity, as they had the lowest IC_{50} values (16 µg/mL for both varieties), while *Salad Blue* peels also showed the lowest antioxidant activity (IC_{50} = 294 µg/mL) [86]. Potato peels could also inhibit lipid peroxidation in rat liver homogenates and iron ion chelation [128]. Potato peels aqueous extract showed in vivo antioxidant activity in rats fed on 2% and 3% Potato peel extract which showed significant increase in liver glutathione and trolox equivalent antioxidant capacity [73].

Anti-Inflammatory Activity

It has been demonstrated that Onion peel extract and their active constituents possessed promising anti- inflammatory activities. Incubation of lipopolysaccharide-stimulated HT-29 human colon carcinoma cells with OPE induced down-regulation of gene expression of tumor necrosis factor-α (TNF-α), heme oxygenase-1 (HO-1), and glutathione S-transferase (GSTs). These findings can be attributed to the contained active components such as epicatechin, morin, and *p*-coumaric acid [35]. Another study on RAW 264.7 murine macrophage cell line elucidated the decreased production of inflammatory cytokines (IL-6, TNF-α, and IL-1beta) by onion peel hot water extract [158]. For ear oedema in mice exposed to croton oil, onion peel hot water extract decreased the release of these inflammatory cytokines [158].

Ethyl acetate fraction of Onion peel extract showed profitable anti-inflammatory activity in L6 myoblast cells through inhibition of featured process of inflammation and protein denaturation [159]. Inflammatory cascade in tissue damage embraces the release of leucocyte's proteinase and cell membrane damage. Synthesis of gold nano-bioconjugates with high concentration of ethyl acetate Onion peel extract has induced remarkable inhibition of proteinase and bovine serum albumin denaturation [159]. Despite these data, further in vitro and in vivo studies for the molecular anti-inflammatory mechanism are still required.

The anti-inflammatory activity of the hydroethanolic extracts of the peels of potato different varieties was

assessed by lipopolysaccharide (LPS)-induced nitric oxide (NO) production by mouse macrophages RAW 264.7. The extract showed significant inhibitory activity on the growth of RAW 264.7 mouse macrophages with $IC_{50} = 141$ µg/mL [86]. Additionally, the in vivo anti-inflammatory properties of Potato peel extract were evaluated using carrageenan-induced paw edema using diclofenac as the positive control. At doses of 100, 200, and 400 mg/kg, there was significantly decreases in the edema volume in male Wistar rats [160]. Moreover, Potato peel extract at a dose of 100 and 200 mg/kg significantly ($p < 0.05$) decreased pain stimuli in male Wistar rats, compared to paracetamol as a standard drug using the hot plate test [160].

Cytotoxicity

It is well known that cancer is one of the predominant leading cause of death, with approximately 9.6 million deaths in 2018 [161]. Extensive research have revealed the anticancer activity of many natural products including onion and potato biowastes [33, 86, 161, 162]. Twenty-four-hour incubation of HT-29 colorectal adenocarcinoma cells with different concentrations of Onion peel extract showed decrease in cell viability in a dose-dependent manner. At 250 µg/ mL Onion peel extract, most of HT-29 cells exhibited loss of the normal architecture of their nuclei and showed significant increase in the level of lactate dehydrogenase (LDH); indicating damage of cell membrane and cell death [85].

A recent work has examined the anti-proliferative activity of red and yellow Onion peel extract on three cell lines [42]. This work proved that the anti-proliferative activity of red variety of *Allium Cepa* L. is better than that of yellow variety in two cancer cell lines; HCT116 human colon cancer and U2OS osteosarcoma. Quercetin glycosides and other bioactive constituents of the extracts contributed to this anti-proliferative effect. Furthermore, investigators revealed that quercetin glycosides displayed reasonable activity on these three cancer cell lines in comparison with the red and yellow Onion peel extract. Quercetin mono-glucoside showed a 50% lower inhibitory concentration (IC_{50}) and better anti-proliferative activity than quercetin di-glucoside [42].

Nile et al. examined the cytotoxicity of Onion peel extract and flavonol glucoside from the extract on ACHN human renal carcinoma, Panc1 human pancreatic carcinoma, Calu 1 human non-small lung carcinoma, H460 human non-cell lung carcinoma, with HCT116 colorectal carcinoma and was found these bioactive molecules has a dose-dependent in vitro cytotoxic effect [38]. *Muoth* et al. clarified that quercetin was the most potent cytotoxic flavonol in DLD-1 human colon cancer cells ($IC_{50} = 10.5$ µM) compared to epicatechin and catechin ($IC_{50} = 415.3$ µM) [163]. Inhibition of cyclooxygenase-2 (COX-2) transcriptional activity might be the mechanism of cancer cell growth inhibition by flavonoids in Onion peel extract [163]. Further in vitro and in vivo studies for Onion peel extract and its individual components is highly recommended to elucidate their mechanism of action as cytotoxic agents.

The anti-proliferative activity of the hydroalcoholic extracts from different potato varieties was evaluated using four human cancer cell lines: MCF-7 (breast carcinoma), NCI-H460 (lung carcinoma), HeLa (cervical carcinoma) and HepG2 (hepatocellular carcinoma). All the tested hydroethanolic extracts showed anti-proliferative activity against the tested cancer cell lines, where the extract of the Rosemary variety showed the highest activity [86].

Anti-Microbial Activity

Microbial infectious diseases have been a major public risk as the antimicrobial resistance. Several herbs were reported as effective antimicrobial agents [12]. Yellow and red Onion peel extract had better growth inhibitory effect on gram-positive bacteria than gram-negative [164, 165]. Fredotovi´c et al. reported that the yellow *Allium Cepa* L. peel extract was more effective than the red variety as demonstrated by strong growth inhibition of the two *Staphylococcus aureus* strains (Clinical/ MRSA and ATCC 29,213) [42]. Similar results for onion biowastes and the bulb were reported [96, 166, 167]. Conversely, both varieties exhibited slight or no inhibition against the growth of some gram positive bacteria such as *Streptococcus pyogenes*, *Listeria monocytogenes, Bacillus cereus, Enterococcus faecalis* as well as gram negative bacteria (*Escherichia coli* and *Klebsiella pneumoniae)* [42].

Quercetin 3,4-diglucoside and quercetin 4´-monoglucoside showed the same observed inhibitory effects on the above-mentioned strains, except *Enterococcus faecalis*, which was somewhat more affected by quercetin monoglucoside [42]. Data from previous works have shown that quercetin aglycone had better growth inhibition of microbes than quercetin glycosides forms [165, 167, 168]. No statistically significant anti-fungal activity of yellow and red Onion peel extract against *Candida albicans* and food-poisoning mold, *Aspergillus niger* were reported [165, 168].

Potato peels acidified ethanolic extract of the commercial Russet samples had inhibitory activity against one *Trichomonas vaginalis* strain and two distinct strains of the related *Tritrichomonas foetus* with also had antibacterial activity against *Escherichia coli* and *Salmonella Typhimurium* [53]. Potato peels acidified ethanolic extract also had antiviral effects opposed to human enteric viruses [75]. PPE inhibited biofilm formation in *Streptococcus mutans* using crystal violet assay ($p < 0.05$) [160].

Anti-Diabetic Activity

Diabetes is one of the serious metabolic syndromes characterized by abnormal increase of blood glucose level. The predominant causes of diabetes mellitus are insulin deficiency in type 1 or insulin resistance in type 2. Poorly controlled hyperglycemia will result in glycation of proteins and formation of advanced glycation end products (AGEs) [169]. Fortunately, high concentrations of the most bioactive hypoglycemic flavonoids and quercetin derivatives are present in the outer dry layers of onion bulb [170, 171]. A methanolic extract of Onion peel extract demonstrated inhibitory activity of α-glucosidase in yeast at $IC_{50} = 0.159$ mg/mL. Feeding type 2 diabetic mice with a diet supplemented with 0.5% Onion peel extract for seven weeks significantly reduced blood sugars and glycated hemoglobin primarily through α-glucosidase inhibition [172].

Jung et al. reported that therapy of type 2 diabetic rats with 1% Onion peel extract improved insulin resistance and glucose tolerance through up-regulation of insulin receptors and glucose transporters (GLUT4) in the muscle tissue [173]. Significant elevation of glycogen level in the liver and skeletal muscle supported the insulin sensitizing effect of Onion peel extract. Subjects with type 2 diabetes mellitus have impaired blood lipid profile and are characterized with metabolic dysregulation of FFAs (free fatty acids) [169]. Previous lines of evidence suggested that FFAs have a significant contribution in the production of ROS with activation of macrophage to release inflammatory cytokines making the muscle cells insulin resistant [174]. Administration of 1% Onion peel extract in diabetic rats showed anti-inflammatory activity, by reducing TNF-α and IL-6, besides antioxidant activity by suppressing MDA level in liver tissue and increasing SOD activity. Therefore, it was suggested that Onion peel extract can improve insulin sensitivity, by its lipid metabolism enhancing, antioxidant, and anti-inflammatory activity [173].

Moreover, feeding diabetic rats with bread supplemented with 1% and 3% Onion peel extract for eight weeks lowered blood glucose level and alleviated oxidative stress in liver and kidney tissues [175]. Supplementation of streptozotocin-induced diabetic mice with AIN93G diet with 0.1 or 0.5% quercetin for two weeks resulted in decreased levels of blood glucose and plasma insulin. Additionally, diminished oxidative stress, decreased gene expression of cyclin-dependent kinase inhibitor 1a (Cdkn1a) that regulates cell cycle, altered expression of hepatic genes affected by streptozotocin were recorded in diabetic mice fed on dietary quercetin [170]. Hence, we suggested to examine the postprandial metabolic and appetitive responses toward an established dietary formula like bread with health-promoting effects in human trials. Further, the in vitro α-glucosidase inhibitory activity of the hexane, ethyl acetate and methanol extracts of potato peels powder were compared where it was found the methanol extract had the highest activity with $IC_{50} = 184.36$ mg/mL [72].

Anti-Hyperlipidemic Activity

Obesity lead to many chronic disorders; diabetes, hypertension, and cardiovascular disorders [109, 176]. Where, Onion peel extract and Potato peel extract were effective in the management and prevention of obesity [82, 177, 178]. In 3T3-L1 preadipocyte cells, Onion peel extract demonstrated anti-obesity effect by suppressing preadipocyte differentiation and inhibiting adipogenesis through modulation of the pathways for fatty acid β-oxidation, thermogenesis, and lipid metabolism [177]. It was found that quercetin exerted anti-adipogenesis activity by activating the AMP-activated protein kinase (AMPK) signaling pathway in 3T3-L1 preadipocytes [179]. Eight-week supplementation of obese rats with quercetin-rich Onion peel extract showed a significant weight reduction. This anti-hyperlipidemic effect could be traced to down-regulation of fatty acid synthase (FAS), peroxisome proliferator-activated receptor γ (PPAR γ), acetyl-CoA carboxylase (ACC), and CCAAT/enhancer binding protein (C/EBP-α). High-fat diet supplemented with 0.36 or 0.72% Onion peel extract significantly up-regulated the mRNA expression of carnitine palmitoyl transferase-1 α (CPT-1α) [177]. In a randomized double-blinded placebo-controlled study, obese women were received capsules of Onion peel extract containing 50 mg of quercetin twice daily for 12 weeks had decreased their body mass index and improved lipid profile [146, 178]. Additionally, dietary intake of potato peels powder prevent weight gain in mice having high-fat diet which suggest the significance of potato peels as effective food for management of obesity [82]. Various researchers have documented that onion peel extract had anti-obesity effect as it is rich source of bioactive polyphenolic compounds [124].

Cardioprotective Activity

Dyslipidemia and hypertension are risk factors for cardiovascular disorders as stroke and coronary heart disease [180]. Naseri et al. reported that Onion peel extract had hypotensive and vasorelaxant effects in rats through excellent antioxidant activity of quercetin and inhibition of vascular smooth muscle cells Ca^{2+} influx [181]. An *in vitro* study revealed the preventing effects on collagen-induced platelet aggregation of Onion peel extract was mediated by preventing of aggregation-inducing molecules; intracellular Ca^{2+} and thromboxane A_2 (TXA_2), cyclooxygenase-1 (COX-1) and XA_2 synthase (TXAS) activities. Also, Onion peel extract elevated the formation of aggregation-inhibiting molecule; cyclic adenosine monophosphate (cAMP) [182].

Furthermore, ethyl acetate Onion peel extract showed a remarkable reduction in systolic and diastolic blood pressure, pulsation, cardiac oxidative stress and creatine kinase in rats when administered (40 mg/kg) [183]. In another trial, 162 mg/day Onion peel extract-extracted quercetin reduced ambulatory blood pressure in obese participants with pre-hypertension and stage I hypertension [184]. Consequently, Onion peel extract can be beneficial and safe for the management of cardiovascular disorders.

Industrial Applications, Including Food and Biofuels Productions

Complete utilization of the raw material produced from onion and potato processing industries attracts more attention in the last years for reducing feedstock waste. The production of these wastes in unavoidable since food processing cannot be completed without peel removal. Current researches focus on peel recycling for the development of phyto-pharmaceutical and biosynthesis industries [185]. Consequently, recycled value-added applications onion and potato peel wastes deserve more investments for the development of eco-friendly products (Fig. 3).

Phenolic acids are used widely in food preservation, feeds, and pharmaceuticals. Potato and onion peels are rich in several phenolic acids, of which, chlorogenic acid hydrolytic products, quinic and caffeic acids, are of high medicinal value. Quinic acid is a starting material for the synthesis drugs as Oseltamivir for influenza [186]. Caffeic acid and its derivatives have antimicrobial, antioxidant, anti-inflammatory and anticarcinogenic activities [187]. Conventional

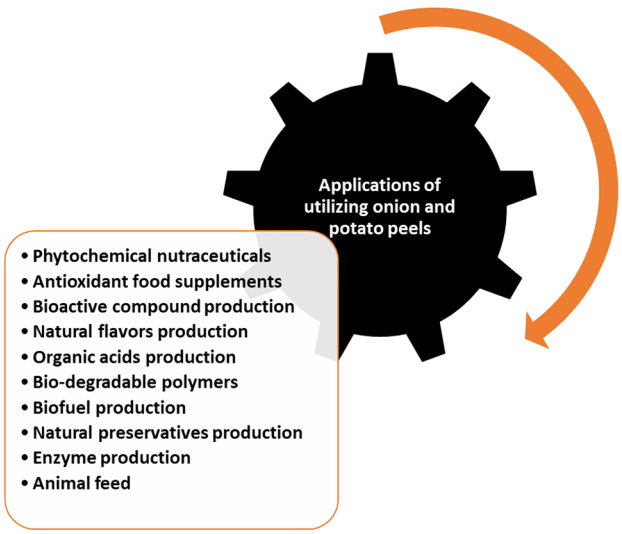


Fig. 3 Recycled value-added applications onion and potato peel wastes

extraction of phenolic compounds using organic solvents such as methanol, ethanol and ethyl acetate has environmental concerns, thus, alternative green solvents facilitate food applications, avoiding environmental and toxicological concerns. The complicated extraction processes are of high cost, therefore, the urgent demand for production of biologically active compounds from zero value by-products will achieve low costs driven by large scale industrialization,

Environment friendly extraction of gylcoalkaloids from potato peel waste, can also be scaled up to an industrial level [188]. Glycoalkaloids production from waste can pave the way for phyto-pharmaceutical industry [189]. Onion and potato peels have been also suggested as sources of dietary fibers in food applications. The chance of producing functional foods complemented with onion peel powder will increase the antioxidant phenolic compounds and the dietary fibers content. Several organic acids such as lactic acid is useful for food, pharmaceuticals, and cosmetics industry. Lactic acid can be produced through microbial-aided carbohydrates fermentation. Lactic acid production from potato peel waste fermentation has been successfully reported together with acetic acid and ethanol production [190]. Citric acid production from potato residues has been also investigated. Potato peel waste can also provide a basis for enzyme (α-amylase and β-mannanase) production through fermentation.

Diversification of energy resources represents an important opportunity for the environmental damage caused by fossil-fuel dependent single source energy system. Energy replacement through biogas production, a renewable and environmentally friendly fuel which can be obtained through the processing of organic waste, helps in the global reduction of CO_2 emission. Biogas production is a complicated process involving several stages from anaerobic digestion to methanogenesis. Potato processing has been utilized in biogas production, however, further research is needed for successful utilization of waste [185].

Conclusion

The food industry makes a great number of agro-industrial wastes, making them essential to seek for potential ways for their valorization. One approach may be to utilize these wastes such as a natural supply of high-value functional components, while they are valuable in numerous groups of constituents, with numerous benefits to human health. Acting as main crops, potato and onion play an indispensable role in the human diet worldwide. Potato and onion food processing generate annual tons of waste as by-products, which are discarded in most countries. These by-products cause environmental concern due to microbial spoilage. Traditionally, these wastes have been used in the production of

fertilizers and animal feed. On the other side, such wastes are rich in bioactive compounds which possess antioxidant, antidiabetic, antibacterial, anti-hyperlipidemic, chemo-preventive and anti-inflammatory activities. Quercetin with its derivatives are key dominant components of onions, where chlorogenic acid and glycoalkaloids are the important ones in potato peels. Future mass production of phyto-pharmaceuticals, biogas and lactic acid from these products should be increased. Processing of waste in the direction of industry is of high cost and future efforts should find a way to develop the waste into practice as lower costs. To bring these value-added products, more regulatory approval and countries' investments are essential. The conversion of onion and potato agro-industrial wastes to value-added products may not only provide sustainable resources for production but also will reduce the current environmental hazards.

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Data Availability Enquiries about data availability should be directed to the authors.

Declarations

Conflict of interest The authors declare no conflict of interest.

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