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Onion Solid Waste as a Potential Source of Functional Food Ingredients

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Abstract

Onion (Allium cepa L.) is one of the most basic and most consumed vegetables in human diet with a long tradition of use in food and medicine. It is grown and traded worldwide for culinary purpose because of its distinctive aroma and high nutritive value. Nowadays, onion production is increasing as well as the demand for processed onion, leading to the generation of a substantial amount of industrial waste. The waste biomass is mainly composed of outer scales, skin, roots, tops of the bulbs, and deteriorated bulbs. The use of onion waste as a potential source of functional food ingredients is one way of its valorization, highly in line with the current trends in the food industry to improve by waste reuse while responding to the increasing demand for functional food. Onion waste components exhibiting functional potential are: (i) flavonols – quercetin and quercetin glucosides, known for antioxidant activity; (ii) fructooligosaccharides, well-established prebiotics; (iii) cell-wall polysaccharides, as a part of dietary fibre, or specifically pectin as a known food additive and/or a potential source of prebiotic oligomers; and (iv) organosulfuric compounds. The use of onion waste in food production is still in the research stage, but shows promising results in the incorporation of powdered onion waste concentrates and extracts into various food matrices to obtain innovative products with improved antioxidant and prebiotic quality.

Keywords: *fructooligosaccharides, functional food, onion solid waste, quercetin, valorization*

1. Introduction

Industrial food production is steadily increasing with the growth of world's population as well as with changes in consumers' behaviour, seeking for "instant", "ready to eat" and "fast" food (Chandrasekaran, 2013). Food processing inevitably generates by-products of varying composition and structure, depending on the primary raw material and the technological process involved. In case of plant-origin food, agro-industrial residues usually comprise peels, shells, skins, pods, stems, straw, stones, pits, seeds, exhausted pulp, pomace and other non-edible and/or non-usable plant parts (Galanakis, 2012; Chandrasekaran, 2013). The management of such materials usually includes composting and animal feed; however, only a limited type of plant residue is suitable for these uses, while the others become waste Inadequate disposal of agro-industrial wastes leads to serious problems at environmental, economic and socialy-responsable levels (Chandrasekaran, 2013). Nowadays, a concept of valorization is intensively being introduced to the agro-industrial waste management, by which the residues are regarded as valuable secondary raw materials for the production of value-added products (Galanakis, 2012; Matharu et al., 2016). New ways of agro-industrial residues use are focused on the recovery of their interesting and rich chemical composition, namely of target micro- or macro- components with certain potential (Laufenberg et al., 2003; Galanakis, 2012; Otles et al., 2015). The advantage of waste materials as secondary sources of valuable components is promoted by their low initial value, abundance and availability, renewability and non-competitiveness to food.

In view of the fact that plant residues were originally a part of food raw materials, their possible reuse again in food production is possibly the most interesting valorisation option. For that matter, constituents with potential health-promoting properties are the most interesting target molecules for the recovery from agro-industrial wastes (Kumar et al., 2017). Their incorporation into food products falls into a specific segment of food industry – production of functional food. The market for functional food is continuously increasing and it is believed to reach 305.4 billion dollar value in 2020 (Bogue et al., 2017). Key drives for the accelerated development of the functional food market are the strong interest of consumers for the prevention of certain health problems, raising costs of health care, prolonged life expectancy and the trend of an ageing population towards a better quality of life (Bigliardi and Galati, 2013).

Many different waste materials are being studied (Mirabella et al., 2014) as potential sources of functional food ingredients. The aim of this paper is to provide a systematic review of the most important functional constituents of onion waste which enable its potential reuse in innovative functional food development, as well as to report on the current uses of this waste material for such a purpose.

2. Onion – importance of the crop, its production, and waste generation

Onion (*Allium cepa* L.), also known as common, bulb onion, or Egyptian onion, is one of the world's most important food crops. Its cultivation has been known for more than 4000 years, believed to originate from central

Asia, but nowadays spread all over the world owing to the high adaptability of the plant to different climates and water supply (Halnet, 1990; Griffiths et al., 2002; Lewande, 2012). Onion is a biennial plant, although mostly grown as an annual crop due to the finished formation of its most usable part – the bulb, by the end of the first year of growth (Slimestad et al., 2007). Morphologically, the bulb consists of cylindrically oriented leaf bases, called scales, attached to a short disc-like stem, called the basal plate. The scales accumulate water and products of photosynthesis which causes them to swell, thus forming the bulb. As the bulb ripens, the outer scales develop into a dry and impermeable skin, which helps in preventing drying-out (Teshika et al., 2019). Onion is considered to be among the oldest vegetables and traditionally has been used in folk medicine and for culinary proposes since ancient times. Today it is one of the most important crops and ranks third after potato and tomato as the most important food crop (Teshika et al., 2019). Onions are grown in a variety of forms, including shape, colour, size, dry matter content and pungency, to meet specific culinary and nutritive requirements and so have become an almost universal ingredient in food preparation worldwide. Onion production falls into three major product segments: (i) bulbs for fresh market, (ii) dehydrated onions for food processing, and (iii) green, salad onions for fresh consumption (Griffiths et al., 2002). World production of onion bulbs (dry onions) in 2018 was estimated at 96.7 million tonnes (FAO, 2020). The biggest producers are Asian countries, accounting for 67.5 % of world production, referring primarily to China and India. European countries contribute with 9.3 % to the world production, 66 % of which comes from EU, with leading Spain and The Netherlands (FAO, 2020). If refrigeration or controlled atmosphere storage is available, onions can be stored for up to 9 months, which, as a major advantage, adds up to their massive production and prevalence all over the world (Griffiths et al., 2002). Still, long storage of onions in bulks can results in notable losses, up to 25-30 % (Lewande, 2012). Therefore, processing of onions ensures product stability while protecting its specific sensory quality. The international market is increasingly focused on dehydrated products such as flakes, rings, granules, powder, etc., and processed onion as frozen or canned, or onions in vinegar and in brine (Lewande, 2012). Processing of onions generates waste material mainly composed of onion skins, outer fleshy scales (usually 2), roots and tops of the bulbs, resulting from the mechanical peeling of the bulbs, as well as of deformed, damaged or rotten bulbs, not suitable for usage (Benítez et al., 2012; Sharma et al., 2016; El Mashad et al., 2019), as can be seen in Figure 1.

Approximately 38 % of the fresh weight of processed onion is not suitable for consumption and discarded as waste. In addition, approximately 10 % of harvested onions are worthlessly marketed, meaning that they do not meet the quality standards for marketing (El Mashad et al., 2019). In the available literature it is reported that annual generation of onion waste in the EU is as high as 500 000 tonnes, dominantly in countries with significant onion production, such as Spain, The Netherlands and United Kingdom (Waldron, 2001; Sharma et al., 2016). Onion waste disposal poses certain problems for conventional ways of vegetable waste disposal, namely: (i) onion solid waste cannot be used as fodder due to the specific aroma or possible toxicity; (ii) also its composting is limited due to the high susceptibility for the growth of phytopathogen Sclerotium cepivorum (white rot) and high content of sulfur-containing compounds; as well, (iii) the combustion of onion waste is rather expensive due to the high moisture content (Jaime et al., 2002; Benítez et al., 2012).

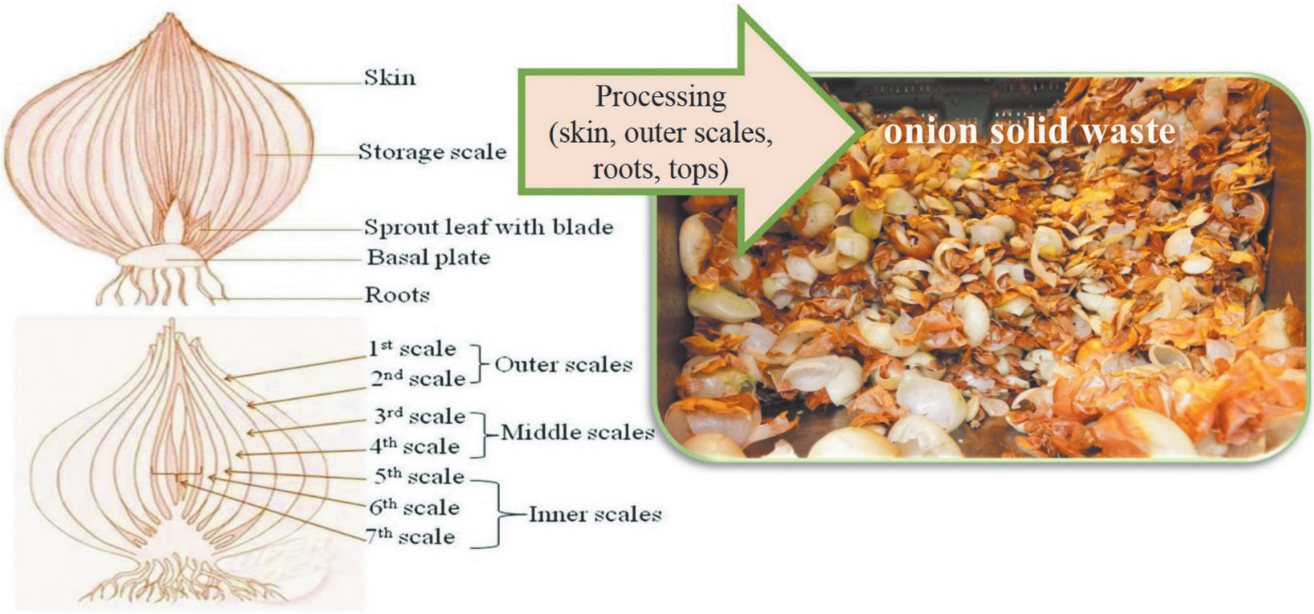

Fig. 1. Onion solid waste generation by discarding unusable parts of the bulb (Sharma et al., 2016)

Onion demand and production is steadily increasing; in the last 10 years, from 2008 to 2018, onion production has increased by about 30% (FAO, 2020). Due to the increasing production, combined with a relatively large amount of generated solid waste without adequate ways of its disposal, onion waste has become an attractive challenge for researchers trying to establish efficient reusing strategies for this biomass. These mainly focus on the production of value-added products, such as functional food in the food industry sector.

3. Constituents of onion waste with bioactive potential

The potential for valorization of onion waste as a source of functional ingredients lies within its interesting and rich chemical composition as well as its well-known health-promoting properties. Onion composition varies with cultivar, stage of maturation, environmental and agro-technical conditions, storage time and bulb section (Jaime et al., 2002; Benítez et al., 2012). Since onion waste is composed of different parts of the bulb in different proportions, and taking into account the above mentioned differences, onion waste chemical composition can notably vary and therefore it is necessary to determine the content of target compounds from case to case. However, onion waste has generally been identified as a source of flavour compounds, fibre, non-structural carbohydrates and polyphenols (Benítez et al., 2012; Sharma et al., 2016) which opens possibilities for its further employment as a source of functional food ingredients for enhancing antioxidant and prebiotic quality of novel products.

3.1 Polyphenols – flavonoids

Flavonoids are a group of polyphenolic compounds known for their strong antioxidant potential. Most important dietary sources of flavonoids are fruits and vegetables, with onion being one of the richest. In addition, flavonoids are dominant polyphenolic compounds found in onion, represented by 2 major subgroups: (i) flavonols, characteristic for yellow varieties, and (ii) anthocyanins, found in red/purple varieties (Griffiths et al., 2002). Representation of flavonol groups, as well as individual compounds within a specific group, is highly dependent on onion variety, as well as on bulb portion and onion growing conditions (Benítez et al., 2011). Main flavonols in onion are quercetin and its glucoside derivatives, with dominant quercetin-4’-glucoside and quercetin-3,4’-diglucoside, which represent up to 80 % of total flavonoids in onion (Benítez et al., 2012). The monoglucoside:diglucoside ratio varies among bulb portions in favour of monoglucoside content towards the outer scales (Benítez et al., 2011). It is believed that quercetin diglucoside is formed during storage and its higher contents are expected in inner scales (Slimestad et al., 2007). Generally, the content of quercetin glucosides decreases towards the outer scales, while the content of aglycone quercetin increases in the same direction, reaching its maximum in the brown onion skin. The increase in aglycone content results from deglucosilation of quercetin glucosides, probably in the presence of sunlight (Higashio et al., 2005). Further oxidation of quercetin by peroxidase results in formation of protocatehuic acid (Takahama and Hirota, 2000) which exhibits antifungal properties. This suggests an enzymatic formation of quercetin-derived defence substances against infection in the dry onion skin (Slimestad et al., 2007). Quercetin, its glucoside derivatives, protocatehuic acid as well as their oxidation products are responsible for yellow and brown shades of onion skins. Slimestad et al. (2007) report that outer dry skins contain 2.5-6.5 % of flavonols by weight, with 67-86 % being quercetin aglycone while quercetin-4’-glucoside only to a smaller extent. On the other hand, a study by Benítez et al. (2011) found quercetin-4’-glucoside dominant over quercetin aglycone in the brown onion skin. As well, in the mentioned study, the outer scales contained the highest content of flavonols, dominantly quercetin-4’-glucoside and quercetin-3,4’-diglucoside. Other quercetin derivatives, besides 4’-glucoside and 3,4’-diglucoside, also can be found in some onion varieties, namely quercetin-3-glucoside (isoquercetin) and quercetin-7,4’-diglucoside, but to a minor extent. Of other flavonols, derivatives of kaempferol, isorhamnetin and possibly myricetin, as well as their aglycones, can be found at low contents (Griffiths et al., 2002; Slimestad et al., 2007). In addition to the mentioned flavonols, dihydroflavonols, such as taxifolin (dihydroquercetin) and its glucosides, also contribute to the polyphenolic profile of onion, while their concentration highly depends on onion cultivar (Slimestad et al., 2007).

Quercetin and its derivatives expose a number of biological activities, including antioxidant, anti-inflammatory, anticancer properties and prevention of cardiovascular diseases (Griffiths et al., 2002; Wang et al., 2016). Therefore, many extraction approaches are being investigated for their efficiency in quercetin recovery (Ren et al., 2020). Moreover, postharvest storage manipulations and processing, such as temperature control, UV irradiation and high pressure have shown a potential in increasing, or at least preserving, quercetin levels in onions (Ren et al., 2020). These measures are being investigated to enhance the bioactive quality of onion as a raw material, and consequently of its waste.

Besides flavonols, a number of anthocyanins has been detected in some onion varieties (red onions), contributing to their distinctive colour in shades of red and purple. These comprise cyanidin-3-glucoside, cyanidin-3-(3″-glucosylglucoside) (also known as cyanidin 3-laminariobioside), cyanidin 3-(6″-malonylglucoside), and cyanidin 3-(3″-glucosyl-6″-malonylglucoside) as the main anthocyanins in most of the cultivars (Slimestad et al., 2007). Most of the anthocyanins reported to occur in various cultivars of red onion are cyanidin derivatives, although minor amounts of peonidin derivatives have been identified, as well as of delphinidin and petunidin derivatives in some cultivars (Slimestad et al., 2007).

3.2. Other constituents

3.2.1 Organosulfuric compounds

Organosulfuric compounds in onion are carriers of its specific aroma and flavour. They derive from non-volatile precursor sulphuric compounds – S-alk(en)yl-L-cystein sulfoxides (ACSO), commonly known as aliin (Rose et al., 2005). Most relevant ACSO in onion are (+)-*S*-methyl-L-cysteine sulfoxide (metiin), (+)-*S*-propyl-L-cysteine sulfoxide (propiin) and *trans*-(+)-*S*-(propen-1-yl)-L-cysteine sulfoxide (izoaliin), the latter being most dominant, representing up to 80 % of ACSO in onion, and thus most responsible for onion characteristic flavour (Griffiths et al., 2002; Benítez et al., 2012). Common to all *Allium* species is the enzyme alliinase that catalyses decomposition of ACSO into pyruvate, ammonia and sulfenic acids. In intact onion tissues, the enzyme is located in the vacuoles, while the ACSO in the cytoplasm. Upon cell disruption, for example by cutting, the enzyme and ACSO come in contact generating sulfenic acids which further spontaneously react among themselves and with other compounds to produce various other volatile organosulfuric compounds, such as thiosulfinates (Griffiths et al., 2002; Rose et al., 2005). Aroma of onion is therefore very complex and changes with time as the volatiles generate and decompose. Besides their importance as aroma compounds, organosulfuric compounds of onion exhibit many health promoting effects as summarized in papers of Griffiths et al. (2002), Rose et al. (2005) and Sharma et al. (2016). In addition, low molecular sulphuric compounds, such as thiols, can act as polyphenol oxidase inhibitors, which opens up the possibility of being used as preservatives and anti-browning agents in the food industry (Sharma et al., 2016).

3.2.2 Carbohydrates

Carbohydrates found in onion can be divided into two major groups: (i) non-structural carbohydrates, and (ii) cell wall polysaccharides. Non-structural carbohydrates in onion comprise glucose, fructose, sucrose and fructo-oligosaccharides (FOS) which constitute a large portion of onion's dry matter, up to 65 % (Griffiths et al., 2002; Sharma et al., 2016). While glucose, fructose and sucrose contribute to nutritive and caloric value of onions, FOS are considered as non-nutritive functional components by being a part of dietary fibre and furthermore well-known and recognized prebiotics. FOS (polyfructosylsucrose) are a sub-group of fructans – complex polymers made of fructose monomers linked with sucrose molecule, which can be found in a wide range of structural diversity and degree of polymerisation (Benkeblia, 2013). In comparison to other fructans, FOS are generally characterized by lower degree of polymerisation (DP). Although, oligomeric and polymeric forms are not clearly distinguished until today so the literature provide different data on the classification of FOS according to degree of polymerisation (Benkeblia, 2013). FOS content in onion, determined as a sum of kestose (GF2 – G-glucose; F-fructose; DP3; β-(1,2) bond), nystose (GF3; DP4) and fructofuranosyl nystose (GF4; DP5), exhibited 30-60 % of total fructans, depending on the onion variety, with kestose being dominant among the three (Jaime et al., 2001). This implies that onion FOS are mainly inulin type oligomeric (DP3-DP5) fructans (Jaime et al., 2001; Benítez et al., 2012). Further studies showed as well the presence of other FOS forms, namely inulin neoseries (Benkeblia, 2013). The FOS content in onion is generally relatively decreasing towards the outer scales (Benítez et al., 2011). Tops and bottoms of the bulbs, as well as dry brown skins show low contents of FOS (Jaime et al., 2001; Benítez et al., 2011). However, since onion solid waste usually comprises a part of fleshy scales, it can be regarded as a potential novel source of FOS. Dietary importance of FOS results from their significant prebiotic effect (Roberfroid, 2007).

Cell wall polysaccharides of onion waste, determined by monomeric sugars analysis upon complete hydrolysis of the material, reveal the dominance of uronic acids (galacturonic acid) and glucose, exhibiting 21 % and 27 % dry matter basis, respectively (Vojvodić et al., 2016), which is correlated to the presence of pectic substances and cellulose (Ng et al., 1998; Jaime et al., 2002; Vojvodić et al., 2016). Dietary fibre analysis revealed predominance of insoluble fibre in onion solid waste, especially in the dry brown skin, tops and bottoms of the bulb (Jaime et al., 2002), but as well in the waste containing fleshy scales, exhibiting approximately 59 % dry matter basis (Vojvodić et al., 2016). High insoluble fibre content is related to the increased content of lignin in the outer parts of the bulb (Jaime et al., 2002). Regarding the high content of galacturonic acid in onion waste, the low soluble fibre content is possibly unexpected. However, these results indicate on structural characteristics of onion waste pectin, making it insoluble for the applied fibre analysis (Vojvodić et al., 2016). Indeed, onion waste pectin is largely chelator-soluble and therefore cannot be readily solubilised using water or diluted acids (Babbar et al., 2015). The application of onion waste pectin and fibre has not been sufficiently supported by the available data so far. However, limited studies suggest the use of solid onion waste (paste and bagasse) in the form of dietary fibre concentrates to enrich foods with dietary fibre and, in addition, to achieve possible additional functionality with regard to hypoglycaemic effects (Benítez et al., 2017). Lecain et al. (1999) suggest onion waste as a potential novel source of cheap pectin. Innovative ways of onion waste pectin valorization include the production of potentially prebiotic pectic oligosaccharides (Babbar et al., 2016; Baldasaree et al., 2018). Valorisation of the second most dominant cell wall polysaccharide – cellulose, could be directed towards its fermentation and bioconversion potential (Choi et al., 2015).

4. Perspectives for onion waste uses

Due to its rich chemical composition, onion waste offers a number of possibilities for reuse. One of the most perspective uses is within food industry as a source of functional food ingredients. For this purpose, onion waste can be used in powdered form, but also in a form of various extracts rich in target compounds or microencapsulated extracts designed to preserve specific quality of the extract (Table 1). As can be seen from Table 1, potential food uses focus on the enrichment of conventional food products with dietary fibre and polyphenols, while food matrices can be very different, from bakery and cereal-based products and meat products to confectioneries. In addition, onion waste as well could be used as flavouring and colouring agent for some food products.

With respect to the carbohydrate content of onion waste, specifically non-structural carbohydrates, onion waste has shown potential as a raw material for vinegar production (Hiriouchi et al., 2000).

Prior to implementation into food products, onion waste needs to be adequately stabilized in microbiological terms, as well as to protect the material from degradative processes that could decrease material's quality. In addition, stabilization is mandatory to ensure waste material's preservation over the time gap between waste generation and its further processing. As reported by Sharma et al. (2016) stabilizing techniques commonly used are sterilization, pasteurization, and freezing, presenting crucial steps for valorization of onion waste as a safe food ingredient, since the waste involves risk for microbiological growth and decomposition of value-added compounds. Since these methods can affect quantitative and qualitative profile of bioactive constituents, the choice should be made with respect to the aim of waste usage.

Besides stabilization, further steps of onion waste preparation also must be carefully planned. This is particularly important in the preparation of onion waste extracts where it is desired to have efficient extraction of target compounds while reducing negative environmental impact and hazard. From the life-cycle assessment approach, conventional extraction strategies for the recovery of quercetin and FOS from onion waste resulted in significant environmental burdens and therefore the development of alternative extraction techniques should be encouraged (Santiago et al., 2019).

Table 1. Summary table of potential food uses of different forms of onion waste

Form of onion waste	Application matrix /final product	Functional/technological benefits	Reference
onion peel powder	fermented onion peel	• functional food based on fermented onion peel rich in flavonoids and prebiotics	Kimoto-Nira et al., 2019
onion peel powder	wheat flour extrudates	• extrudates with higher antioxidant activity, smaller diameter and pore size	Tonyali and Sensoy, 2017
onion peel extract	emulsion pork sausage	• product with improved quality characteristics and higher shelf life stability	Lee et al., 2015
onion peel powder	bread	• bread with enhanced antioxidative properties	Gawlik-Dziki et al., 2013
onion peel extract	film from *Artemisia sphaerocephala* Krasch gum (ASKG)	• onion peel extract-containing ASKG films express potential as intelligent packaging materials and gas-sensing labels with pH indicator	Liang et al., 2018
onion peel powder	Hanwoo Tteokgalbi	• natural preservative and antioxidant properties of product with great water retention	Chung et al., 2018
onion peel powder	gluten-free bread	• consumption of enriched bread increased antioxidant activity of consumers' blood	Bedrnicek et al., 2020
onion peel extract	wheat bread	• bread with higher antioxidant activity and phenolic content	Piechowiak et al., 2020
onion peel extract	bean paste	• paste with higher antioxidant activity and phenolic content	Sęczyk et al., 2015
onion peel extract	hard candy and glazing jelly	• natural food colorant	Om-Hashem et al., 2016
onion skin powder	wheat pasta	• enhancement of nutritional and antioxidant quality while maintaining sensory acceptability; authors recommend onion skin powder as a possible additive in pasta making	Michalak-Majewska et al., 2020
microencapsulated onion peel extract	cake	• cake of higher specific volume, enhanced moisture absorption and texture as well as phenolic content	Elsebaie and Essa (2018)

5. Conclusions

Increasing world production and processing of onion results in a substantial amount of generated waste. Conventional ways of vegetable waste disposal seem to be inadequate in the case of onion so other options are intensively being explored. Due to its abundance in components with bioactive potential, the reuse of onion waste for the production of enriched food products possibly presents the best valorization strategy. In this way, the low-value material is reduced as waste and simultaneously upgraded to a valuable secondary raw material.. By its reuse in food, one part of the originally produced biomass intended for food, could be brought back to the food chain while additionally exhibiting added value through the health-promoting effects of its bioactive constituents. The most important potential ingredients from onion waste to consider are quercetin and its glucosides, and dietary fibre – as a whole or separated fractions of FOS and pectin. However, onion waste reuse in practical large-scale terms is not easy to achieve. Many researchers worldwide try to find solutions for efficient stabilization of the material, efficient and environmentally acceptable extraction techniques of target compounds, preservation of extracts' functional characteristics through various delivery forms, optimal ways of implementation into food products and finally, ways to prove health claims. To the present day, many studies have prepared the ground for presenting onion waste as a material to be explored. Indeed, onion waste has shown a great potential to be incorporated into different food matrices in various forms: as a powdered concentrate, an extract, or most innovatively as microencapsulates, in order to obtain innovative food products with enhanced antioxidant and prebiotic quality. There are still many unexplored possibilities for food implementation and research to discover its full potential.

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