

High value co-products from plant foods:

Nutraceuticals, micronutrients and functional ingredients

- The waste portion in the processing of some fruits and vegetables can be as large as 70% of the harvested material.
 - In leafy vegetables (lettuce, spinach etc.) the external leaves are often removed as they are too hard and green and often have some defects (bruises, cuts etc.).
 - In other products, the edible portion is the flower and in this case the leaves, stems and some parts of the flower are discarded.
 - In onions, the residues are external membranes and sometimes scales.
 - The peels are frequently wastes, as in the case of most fruits, potatoes, tomatoes etc.
 - In other products the wastes are the fruit husks (banana, citrus, pomegranates, etc.) and shells (pistachio, almonds, walnuts, etc.)
 - The fruit stones are also wastes from fruit processing (peach, apricot, etc.).
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- In some cases the wastes generated are the waters of industrial processing (brines, blanching waters, cooking waters, etc.), and these are generally rich in secondary metabolites.
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- The use of waste as an animal feedstuff is a common practice, being the main use for plant food industry residues.
 - Bio-fuel and compost production as well as the preparation of dietary fibres are also alternatives already in use.
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- The use as animal feedstuff has some limitation as the wastes are generally very rich in water and are highly perishable, fungal development is very likely to occur with the risk of mycotoxin production. These mycotoxins could then pass to the animal tissues and therefore to man.
 - The use of waste for composting also has some application, and composts and manures from different wastes are available on the market.
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- These waste tissues are also rich in bioactive secondary metabolites, and therefore there is an opportunity for the extraction of high-value compounds from wastes.

- Once they are extracted the residues could still be used for animal feeding or for composting or fuel production.
- In addition, there is a demand for functional foods (foods with specific physiological effects in humans) and nutraceutical preparation both from society and the industry, and the phytochemicals present in these plant food residues can be an excellent raw material for the production of these extracts.

Phytochemicals present in plant food residues

- The main groups of plant secondary metabolites that are suitable for use in nutraceuticals or as functional food ingredients are the terpenoids, the polyphenols and the organosulphur compounds.
- The **terpenoids** are biosynthesized by the acetate-mevalonate pathway and constitute a group of lipophilic compounds with a wide range of molecular weights, biological properties and potential uses.
- Monoterpenes (10 carbon atoms) are generally volatile compounds that are constituents of the essential oils (i.e. limonene) and are key compounds in the flavor of some fruits. Some of them have relevant biological properties.
- The sesquiterpenes and diterpenes (15 and 20 carbon atoms, respectively) are less relevant in food, while the triterpenes (30 carbon atoms) are relevant phytosterols (ergosterol, sitosterol, etc.) and the tetraterpenes (40 carbon atoms) including carotenoid pigments with interesting biological properties (lycopene, beta-carotene, etc.).
- The **polyphenols** constitute a very large group of secondary metabolites characterized by the presence of phenolic hydroxyls in the molecule.
- Their chemical and biological properties are also very wide. Some of them are water soluble (some anthocyanins), while other are highly lipophilic (the citrus flavone tangeretin).
- They have been classified as flavonoids and non-flavonoid compounds.
- Flavonoids include anthocyanins, flavones, flavanones, chalcones, isoflavones and procyanides (flavon-3-ols).
- Non-flavonoids compounds include benzoic acid derivatives, hydroxycinnamates, ellagic acid derivatives and ellagitannins, and stilbenoids.

- **Organosulphur compounds** are biosynthesized from sulphur amino acids and include the compounds of the alliaceae (alliin and allicin) and those of the brassicaceae (glucosinolates).

Use of plant food residues as sources for phytochemicals

- Examples of the actual use of wastes from fruit processing industry to produce extracts that are available in the market include orange, grape, apple and olive residues.
- The residues from orange-juice extraction industries (orange albedo and flavedo, and fruit segments) have already been exploited for many years for the extraction of flavanones (hesperidin and related compounds) and pectin.
- Grape wastes from the wine-making industries (grape pomace and seeds) are also used industrially for the extraction of anthocyanine pigments, procyanidins and polyphenol extracts.
- From the olive-oil extraction industries, the residues can be used for extraction of hydroxytyrosol.
- From the cider industries, the apple pomace are already used for extraction of pectins although phytochemical extraction has not yet been implemented.
- Recently research has been developed to use the tomato-juice production residues for the extraction of lycopene, a bioactive terpenoid pigment from tomato, and this has been studied by different groups using specific extraction techniques.
- The exploitation of residues from vegetable production and handling for extraction of phytochemicals is actually less developed.

Potential uses of high value co-products

- The phytochemical extracts can be used either for their biological properties as ingredients for nutraceutical preparation or functional foods, or for their food quality related properties, which include antioxidant properties, color properties and flavor properties.
- The health related uses of phytochemical extracts include their use as ingredients for nutraceutical preparation or functional ingredient.

Nutraceuticals

- Examples of these would be pills or capsules containing olive waste extracts or grape seed extracts. In many ways, they are pharmaceutical like forms.

- Although they are produced from food products, and the active phyto-chemical are constituents of food normally consumed in the diet, they are concentrated and presented in pharmaceutical forms in which the active principles are present in higher amounts.
- The concentration and presentation as pharmaceutical forms affect their bioavailability and bioactivity.

Functional foods

- In this case, the extract constitutes ingredients that are added to food.
- Two different strategies can be followed. One related to “food enrichment” and another to “novel formulation”.
- In the food enrichment strategy, the extract are added to the food of the same origin e.g. a grape or berry juice in which the extracts obtained from the press-cake wastes, are incorporated into the juice to produce a “whole-bran” juice, olive oil in which phenolic antioxidants remaining in the residues are incorporated into the oil, etc.
- In the “novel formulation” approach extracts added to different foods for increasing the phytochemical content (e.g. orange juice with added berry press cake extracts will provide the anthocyanines and other polyphenols from berries in addition to the natural constituents of orange).

Important sources of high-value co-products

1. Fruit processing

Apple:

- Residues are mainly generated in the juice and cider production industries.
- The wastes are in the form of pomaces, and include peels and seeds in addition to other solid tissue parts.
- The composition of these residues is very variable and depends largely on the apple cultivar processed.
- The main use of pomace is for pectin extraction.
- Other potential uses would be extraction of phenolic compounds.

Peach and apricot:

- These fruits are used for juice production and pomace are produced but not yet used for phytochemical extraction.

- Only fiber is industrially processed today and can be found in the market although phenolic and carotenoid extracts could be alternative extracts for the future.

Citrus:

- Essential oils are directly produced in the juice production plants as a co-product and have a market.
- The main wastes include the citrus peels, residues from segments and seeds after pressing.
- These residues are rich in pectin and flavonoids.

Berries:

- Different berries are processed as juice and the press-cake constitutes a relevant by-product rich in phytochemicals.
- In blueberry and bilberry, the residues are especially rich in anthocyanins and flavonols.
- These extracts are already traded and have a place in the dietetic and pharmaceutical markets.

2. Vegetable processing

- Vegetables are processed as fresh-cut products to produce salad mixes, as ready to cook preparation (spinach, potatoes etc.), and also as a juices (tomato and carrot), frozen vegetables, canned products.

Tomato:

- Tomato pomace consists of the dried and crushed skins and seed of the fruit.
- This residue is rich in lycopene and carotenoids.

Carrot

- A pomace is generated after juice production.
- This is rich in beta-carotene and phenolic compounds.

Onion

- Onion handling activities produce wastes that include the external membranes, in the fresh cut industry; scale tissues are also included in the residues.
- These external tissues are the richest in onion flavonoids.
- In addition, the residues can be a good source of organosulphur compounds that have relevant biological activities.

Technological processes for phytochemical extraction from residues

- Taking into consideration the nature of the residues, the extraction processes used for the preparation of these phytochemical extracts have to meet some requirements.
- Firstly, it is preferable to use fresh raw materials for extraction as a drying process, although allowing storage, leads to unacceptable increases in production costs.
- It is also necessary to use food-compatible solvents, for example water, ethanol, methanol or a mixture of these.
- Thermal treatment is generally necessary to inactivate enzymes that can degrade the phytochemical during the extraction process.
- In some cases, the phytochemical yield extracted from residues can be enhanced by adding enzymes such as pectinases or cellulases.

Safety issues

- It is essential to make sure that the pesticide and other agrochemicals are not concentrated in the extracts in the same way the phytochemicals are.
- Another risk is mycotoxin contamination of the extracts due to fungal growth in the residues before extraction.
- Another is related to the presence of microbial contamination in the extracts if thermal treatments are not used during the extraction process.