# Extraction of bioactives from fruit and vegetables: State of the art and perspectives



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Abstract: Fruit and vegetables are rich in bioactive compounds that contribute to the prevention of a number of degenerative diseases. These components are also present, often in even higher concentrations, in the co-products from fruit and vegetable processing. Such fact, makes these co-products an attractive source for the extraction of bioactives, turning the extraction itself into an attractive valorization strategy for these co-products. There has been recently renewed interest in extraction methods, notably with a process intensification using physical phenomena and the search for alternative solvents.
This paper will present the main bioactives in fruit and vegetables, and their co-products, and the precautions to preserve these molecules in the food processing chain, with a main focus on the pros and cons of recently proposed extraction developments, particularly on extraction mechanisms, sample pre-treatment, and solvent choice.

Cover Letter

UMR408 SQPOV

Avignon, August 21, 2017

Dear Professor Sathe,

Please find attached the text of a short review which I would like to submit to LWT-Food Science and Technology, titled: "Bioactives in Fruit and Vegetables and their Extraction Processes  State of the Art and Perspectives". The aim is a general overview of the newly proposed extraction methods and the specific challencges when they are used for extraction of bioactives from co-products of fruit and vegetables.

I am the sole author. The review has 3200 words, 2 tables and 49 references

Cordially

Catherine Renard

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***Detailed Response to Reviewers**

Answer to reviewers

The manuscript is a short and focused review on an important topic. The author succinctly covers the important issues in this arena of research from a practical viewpoint and summarizes what is known and what should be looked at in the future. While discussing the issues the author explains the reasoning and possible causes/problems encountered in a lucid manner. Overall, the review is well written. A minor suggestion is to tidy up the write-up. A few points in this regard are noted below:

Thank you for your appreciation. I have had the manuscript corrected for English by a commercial service, which should have substantially tidied up the write-up, at least there were a number of English language corrections. (in blue)

1. Line 48, colour should be "color"?
2. Line 51, suggest use inexpensive instead of cheap
3. Line 80, sa(Brewer, 2011)ponins should be saponins (Brewer, 2011)
4. Line 85 (energy production---) should be (e.g., energy production, protein synthesis and others) to avoif the use of …. In a sentence.
5. Line 89, (anthocyans? Is it meant to be- (anthocyanins).
6. Line 132, carotene should be carotene
7. Line 184, replace cheap with inexpensive or affordable

All of these have been done (in red)

8. Lines 310-319, Include a sentence or two either in this paragraph or any other place in the conclusion section about the lack of investigations addressing the in vivo absorption and bioavalability of the "functional" ingredients purported to be "bioactive". In addition there is a clear devoid of valid information based on in vivo studies that demonstrate, beyond reasonable doubts, efficacy of several reported "bioactive and/or functional ingredients". A good example is that of the time and again some reporting the functionality of "ginko biloba" where the is no proof it has, beyond reasonable doubt, efficacy in vivo in a living organism.

The author may consider adding a short table summarizing a list of "functional or bioactivess" reported but not demonstrated to be effective in vivo (particularly in humans). The author has pointed this out in a subtle way when discussing the "chronic diseases and the role of extractives". May consider expanding that section with a couple of specific examples.

I totally agree with the reviewer; however this deserves a review (metaanalysis?) of its own and goes much beyond the scope of the present, more technical, review. I have therefore:

- Changed the title to make it clearer that my focus was on the extraction process itself
- -Added a number of qualifiers regarding the fact of “bioactivity” (in red)

***Highlights (for review)**

Highlights

New extraction methods have received a lot of attention in the last 10 years

Most studied methods were microwave and ultrasound-assisted extraction

Alternative solvents are sought with improved eco-toxicity

More attention should be paid to pre- and post-extraction processes

Use of co-products is limited by their availability and limited choice of bioactives.

# Extraction of bioactives from Fruit and Vegetables: State of the Art and Perspectives

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**Abstract**

Fruit and vegetables are rich in bioactive compounds that contribute to the prevention of a number of degenerative diseases. These components are also present, often in even higher concentrations, in the co-products from fruit and vegetable processing. Such fact, makes these co-products an attractive source for the extraction of bioactives, turning the extraction itself into an attractive valorization strategy for these co-products. There has been recently renewed interest in extraction methods, notably with a process intensification using physical phenomena and the search for alternative solvents.

This paper will present the main bioactives in fruit and vegetables, and their co-products, and the precautions to preserve these molecules in the food processing chain, with a main focus on the pros and cons of recently proposed extraction developments, particularly on extraction mechanisms, sample pre-treatment, and solvent choice.

Keywords: micronutrients, functional properties, stability, process intensification, solvent

## 1. Introduction

The increase in consumers' demand for naturalness and the trends towards plant-based foods has sparked a renewed interest in fruit and vegetables and their co-products as sources of bioactive and functional components. Most hydrocolloids (polysaccharides) as well as a number of colorants (anthocyanins, carotenoids, betalains) or antioxidants (rosemary leaf extract, E392) are extracted from plants. These have clear technological functions in the foods and can be used to replace some synthetic additives. The concept of "bioactives" is much more difficult to substantiate. A high level ("five-a-day") of consumption of varied fruit and vegetables is associated with better health, and there has been great interest in identifying the molecules behind this effect. In recent years, this has progressed beyond the oversimplifying "antioxidant" hypothesis towards the identification of mechanisms by which these molecules, or rather their metabolites, interact with specific targets in the human organism (Dangles, 2012). However, there is still a lack of critical outlook on which the actual activities of these “bioactives” are, and many papers use simplistic colorimetric antioxidant assays as proxy for bioactivity.

Concurrently, there has been renewed interest in methods to obtain these bioactive or functional components either for food uses, which are mostly relevant for molecules with functional properties (texture, color, antioxidant, aroma or taste), as food supplements, though their use as isolated molecules has proven disappointing, or as cosmetics. For economic reasons, the preferred sources are the co-products from fruit and vegetable processing as these are inexpensive and often highly concentrated in some bioactives. The ideal situation would be a complete use of the fruit and vegetable biomass in a biorefinery that would take into account food uses, high value bioactives, and the use of the remaining bulk material. Major issues for development of such a biorefinery lie in conciliating the different aims and qualities of the products as well as in dealing with availability issues.

Classical extraction techniques such as maceration or supercritical fluid have been supplemented with many “assisted” extraction techniques where an additional physical phenomenon is used to intensify the process. There has been an explosive growth of publications on these topics since the year 2000 (Kala, Mehta, Sen, Tandey, & Mandal, 2016; Mandal & Tandey, 2016). The physical phenomena range from ultrahigh pressure to void (instant controlled pressure drop), from microwave to ultrasound or electric fields. Many of these techniques were first developed for analytical purposes in order to obtain a true quantification of the bioactive molecules, and some have proven to be profitably up-scalable, at least at pilot-scale level. Newer challenges concern the solvents used in the extraction, as REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals regulation) comes into application and costs of solvent recovery become more and more significant. Biosourced solvents, subcritical liquids or ionic liquids thus appear now more frequently in the scientific literature and also pose specific challenges.

## 2. Bioactives in fruit and vegetables: chemical classes and activities

The very notion of “bioactive” or bioactive compounds can have different definitions in scientific literature. It is generally associated with the existence of a positive effect on chronic pathologies, with different levels of proof (Amiot, Coxam, & Strigler, 2012). In the most common meaning of the term, it does not cover vitamins or dietary fibers, although they are proven to be indispensable for human health, or compounds with demonstrated acute pharmacological or negative activities (notably alkaloids). Indeed, fruit and vegetables by definition have no detectable acute effect in a normal dietary pattern, at least in the Western world, while many drugs were originally identified in plants, giving rise to the large field of phytochemistry. Some chemical classes such as saponins (Brewer, 2011) are “borderline”. The level of proof or activity needed for a health claim appropriate to a functional food or nutraceutical is therefore a tight balance between the demonstration of a pharmacological effect and unsubstantiated claims. The best evidence of such fact is that very few molecules or extracts have been able to pass the stringent evaluation of claims made by EFSA (European Food Safety Agency).

In terms of plant physiology, most of these compounds are secondary metabolites, i.e. they are not necessary to the plants’ basic metabolism (e.g. energy production, protein synthesis, and others). It is generally believed that their role *in planta* concerns interactions with the outer environment, where they may act as protective agents against UV radiation (flavonols), as deterrents against herbivores (glucosinolates, some polyphenols), or as attractants for pollination (anthocyanins), among other properties and functions. The underlying chemical complexity explains that relatively few of these molecules have been studied for their action in preventing life-style diseases or the relatively low levels of proof for many of them. This may also explain why most developments have been focused on a few classes that are either remarkably abundant (like the polyphenols or carotenoids) or remarkably active (glucosinolates, isoflavones).

Table 1 summarizes the classes of compounds that are most commonly called “bioactives” and which can be found in fruits or vegetables *sensu largo*, i.e. including herbs and spices, but not medicinal plants. Some of the classes are very specific of a given botanical family, for example the capsaicinoids (Capsicum) or glucosinolates (Brassica) while others are very widespread, like the phenolic acids or flavonols.

Many of these compounds have antioxidant properties. It is now generally recognized that the health effects of bioactives are mediated by specific interactions of their circulating metabolites with cellular targets (Dangles, 2012) and not antioxidant activity per se. However the antioxidant properties may be relevant when focussing on food or cosmetics stabilization, for the replacement of synthetic antioxidants such as butylhydroxytoluene or the prevention of oxidation of polyunsaturated fatty acids in the gut (Brewer, 2011).

## 3. Co-products from fruit and vegetable processing and their stabilization

Many of the secondary metabolites are concentrated in the outer, least palatable parts of fruit and vegetables and are therefore present in high concentrations in the co-products processing (Baiano & Del Nobile, 2016; Banerjee et al., 2017; Lavelli & Torresani, 2011; Le Bourvellec et al., 2011; Martins & Ferreira, 2017; Strati & Oreopoulou, 2014). However, these high concentrations are relative: polyphenols may reach from 10 to 50 g/kg DW (dry weight) in pomaces from fruit juice extraction (Juśkiewicz et al., 2015; Kolodziejczyk et al., 2009; Pieszka, Gogol, & Pietras, 2015), while carotenoids yield under 10 g/kg DW even in tomato by-products (Kalogeropoulos, Chiou, Pyriochou, Peristeraki, & Karathanos, 2012; Lavelli &

Torresani, 2011), and dietary fibers represent over 500 g/kg DW (Garcia, Valles, & Lobo, 2009; Kolodziejczyk, et al., 2009).

A major limiting factor is that of an eventual co-product resource as the question of bioactives cannot be addressed from the target property but from availability. We do not ask ourselves "what can I extract this molecule of interest from" but "what can I do with the co-product I have". Another point to be considered is the high variability of the resource: concentrations of the target compounds are likely to vary, sometimes over 10-fold, depending on the exact variety (and its maturity stage) (Garcia et al., 2009).

The alternative is the establishment of a specific production chain, which demands a demonstrated and sufficient final value of the bioactive. Indeed, there are often alternatives using specific plants or other parts of plants, which are economically more viable than relying on fruit and vegetables. For example, lutein is extracted from *Tagetes* flowers and alfalfa; β-carotene from specific varieties of carrot with high concentrations; phloridzin is much more abundant in apple leaves than in apple fruit (Gaucher et al., 2013).

In practical terms, this means that research on bioactives from fruit and vegetables is still very much "opportunity-driven", i.e. focused on products that meet conditions of availability and potential interest. The availability of a co-product is in turn linked to the existence of a production chain. Thus, the most studied sources (Galanakis, 2012) are pomace from grapes (wine) (Barba, Zhu, Koubaa, Sant'Ana, & Orlien, 2016), tomato (pulp and concentrate), apples (juice), berries (juice), peels from Citrus (juice) or mango (puree or dried mangoes), sugar-beet pulp (sugar refining), waste water from olive processing (olive oil), and peels from onion or salad (fresh-cut onions or salads). Dietary fibers and polyphenols are the main chemical classes of interest, only with tomato co-products being abundant and rich in carotenoids.

The treatments that take place for the initial product preparation (for example preparation of cloudy or clear juice, Kolodziejczyk et al., 2009) as well as those used for the stabilization of the co-product will also impact its composition and potential as a source of bioactives. Two phenomena must be taken into account when envisioning the extraction of polyphenols from e.g. apple pomace: one is that the molecules present in the pomace may not be those of the original fruit, as there can be extensive enzymic oxidation during the juice extraction and pomace processing (Heras-Ramirez et al., 2012) as well as chemical degradation; and the other is that some polyphenols, notably the condensed tannins, form strong adducts with the cell wall material (Renard, Watrelot, & Le Bourvellec, 2017) and may become un-extractable. Whether the pomace is initially treated to inhibit enzymes or not, the drying method and temperature as well as its final water content and storage temperature will all impact the final composition (Heras-Ramirez, et al., 2012; Lavelli & Corti, 2011; Lavelli & Torresani, 2011; Yan & Kerr, 2013). Carotenoids, in contrast to polyphenols, appear less stable at the lower $a_w$ values (Lavelli & Torresani, 2011).

One major difficulty in going from a laboratory demonstration to actual industrial production lies in the seasonal availability of fruit and vegetables and also of their co-products. For example, industrial tomatoes are harvested and processed over a period of about two months. Therefore, their pomace, although remarkably high in lycopene, is only available fresh during this short period. The implementation of co-products, which are prone to microbial waste, may require immediate processing or a stabilization step, most often by drying, which may lead to some loss of bioactives by thermal degradation of the more fragile molecules or interfere with the extraction procedure itself (Rajha et al., 2014).

## 4. Recent developments in extraction methods

### 4.1. Conventional methods

The most classical methods for extraction of bioactives rely on maceration (with more or less intense stirring) in a solvent of appropriate polarity (Galanakis, 2012). A first improvement is increasing the extraction temperature for better dissolution and lower solvent viscosity, as done e.g. in heated reflux extraction (which also takes advantage of concentration equilibria) or in a Soxhlet apparatus (which has the further advantage of separating the soluble from the insoluble fractions). Decreasing particle size is also a factor that has long been taken into consideration as it facilitates mass transfer and thus increases extraction speed (and yields). Supercritical fluids, and among them mostly carbon dioxide, have been used industrially in the food and cosmetics industries. Supercritical carbon dioxide has a low critical temperature and pressure (31 °C, 7.39 MPa), which is of interest for labile molecules, and its polarity can be increased by adding co-solvents (e.g. ethanol). It is GRAS (Generally Recognized as Safe) and non-explosive, relatively affordable, and the extracted compounds can be recovered by evaporation of the gas. It is commonly used for the extraction of essential oils and has a good potential for carotenoids.

Enzymic pre-treatments have also been used in improving extraction yields, because it has long been acknowledged that plant cell walls are one of the limiting factors. However pre-treatments with cellulases or pectinases demand long incubations (typically a few hours) in aqueous media.

## 4.2. Emerging technologies

More recent developments concern the use of non-thermal concepts to facilitate the extraction without risking the matrix overheating while decreasing energy use. Recent reviews describe the application of conventional and emerging technologies to the extraction of various classes of bioactives (Ameer, Shahbaz, & Kwon, 2017; Gil-Chavez et al., 2013; Lu, Ho, & Huang, 2017; Poojary et al., 2016; Wijngaard, Hossain, Rai, & Brunton, 2012). All aim to destroy cell integrity by elimination of the cell membranes or cell walls. The most studied applications since 2005, as identified from scientific publication trends, concern microwave and ultrasound-assisted extraction (Mandal & Tandey, 2016).

Microwaves are electromagnetic waves, generally used at 2.45 GHz, which interact with polar molecules (typically water, ethanol…) and generate heat (Zhang, Yang, & Wang, 2011). In microwave-assisted extraction, the moisture inside the cell is heated and its evaporation increases the porosity of the biological matrix, which in turn allows the better penetration of a solvent (Ho, Ferruzzi, Liceaga, & San Martín-González, 2015). The elevated temperature also generally increases solubility and improves yield. Its main advantage is a reduction of the extraction time and solvent use. Elevated temperatures may still result in some degradation of the more labile molecules (Cardoso-Ugarte, Sosa-Morales, Ballard, Liceaga, & San Martín-González, 2014).

Ultrasound (> 20 KHz) improves extraction through acoustic cavitation: above certain energy levels, the acoustic waves interact with the solvent and dissolved gas by creating free bubbles that can expand to a maximum size and violently collapse, generating locally extreme heat and pressures (Tiwari, 2015). Due to this cavitation phenomenon, the cell walls can be ruptured, providing channels for solvent access, and mass transfer is improved (Pananun, Montalbo-Lomboy, Noomhorm, Grewell, & Lamsal, 2012). The small size of the bubbles means that the heat generated upon collapse can be dissipated rapidly and the bulk temperature increase can remain limited (Virot, Tomao, Le Bourvellec, Renard, & Chemat, 2010). However, liquid-solid separation may be hindered since ultrasound can lead to the swelling and disintegration of the plant material (Virot et al., 2010).

Although many articles report the “optimization” of microwave or ultrasound treatments for extraction, many of them fail in their purpose. This is particularly true for the frequent use of response surface methodology (RSM) to conclude that the highest yields are obtained at the highest power, longest durations, highest temperature and highest solvent/solid ratio. All can be expected and this does not correspond to the correct use of RSM. If the optimum is at an extreme of the experimental plan, by definition the limits of the RSM were not well chosen, or the authors have used statistics to avoid thinking about the actual mechanisms.

Among electrotechnologies, different pulse protocols and intensities of electric fields have been used to generate cell disintegration and thus enhance extraction of intracellular compounds. The most studied is Pulsed Electric Fields (PEF), in which the sample is submitted to very short periods (from several nanoseconds to several milliseconds) of an intense electric field. This causes the formation of pores in the cell membranes (electroporation), which helps in solvent diffusion and facilitates mass transfer (López, Puértolas, Condón, Raso, & Ignacio, 2009; Puértolas, Cregenzán, Luengo, Álvarez, & Raso, 2013; Rastogi, 2003). PEF is also used to increase juice yields, i.e. non selective extraction of intracellular fluids (López, Puértolas, Condón, Raso, & Ignacio, 2009)

Pressurized liquid extraction (or accelerated solvent extraction) relies on increased temperature and pressure in a solvent kept below its boiling point to enhance mass transfer and modify surface equilibria in the solid – liquid extraction (Mustafa & Turner, 2011). Pressure is primarily used to maintain the solvent in the liquid phase, though it may also facilitate solvent entrance in the pores of the matrix. It is commonly used in the analytical quantification of bioactives and also pesticides. The elevated temperature also modulates the polarity of the solvent and thus its extraction selectivity.

Negative pressure cavitation is a patented technology that aims to produce cavitation by depression to generate an intense erosion of solid particles and increase turbulence and mass transfer from the solid matrix to the solvent (Roohinejad et al., 2016).

Another potential pre-treatment is high pressure homogenization (Corrales, Garcia, Butz, & Tauscher, 2009; Xi, 2017), a wet milling process where plant particles are disintegrated by high intensity mechanical stresses as a consequence of the liquid flow through a homogenization chamber at high pressures (50-500 MPa). It can be used on wet samples.

Another method which has been proposed for sample disintegration prior to extraction is instant controlled pressure drop (DIC for Détente Instantanée Controllée) (Allaf et al., 2013). In DIC, the sample is subjected to saturated steam for a short time and then to a sudden pressure drop at low pressures. This causes the instantaneous vaporization of water, resulting in a cell wall expansion and rapid cooling. The instantaneous vaporization allows the recovery of essential oils while polyphenols or carotenoids are more easily extracted from the remaining fine powder (Allaf et al., 2013). Similar results may be obtained by intense grinding, provided that care is taken to prevent temperature increase during grinding.

## 4.3. Alternative solvents

The solvent choice is a concern as it impacts selectivity, the removal and disposal method, costs and safety. The REACH directive has notably been an incentive for “green” solvents in replacement of *n*-hexane. For example, among alcohols, ethanol is often proposed due to its low boiling point and GRAS status but may not be efficient for less polar molecules such as carotenoids. Water is also often tested, alone or in mixture with ethanol or acetone, in spite of its high energy requirements for evaporation (Wiboonsirikul, Hata, Tsuno, Kimura, & Adachi, 2007). More apolar solvents, mostly terpenes (limonene, alpha-pinene), have also been proposed (Filly, Fabiano-Tixier, Fernandez, & Chemat, 2015). Another option is the use of subcritical solvents such as liquefied gases (e.g. *n*-butane), which may ally low polarity and facile solvent elimination by decompression at or close to room temperature (Rapinel et al., 2017). However, safety issues must be addressed for these new solvents.

Recently, ionic liquids have been proposed for the extraction of bioactives. Ionic liquids *senso strictu* are organic salts in a liquid state. Although they are viscous, their polarity can be adjusted across a wide range of hydrophobicity/hydrophilicity, and some of them are distillable in conditions compatible with the recovery of bioactives (Almeida et al., 2014; Lu et al., 2013). The most recent trend in this field is the use of “natural deep eutectic solvents” (NADES), which are combinations of natural components such as sugars, organic acids or aminoacids with tailored solvent properties (Radosevic et al., 2016). However, solvent removal becomes more complex.

## Conclusion

A lot of experimental work has been devoted in the last 10 – 20 years to the development of “alternative” technologies for the extraction of bioactives from plants, including fruit and vegetables. It is time for this body of experimental data, which mostly relies on the statistical optimization of yields, to give place to more mechanistic oriented research. In addition, post-extraction treatments (elimination of the solvent, purification…) are the poor relatives in this research.

A number of technical issues have to be addressed before and after extraction: will the raw material be stabilized or only extracted fresh, i.e. over a short period? If it is stabilized, how shall it be done with the least loss of bioactive? Is a purification step needed? Most of these molecules are only present in low concentrations. Therefore, their extraction will still leave large amounts of waste: can that waste in turn become a co-product? This requires anticipation and conceiving the whole chain in an integrated manner for the valorization of the whole biomass.

Two main conditions must be met for the extraction of bioactives from fruit and vegetables to be economically interesting:

- The activity or functionality of the molecules must have a market potential;

- It must be present in an amount that is compatible with its market in an inexpensive co-product – or the market potential must be sufficient for specific production.

Color and antioxidant capacity are properties relatively easy to assess, which may explain why they constitute the main fields of application for extracts from fruit and vegetables. Having sufficient data for a health claim or nutraceutical use is a totally different proposition since the cost of demonstrating the claim becomes high. This may explain the lack of valid information based on *in vivo* studies that demonstrate, beyond reasonable doubts, the efficacy of several reported "bioactive" ingredients.

All of this may explain why, in spite of the wide research, few fruit and vegetable co-products are actually used at industrial scale for the production of bioactives (Galanakis, 2012): anthocyans from grape skin, (oenological) tannins from grape seeds, lycopene from tomato waste (Strati & Oreopoulou, 2014), polyphenols from olive mill waste water and flavonoids from citrus peel. The production of oil from grape seeds or kernels of plums, apricots and peaches, dietary fibers from vegetable wastes and pectin extraction (from citrus peel, apple pomace or sugar-beet pulp) may also be counted in this valorization of fruit and vegetable co-products. The few successful examples need to be carefully analyzed, not from a technological perspective but from a socio-economic and legislative point of view to identify the factors of their success.

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Table 1: The main chemical classes of bioactive compounds in fruit and vegetables (from Renard et al., 2012)

| Chemical classes | Main Fruit and vegetable sources | Properties of interest |
|---|---|---|
| **Terpenoids** | | |
| Monoterpenes | “herbs”, citrus | Aroma, digestion, antiseptic… |
| Diterpenes : carnosic acid | “herbs” (rosemary) | Aroma, antioxidant |
| Triterpenes: Phytosterols, | Plant oils | Cardiovascular health |
| Saponins | Soy, chestnut | |
| Tetraterpenes: Carotenoids: | | |
| Carotenes: β-carotene | Orange fruit and vegetables, carrot | Color, provitamin A |
| lycopene | Tomato, watermelon | Color, prostate cancer |
| Xanthophylls: lutein | Green vegetables | Age-related macular degeneration |
| | | |
| **Phenolic compounds** | | |
| Flavonoids | | |
| Flavonols | Onions, fruit, vegetables | Antioxidant |
| Anthocyanins | Red fruits, berries | Color, antioxidant |
| Flavanols and proanthocyanidins | Tea, wine, chocolate, cider, fruits | Astringent, Antioxidant, enzyme inhibition |
| Flavanones | Citrus | Antioxidant |
| Isoflavones | Soy, legumes | Phyto-œstrogen |
| Non flavonoids | | |
| Phenolic acids | Coffee, fruits and vegetables | Antioxidant |
| Lignans | cereals | Phyto-estrogen |
| Hydrolysable tannins | Strawberry, fruits | Astringent, antioxidant |
| Stilbens: resveratrol | Wine, peanut (stressed) | Heart disease? |
| Tyrosol and derivatives | Olive | Antioxidant |
| Coumarins: | Apiaceae | Photosenzibilisation |
| | | |
| **Sulphur-containing compounds** | | |
| Thiosulfinates | Allium | Aroma, antiseptic |
| Glucosinolates | Brassicaceae | Aroma / burning taste, thyroid hypertrophy, inhibition of *Helicobacter pilori…* |
| | | |
| **Nitrogen-containing compounds** | | |
| Capsaicinoides | Capsicum | Burning taste, analgesic |
| Betalains | Caryophylaceae | Color |

Table 2: Conventional and emerging technologies for the extraction of plant bioactives

| Method | Advantage | Disadvantage |
|---|---|---|
| Extraction methods | | |
| Maceration | Low investment cost; modulation of selectivity by solvent choice | Long; low recovery |
| Heating reflux, Soxhlet | Low investment cost; increased yields | High temperature; solvent |
| Supercritical fluid extraction | Low temperature; high yields; mostly for molecules of low polarity but can be modulated | High investment costs |
| Microwave-assisted extraction | Reduction of processing time and solvent use | Locally high temperatures; polar solvents. |
| Ultrasound-assisted extraction | Reduction of processing time, low temperature | Swelling of the plant material |
| Pressurized solvent extraction | Reduction of processing time and solvent use | Investment costs; temperature; low throughput |
| Pulsed electric fields | Reduction of processing time and solvent use | Requires conductivity; activity of enzymes |
| Tissue destructuration methods | | |
| Extensive grinding | Facilitated mass transfer, can be carried out on dry samples | Risk of heating during grinding |
| Enzyme-assisted extraction | Facilitated extraction from a plant tissue | Additional long operation in wet conditions |
| Negative pressure cavitation | Moderate temperature, possibility of anaerobic conditions | Lack of background data |
| High pressure homogenization | Increased yields by tissue disintegration | No selectivity, requires separation |
| Instant controlled pressure drop | Increased yields by tissue disintegration | Pre-treatment only; requires pre-drying. |