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Green analytical chemistry (GAC) applications in sample preparation for the analysis of anthocyanins in products and by-products from plant sources

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ABSTRACT

Agri-food industry manufacturing is an important source of environmental pollution and eutrophication, both intrinsically and due to the generation of significant amount of by-products. For this reason, green chemistry is currently at the forefront of efforts to make all steps of agri-food workflows more sustainable and environmentally friendly and to reduce their carbon footprint. Green analytical chemistry (GAC) is an integral part of these efforts, although it has been largely neglected until now, due to the fact that analytical procedures are mainly limited to quality control in this field, and thus produce just a small fraction of the overall environmental burden of agri-food processes.

In this mini-review, the most recent developments of green analytical methods are described, relative to their applications for anthocyanin determination in agri-food products and by-products. Anthocyanins have been chosen as they are among the most valuable secondary plant metabolites, with a wide range of possible applications exploiting their preservative, antioxidant and coloring properties. Non-separative and separative analytical methods are included in this mini-review. The former are mainly spectrometric in nature, and usually mostly allow to detect and/or quantify groups or classes of molecules. However, they also provide very high throughput and the greatest chance to develop low-energy, low-solvent consumption procedures, even to the point of enabling direct determinations in solid samples as such. On the other hand, separative methods provide far greater selectivity and far wider applicability, but at the price of higher energy and resource consumption and usually lower throughput.

1. Introduction

The agri-food sector is, by its very nature, one of the most important and valuable of all human activities: a large part of the current nutritional and food needs of people in developed and newly industrialised countries rely on the smooth operation of this sector. Developing countries are also heavily dependent on it. As a consequence, it is also one of the most important sources of anthroposphere pollution, arising from both production, transformation and consumption of agri-food products [1,2]. Recently, repurposing of agri-food by-products and waste, and extraction of high added-value substances from them, have been emerging as key factors in the reduction of the environmental impact of current practices [3–7]. However, those procedures must in turn be subjected to close scrutiny to keep rigorous "green" standards during the repurposing and extraction steps, to avoid introducing, or greatly reducing the burden of, further polluting / climate changing agents and procedures within the workflow. Similarly, those procedures should also require minimal levels of energy and non-renewable materials consumption, and generally maintain their environmental impact at a minimum [8,9].

Within this frame, the greenness of analytical workflows has traditionally taken the back seat, regarding both the quality control and the research/development aspects. In either case, indeed, pre-analytical procedures and analytical methods are only applied to a tiny amount of the overall agri-food production, and/or for a very small amount of time, as compared to the overall production chain. Consequently, their

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energy, resource and money consumption, pollution and waste production are comparatively minimal.

In the last few years, however, things are starting to change, since environmental regulations are becoming ever stricter, and the application of analytical quality control and research procedures is increasingly becoming pervasive, thus prompting the implementation of countermeasures to reduce the environmental burden of analytical chemistry in the agri-food sector, making them increasingly greener [10–12].

Green chemistry, and in particular green analytical chemistry (GAC), with its twelve principles and the corresponding SIGNIFICANCE mnemonic practices [13] (see Fig. 1), is being slowly adopted worldwide for this purpose. More recently, ten principles of Green Sample Preparation (GSP) have been defined and described as well [14]. Of course, most of them are similar or superimposable to corresponding GAC principles (e.g., "favour *in situ* operations"; "minimise energy use"), while one ("Choose the greenest possible post-sample preparation configuration for analysis") leads directly to the integration of the two sets of principles (Fig. 2).

In this mini-review, we will detail GAC applications and the GSP coupled to them in the agri-food sector for the determination of one of the most important value-added classes of compounds that can be extracted from, or individuated in, raw food materials or by-products: anthocyanins (Fig. 3). Anthocyanins are a class of specific secondary plant metabolites, chemically belonging to the polyphenol category, found in many kinds of vegetables and fruits. Their intense variety of blue, purple and red colors, coupled to their lack of toxicity, make them valuable dyes and pigments for other foods [15–17]. Moreover, their polyphenolic structure imparts strong antioxidant properties including ability to chelate transition metals to them (and to food that contains them) [18–22]. As a consequence, anthocyanin-rich or anthocyanin-enriched foods could have important health promoting properties, since oxidative stress and redox imbalances are currently believed to be among the most important factors in the development of many chronic conditions [23–26]. In particular, several kinds of neurodegenerative disorders seem to be strongly linked to oxidative stress: for example, Parkinson's disease, Alzheimer's disease, lateral amyotrophic sclerosis and multiple sclerosis [27–30]. Thus, finding, quantitating and giving value to anthocyanins in different kinds of food products and by-products is an important role of current analytical chemistry.

2. Green analytical workflows and greenness evaluation metrics

GAC and GSP are still not widely applied to anthocyanin determination in plant-derived products and by-products. However, things are changing, since the constant repetition of quality control procedures can result in important amounts of non-recyclable, toxic waste; in terms of absolute amounts if not in terms of ratio to manufacturing-related amounts. Moreover, GAC and GSP development is comparatively easier than green chemistry application to industrial-scale agri-food applications, since it does not require the scale-up step. Sample preparation and analytical method miniaturisation are indeed highly valued and a further source of pollution, expenditure, and personnel risk reduction [31–33]. Typically, the most environmentally intensive step of analytical workflows is sample preparation, which often involves considerable amounts (for lab scale) of sample, solvents and energy; thus, GSP is increasingly acquiring importance as an irreplaceable companion of GAC.

A few tools have been developed to objectively evaluate the greenness of analytical workflows, making comparison between methods much easier and meaningful. One such tool for GAC is the HPLC-Environmental Assessment Tool (HPLC-EAT) with Safety, Health, and Environmental scores, which is obviously mainly dedicated to the evaluation of HPLC methods [34], and in particular of the solvents used. The tool linearly combines the safety, health and environmental scores of each solvent, calculated according to the rules established by Koller et al. [35], multiplied by the mass of that solvent used. All solvent scores are added together:

$$\text{HPLC-EAT} = S_1m_1 + H_1m_1 + E_1m_1 + S_2m_2 + H_2m_2 + E_2m_2 + \ldots + S_nm_n + H_nm_n + E_nm_n$$

where *S, H* and *E* are the safety, health and environmental scores and *m* is the solvent mass, for *n* solvents. Obviously, lower scores correspond to greener methods.

Recently, the more generally applicable Analytical Greenness Calculator (AGREE) tool has been devised [36]. In it, each one of the 12 GAC principles is coupled to a mathematical function that produces a score in the 0-1 scale, with higher scores being greener than lower ones. Then, an average total score in the 0-1 range is calculated, which can optionally also be weighted according to the importance of each principle. Both individual and total scores can be visualised in a color-coded pictogram, where low scores correspond to red-tinted hues and high scores correspond to green-tinted hues (Fig. 4a). The pictogram may also graphically show the weight of the individual principles (as the length of the corresponding annulus sector, Fig. 4b).

Even more recently, the Analytical Greenness Metric for Sample Preparation (AGREEprep) tool has been developed to specifically evaluate the greenness of sample preparation procedures [37,38]. It basically follows the same steps as the AGREE tool, of course applying the 10 principles of GSP, producing a similar pictogram. If different weights are used to consider the relative importance of the different principles, they are normally shown in the pictogram as the width, not the length, of the corresponding annulus sector (Fig. 4c).

2.1. Non-separative analytical methods

Non-separative analytical methods are mainly spectrometric in nature, and usually mostly provide very high throughput and the chance to develop low-energy and low-solvent consumption protocols, also enabling direct determinations in solid samples as such [33,34]. Several non-selective methods, based on direct colorimetric or reflectometric measures are widely used to assess total anthocyanin contents. These techniques can be applied either directly *in situ* to the plant part, or to liquid extracts. In the latter case, color-developing reagents may be used to enhance sensitivity and/or selectivity: of course, the specific kind of reagent can have a huge impact on method greenness, or lack thereof.

A completely green method has been developed for the colorimetric detection of total anthocyanins in *Spirodela polyrhiza* through smartphone-acquired images [39]. The method can be directly applied *in situ* to the plants, and color parameters are evaluated through commercial software such as ImageJ to collect and elaborate six color parameters, red (R), green (G), blue (B), hue (H), saturation (S), and intensity (I); the 2G-B value predicted anthocyanins content with a high coefficient of determination ($r^2 = 0.8638$). Reflectance coupled to Gaussian process regression (GPR) has been used to evaluate the total anthocyanin content of leaves from several different plants [40]. Logarithmic transformation of reciprocal reflectance (Log(1/R)) at 564 and 705 nm provided the best estimation, without the use of any solvent nor non-green substances.

Near-infrared (NIR) spectroscopy provides fingerprint analyte signals that can be used for quantitative purposes, although selectivity is low without previous treatment or separations. Regardless, total anthocyanin content was evaluated *in situ* by NIR for example in intact *Sambucus nigra* (elderberry) berries [41]. The method requires neither sample preparation nor extraction and can thus be considered a totally green and sustainable technique. Similarly, a non-destructive machine vision analysis of total anthocyanins in lettuce leaves has been proposed [42]. Many different color parameters were studied (in both the red-green-blue – RGB – and the hue-intensity-saturation – HIS – color spaces) for

THE 12 PRINCIPLES OF GREEN ANALYTICAL CHEMISTRY

① Direct analytical techniques should be applied to avoid sample treatment.

② Minimal sample size and minimal number of samples are goals.

③ *In situ* measurements should be performed.

④ Integration of analytical processes and operations saves energy and reduces the use of reagents.

⑤ Automated and miniaturized methods should be selected.

⑥ Derivatization should be avoided.

⑦ Generation of a large volume of analytical waste should be avoided and proper management of analytical waste should be provided.

⑧ Multi-analyte or multi-parameter methods are preferred versus methods including one analyte at a time.

⑨ The use of energy should be minimized.

⑩ Reagents obtained from renewable source should be preferred.

⑪ Toxic reagents should be eliminated or replaced.

⑫ The safety of the operator should be increased.

«SIGNIFICANCE» MNEMONIC OF THE 12 PRINCIPLES

Ⓢ Select direct analytical techniques.

Ⓘ Integrate analytical processes and operations.

Ⓖ Generate as little waste as possible and treat it properly.

Ⓝ Never waste energy.

Ⓘ Implement automation and miniaturization of methods.

Ⓕ Favor reagents obtained from renewable sources.

Ⓘ Increase operator safety.

Ⓒ Carry out *in situ* measurements.

Ⓐ Avoid derivatization.

Ⓝ Note that sample number and size should be minimal.

Ⓒ Choose multi-analyte or multi-parameter methods.

Ⓔ Eliminate or replace toxic reagents.

Fig. 1. The 12 GAC principles and the corresponding "SIGNIFICANCE" mnemonic. Adapted from [13].

this purpose. The S/H ratio proved to have the highest Pearson correlation coefficient (0.850) with anthocyanin content, while the B/G ratio had the highest accuracy in a quantitative prediction model of anthocyanin content using a quadratic equation (5.5% error rate with a 95% confidence interval).

2.2. Separative analytical methods

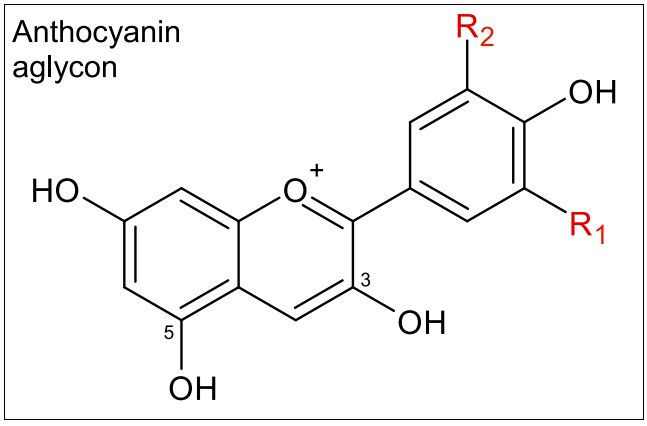
2.2.1. GSP by liquid extraction

On the other hand, more efforts are needed to develop and apply green, environmentally friendly separative analytical methods that can

Fig. 2. The 10 GSP principles. Adapted from [14].

THE 10 PRINCIPLES OF GREEN SAMPLE PREPARATION

① Favor *in situ* sample preparation.
② Use safer solvents and reagents.
③ Target sustainable, reusable, and renewable materials.
④ Minimize waste.
⑤ Minimize sample, chemical and material amounts.
⑥ Maximize sample throughput.
⑦ Integrate steps and promote automation.
⑧ Minimize energy consumption.
⑨ Choose the greenest possible post-sample preparation configuration for analysis.
⑩ Ensure safe procedures for the operator.



	R1	R2
Pelargonidin	H	H
Cyanidin	OH	H
Peonidin	OCH_3	H
Delphinidin	OH	OH
Malvidin	OCH_3	OCH_3
Petunidin	OH	OCH_3

Fig. 3. Generic structure of the six major anthocyanidins found in agri-food products and by-products. Sugar conjugates of anthocyanidins (i.e., anthocyanins) occur most commonly via an *O*-linkage at C3 and/or C5.

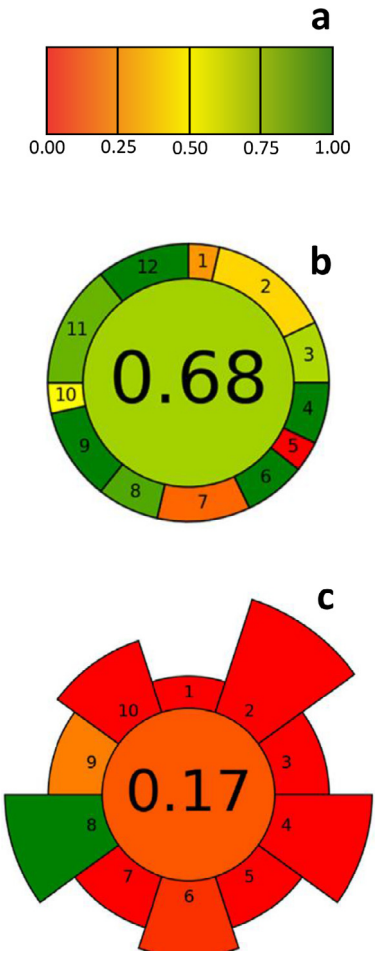


Fig. 4. Pictograms for the (a) greenness evaluation score of (b) analytical methods through the AGREE tool and (c) sample preparation procedures through the AGREEprep tool. Adapted from [36] and [37], respectively.

selectively determine the levels of individual anthocyanins, and current results are mixed in terms of sustainability. Anthocyanins and flavonols were analysed in *Crocus sativus* (saffron) by ultrahigh performance liquid chromatography-diode array detection-electrospray ionisation-tandem mass spectrometry (UHPLC-DAD-ESI-MS/MS) after green microwave-assisted solid-liquid extraction (MASLE) with H_2O or 70% ethanol (EtOH) [43]. The analytical method was not subjected to any green parameter evaluation, and the mobile phase consisted of H_2O, formic acid (FA) and acetonitrile (ACN). The most abundant anthocyanin was delphinidin-3,5-*O*-diglucoside, while the most abundant flavonol was kaempferol-3-*O*-sophoroside.

A method defined as "green chromatography" by its authors was used to analyse 17 anthocyanins in *Nitraria tangutorun* fruits [44]. The

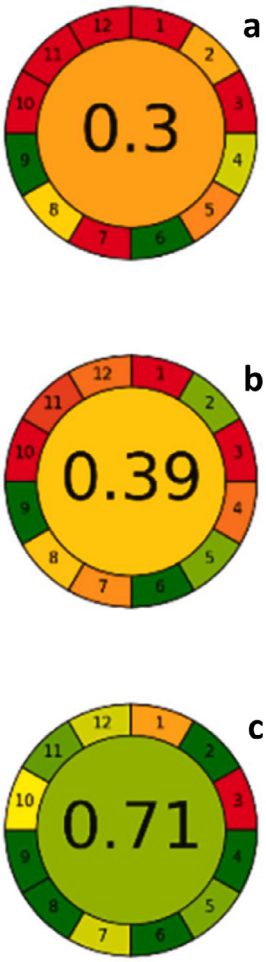


Fig. 5. Comparison of AGREE scores for (a) method [51], (b) method [50], and (c) method [49]. Adapted from [49].

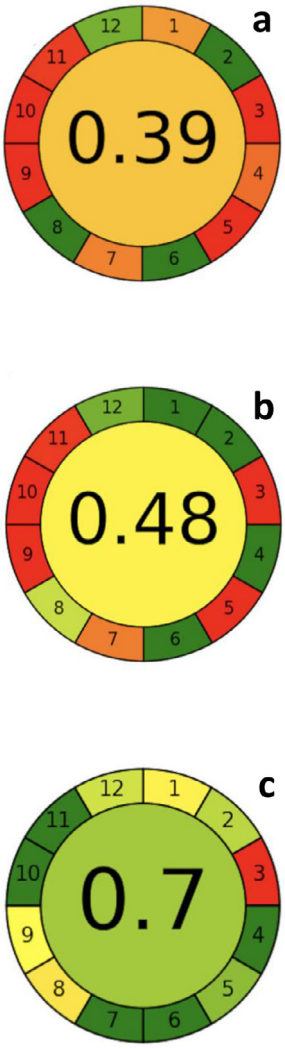


Fig. 6. Comparison of AGREE scores for (a) method [54], (b) method [55], and (c) method [53]. Numbers in the outer rings correspond to the 12 GAC principles (see Fig. 1), while color codes go from dark red (low score) to dark green (high score), with higher scores corresponding to greener parameters. Adapted from [53].

method uses H_2O, FA and EtOH for the mobile phase, flowing in an UHPLC-DAD-MS/MS setup; extraction from freeze-dried fruit powder was carried out by ultrasound-assisted solid-liquid extraction (UASLE) with 70% EtOH at 70 °C. Another green HPLC-DAD method for the analysis of anthocyanins (and polyphenols) from *Nitraria tangutorun* seeds has been described [45]. It uses a mobile phase consisting of EtOH and 5% FA (80/20, V/V), which is claimed in the paper to be accurate, stable and reliable. GSP was carried out by UASLE with 51.5% aqueous EtOH.

The green extraction and analysis of *Hibiscus sabdariffa* anthocyanins in beverages has also been reported [46]. Extraction was carried out by solid-liquid extraction (SLE) with an aqueous solution of hydroxypropyl-β-cyclodextrin (HP-β-CD) at 54 °C. Analysis was by HPLC-DAD, with a mobile phase consisting of EtOH and aqueous tartaric acid (TA); the two main anthocyanins determined were delphinidin-3-*O*-sambubioside and cyanidin-3-*O*-sambubioside. TA has in fact been acknowledged as an effective mobile phase additive for the green HPLC quantitation of anthocyanins: in a recent paper by Sang et al. [47], it was chosen for this purpose among seven different α-hydroxyacids. The mobile phase thus developed, consisting of an EtOH / aqueous TA mixture, had negligible effects on the stability of a C18 column. Cyanidin-3-*O*-glucoside was chosen in this study as the most abundant and representative anthocyanin in several plant-derived matrices, and namely in haskap berry, mulberry and blackberry, for the development of the assay. Anthocyanin extraction was carried out with 0.1% (V/V) HCl in EtOH.

Native β-CD at 55 °C provided good anthocyanin extraction yields (mainly petunidin-3-*O*-(trans-*p*-coumaroyl)-rutinoside-5-*O*-glucoside) from *Lycium ruthenicum* fruits using UASLE [48]. The UHPLC-DAD mobile phase was a mixture of aqueous trifluoroacetic acid (TFA) and EtOH. Since TFA is not currently considered a green solvent, its presence in the mobile phase hinders the GAC compliance of the method.

A new, fast GAC procedure has been recently published for the quantitation of compounds structurally related to anthocyanins (xanthohumol and the six major α- and β-acids of hops and derived products) through a simple and svelte UHPLC method coupled to ultraviolet (UHPLC-UV) detection [49]. Instead of the most common solvents (diethyl ether, methanol -MeOH-, pyridine, toluene, and isopropyl ether) and macroscopic amounts of sample (in the 10–20 g range), the proposed method uses one thousand times less sample (20 mg) and 2 mL of a dimethyl carbonate (DMC) / FA (97/3, V/V) mixture as the extraction solvent. DMC is less flammable than acetone, methyl acetate and methyl ethyl ketone; it is readily hydrolysed to MeOH and carbon dioxide in biological tissues, so its toxicity is similar to that of MeOH. Reduced solvent consumption was also achieved using UHPLC (mobile phase flow rate: 0.35 mL/min). Since the mobile phase was a mixture of H_2O, ACN and FA, it was not particularly environmentally friendly in comparison to other methods. The method was compared to the state of the art [50,51] through the HPLC-EAT [34,52] and the AGREE [36] tools. The sample preparation procedure produced significantly better results on

Table 1
Summary of GAC and GSP procedures for the determination of anthocyanins in agri-food products by separative methods.

Ref.	Plant matrix	Sample Preparation		Sample Analysis	
		Technique	Chemicals	Technique	Chemicals
[43]	*Crocus sativus*	MASLE	H_2O, 70% EtOH	UHPLC-DAD-ESI-MS/MS	H_2O/FA/ACN
[44]	*Nitraria tangutorun* fruits	UASLE	70% EtOH @70°C	UHPLC-DAD- MS/MS	H_2O/FA/EtOH
[45]	*Nitraria tangutorun* seeds	UASLE	51.5% EtOH	HPLC-DAD	H_2O/FA/EtOH
[46]	Beverages from *Hibiscus sabdariffa*	SLE	Aq. HP-β-CD @54°C	HPLC-DAD	H_2O/TA/EtOH
[47]	Haskap berry, mulberry. blackberry	SLE	0.1% HCl in EtOH	HPLC-DAD	H_2O/TA/EtOH
[48]	*Lycium ruthenicum* fruits	UASLE	Aq. β-CD @55°C	UHPLC-DAD	TFA/EtOH
[49]	Hops	SLE	DMC/FA 97/3	UHPLC-UV	H_2O/FA/ACN
[53]	Red wine	LLE	Ethyl Acetate	HPLC-DAD	H_2O/BioEtOH
[56]	Overground parts of *Eclipta prostrata*	MASLE	50% EtOH	HPLC-DAD	H_2O/H_3PO_4/EtOH
[57]	*Prunus cerasifera* leaves	UASLE	0.1% HCl in EtOH	HPLC-DAD	H_2O/TA/EtOH
		Column purification	H_2O washing, 50% EtOH elution		
[58]	*Lycium ruthenicum* fruits	UASLE	DES – 90% choline chloride + 1,2-propanediol, 10% H_2O @52°C	HPLC-DAD	H_2O/TA/EtOH
		Column purification	60% EtOH		
[59]	*Eugenia uniflora* leaves	Dynamic maceration	73.7% BioEtOH@200 rpm	HPLC-DAD	H_2O/BioEtOH
		UASLE	73.7% BioEtOH		
[10]	Sugarcane	2-Mac	70% EtOH, n-heptane	UHPLC-UV, GC-MS	H_2O/FA/ACN, He
[10]	Sugarcane	2-UAEP	70% EtOH, n-heptane	UHPLC-UV, GC-MS	H_2O/FA/ACN, He
[60]	*Vaccinium corymbosum* fruits	Column purification	Modified Hanks' balanced salt solution	LC-MS/MS	H_2O/FA/MeOH@50 °C

both HPLC-EAT, AGREE and energy consumption scores; the complete extraction and analysis procedure was 3-20 times better than existing procedures according to the HPLC-EAT score (see Fig. 5).

Food-grade bioethanol (BioEtOH), coupled to H_2O, was used in the mobile phase for the HPLC-DAD fingerprinting of Brazilian red wine extracts [53], obtaining an AGREE score of 0.70, when most previously adopted method obtained scores between 0.39 and 0.48 [54,55] (higher scores are better, Fig. 6). Ethyl acetate, which is currently considered a green solvent [52], was used for the liquid-liquid extraction (LLE) procedure.

Six flavonoid glycosides, one coumarin and six phenolic acids were identified and quantified in the overground parts of *Eclipta prostrata* after MASLE with EtOH/H_2O (50/50, V/V) and HPLC-DAD [56]. The extraction method provided both high extraction yields and avoided significant analyte degradation, while at the same time employing reduced solvent volumes and energy amounts. The HPLC mobile phase was a mixture of H_2O, phosphoric acid (H_3PO_4), and EtOH.

2.2.2. GSP by liquid extraction followed by column purification

A mobile phase similar to that used for *Hibiscus sabdariffa* was used by the same research group for the HPLC-DAD analysis of anthocyanins (cyanidin-3-*O*-galactoside, cyanidin-3-*O*-glucoside and cyanidin-3-*O*-rutinoside) from *Prunus cerasifera* var. *atropurpurea* leaves [57]. In this case, however, the extraction was by UASLE with 0.1% HCl in MeOH, followed by column purification using water washing and 50% EtOH as the desorption agent.

The same researchers have developed a green HPLC-DAD method for the analysis of *Lycium ruthenicum* anthocyanins [58], where the mobile phase was an EtOH / aqueous TA mixture, similar to those they used for their analysis of anthocyanins in *Hibiscus sabdariffa* and *Prunus cerasifera* extracts. In this case, green extraction was carried out by UASLE with a deep eutectic solvent (DES), a choline chloride / 1,2-propanediol 1/2, mol/mol mixture with 10% H_2O at 52°C, followed by column purification for anthocyanin recovery from the DES using 60% EtOH.

2.2.3. GSP by dynamic maceration

HPLC-EAT was used together with Green Chromatographic Fingerprinting Response (GCFR) to reach a satisfactory trade-off between separation and sustainability in the HPLC-DAD fingerprinting of *Eugenia uniflora* leaves [59], within a chemometric study employing a Fractional Factorial Design (FFD). In this case, GAC principles were satisfied by using food-grade bioEtOH as the organic modifier of the HPLC mobile phase. GSP was carried out by dynamic maceration (200 rpm, 2 h) with a 7.37/2.63 (V/V) food grade EtOH 95°GL / H_2O mixture (corresponding to EtOH/H_2O 7/3, V/V). Maceration was followed by UASLE with the same solvent, centrifugation and filtration.

The Analytical-Eco Scale, AGREE and energy consumption were used to evaluate analytical extraction procedures for multiple chemical classes in sugarcane by-products [10]. Two-Liquid-Phase Dynamic Maceration (2-Mac) and Two-Liquid-Phase Ultrasound-Assisted Extraction with Probe (2-UAEP) produced the most satisfactory results, both using an EtOH/H_2O (70/30, V/V) mixture and *n*-heptane. The hydroalcoholic extract was then analysed by UHPLC-UV, while the heptane extract was analysed by gas chromatography coupled to mass spectrometry (GC-MS). The HPLC mobile phase was made up of H_2O, FA and ACN, while the GC mobile phase was inherently green, thanks to the use of helium (He) as the carrier gas.

2.2.4. GSP by column purification

A recent paper by Gato et al. [60] reports the analysis of multiple *Vaccinium corymbosum* fruit components (including anthocyanins) by LC-MS/MS using a mobile phase made up of H_2O/FA/MeOH at 50°C under gradient conditions; the method is thus not particularly green. On the other hand, the sample preparation procedure extracts anthocyanins from the plant matrix by passing an isotonic saline solution (modified Hanks' balanced salt solution) through a glassed column packed with a sand and a glass wool layer.

As can be surmised from the above information, summarised in Table 1 as well, GAC is still largely behind green extraction techniques, also due to the perceived lower level of pollution / resource consumption caused by analytical methods (quality control – QC – included), when compared to industrial-scale extraction procedures. Moreover, even in analytical methods claimed to be green, the bulk of sustainability assessments and environmental compatibility enhancements are directed toward the sample extraction, preparation and purification steps, rather than toward the analytical technique proper (excluding direct spectrometric methods, of course, which are inherently greener than separative ones). It is clear that more efforts are still needed in this direction, since it is rather paradoxical that green procedures are adopted in industrial processes, while the QC procedures that constantly support and accompany them are still not environmentally friendly.

3. Conclusion

In the last few years, green chemistry has increasingly become commonplace for the very important combined objectives of making agri-food industry products and by-products notable/valuable sources of anthocyanins; and of extracting those anthocyanins from the respective matrices with environmentally friendly, sustainable methods. On the other hand, analytical methods, and particularly selective separative methods for anthocyanins, are still behind the curve in this field. The current paradoxical situation is that the performance evaluation and QC of highly green extraction procedures are mostly carried out using analytical methods that do not have any specific regard for environmental and operator safety. However, GAC and GSP are increasingly finding application in the newest methods. The combined application of miniaturised sampling and sample preparation (micro-scale analytical techniques requiring minute amounts of solvents and green, safe, non-hazardous solvents) are changing forever the landscape of analytical applications, hopefully ushering in a new era of sustainability and environmental neutrality for the chemistry-based workflows that support the agri-food industry and related settings.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Premysl Mladenka, Laura Mercolini and Roberto Mandrioli report financial support was provided by European Commission.

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