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RESEARCH ARTICLE

SUSTAINABLE METHOD FOR FOOD QUALITY ASSESSMENT: LCA STUDY ON BIOGENIC AMINES DETERMINATION

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ABSTRACT

Background: Quality assessment can inform us about the nutritional values of food, but also about its origin (i.e. cultivation techniques) and organoleptic properties. Analysis of foods is continuously requesting the development of more robust, efficient, sensitive, and cost-effective analytical methodologies to guarantee the safety, quality and traceability of foods in compliance with legislation and consumers demands. Biogenic amines are a class of molecular marker, used to recognize and to identify food origin, vegetables maturity, cultivation techniques and storage time. Since sustainability is an actual aim of the scientific research, even "green" analytical determinations in food are going to be developed. Green chemistry introduced several points like less waste, low energetic costs, raw materials made by renewable sources. ***Objectives:*** The aim of the present work is to compare two different HPLC method for determinate biogenic amines in food matrix. Life Cycle Assessment methodology was applied to evaluate the environmental effects/impacts of the two differents scenario. Moreover, the application of the Life Cycle Cost analysis allowed to evaluate costs in the second scenario. ***Methods:*** High Pressure Liquid Chromatography (HPLC) allow to identify and quantify biogenic amines in food matrices. Two different HPLC methods were compared by Life Cycle Assessment and Life Cycle Cost methodologies. These methodologies permit to quantify the environmental negative output, pointing out opportunities to reduce input and output of the system and to choose the most cost-effective option. The environmental variables were calculated by using Simapro 8 software (ReCIPe 2016 method). ***Results:*** The new analysis methodology allows to use just 20.6% of resources. The optimized methodology saves more than 50% with a payback period of 10 analysis. ***Conclusions:*** The implementation of new methods of analysis improves the efficiency and sensitivity, pointing out sustainability topic in food quality assessment field.

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INTRODUCTION

The analytical determinations of chemical species in food are an essential step of food quality assessment (Hellwig, 2018). Food quality can be ascertained by physicochemical analysis, individuating which and how much substances are present in food. Instead, for food safety a microbiological analysis is necessary. Quality assessment can inform us about the nutritional values food, but also about its origin (i.e. cultivation techniques) and organoleptic properties (Sobolev, 2018). Since sustainability is an actual aim of the scientific research, even "green" analytical determinations in food are going to be developed. Green chemistry introduced several points like less waste, low energetic costs, raw materials made by renewable sources (Comino, 2018). Generally, food is a complex matrix therefore a preparative technique is necessary before the analysis. Extraction and purification are the main techniques of preparation (Samanipour, 2018). A lot of solvents are involved in these techniques, for this reason they are going to be substituted. Some of the analysis techniques, like the spectrophotometric ones, born "green" with low quantity of solvents and wastes, especially the not destructive ones which allow the reutilization of samples (Giovenzana, 2018). Instead, for the chromatography techniques, the optimization of methods is necessary to decrease the time of analysis and the use of solvents. The technical development makes "green" the chromatography techniques, thanks to the miniaturization of devices. An example is the decrease of length and diameter of columns used in chromatography, this miniaturization allows the reduction of solvents involved and the time of chromatographic runs (Caprioli, 2018). Also, the management of waste solvent is a key step of sustainable methods. Italian laboratories produce 300,000 tons/year of waste solvents that can be reused after appropriate treatments (Bernacchia, 2017). Analysis of foods is continuously requesting the development of more robust, efficient, sensitive, and cost-effective analytical methodologies to guarantee the safety, quality and

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traceability of foods in compliance with legislation and consumers' demands (European Commision, 2002). The methods used at the beginning of the 20th century, based on the so-called "wet chemistry", evolved into the current powerful instrumental techniques used in food laboratories. This improvement led to significant enhancements in analytical accuracy, precision, detection limits, and sample throughput, thereby expanding the practical range of food applications (Bernacchia, 2017). Besides, currently, there is also a huge interest in the health-related properties of foods because of an increasing public concern on how to improve health through the so-called functional foods, functional ingredients, and nutraceuticals (Rao, 2018). To ensure food quality is necessary to determinate some chemical compounds, considered "molecular marker". Biogenic amines (BAs) is a class of molecular marker, used to recognize and to identify the origin of food, maturity of vegetables, cultivation techniques and storage time (Sobolev, 2018 and Preti, 2017). High Pressure Liquid Chromatography (HPLC) is considered as the "golden standard" to identify and quantify biogenic amines in food matrices (International Organization for Standardization, 2017). Many chromatographic methods were found in literature, often combined with the pre-column or post-column derivatization, to produce in both cases strong chromophores that can be detected fluorimetric (methodology more used) or with ultraviolet (UV) detection. In this study, two recent articles were chosen: Liu *et al*. (2018), and Preti *et al*. (2015). The first takes into consideration "classics" analysis conditions, instead the latter implements an innovation: a chromatographic column packed with Core-shell particles. This column provides speed and efficiency similar to columns packed with smaller porous particles. This allows low back pressure to be maintained and is therefore suitable for use on conventional HPLC instruments, improving their performance. The aim of the present work is to compare two differents HPLC methods for determinate Biogenic Amines in food matrix. Furthermore, Life Cycle Assessment methodology (LCA) and Life Cycle Costing (LCC) was applied in order to identify their sustainability.

MATERIALS AND METHODS

Life Cycle Assessment: The effects of environment change led the society to give more attention to the environmental impact. This more responsible approach can be integrated in the processes of "decision making" business through Life Cycle Assessment (LCA) methodology (Johnson, 2013). LCA is based on the analysis and determination of quantitative variables associated with products, systems and services processed by mathematical equations, composed by data that describe the life cycle.

This methodology permits to quantify the energy and materials used (input) and the wastes released in the environment (output), in order to evaluate tangible opportunities to reduce the environmental negative output (Koci, 2011). The LCA methodology is part of the family of standards related to environmental management: ISO 14040 and 14044 (International Organization for Standardization, 2006 and International Organization for Standardization, 2006). In this study, was used "Simapro software 8" for the calculation of specified environmental indexes, by mathematical processing of data describing the life cycle.

According to the ISO standards an LCA study is composed of four related steps:

Goal and Scope: The ISO standard assert "the scope should be sufficiently well defined to ensure that the breadth, depth and detail of the study are compatible and sufficient to address the stated goal." It's the first phase, necessary to clearly defining the goal and scope of the research (including selecting a functional unit, the intended application and audience).

Life cycle inventory (LCI): regard the collection of data and information, analysis and validation of data. In this step the exact amount of input and output derived from the system is defined and studied. The results are based on the historical records obtained from the company object of our research study.

Life cycle impact assessment (LCIA): provides the information to interpret the environmental significance of the comparison. In this phase, the environmental effects are quantified and visualized as impact categories in accordance with the characterization model implemented in Simapro 8.

Interpretation: interpretation of the results is a key step of a LCA study. The ISO standards fix a number of checks in order to obtain robust conclusions. Right results interpretation helps decision makers make a more informed decision. The Life Cycle Costing analysis was also performed to complete the evaluation of the two processes. LCC is a tool based on another life cycle approach. It looks at the direct monetary costs involved with a specific product for determining the most cost-efficiency and competitive solutions for the production process (Zhang, 2011).

RESULTS AND DISCUSSION

Goal and Scope: The goal of this paper is to contribute to exploring the suitable functional units, system boundaries and allocation procedures for LCA in HPLC analysis for food quality assessment. The purpose of this study is to highlight the environmental and economic differences between two different scenarios of analysis.

Chromatographic methods: Scenario A and Scenario B: To compare the environmental and economic efficiency of the new analysis methodology, two protocols based on the same experimental conditions were compared. The column used is the only optimized variable. Scenario A is defined by experimental conditions reported in Liu *et al*. (Liu, 2018), while scenario B is defined by the experimental conditions in Preti *et al*. (Preti, 2015). The parameters studied were: chromatographic column, temperature, mobile phase composition and mobile phase flow as reported in Tab 1. The chromatographic column, in scenario A, was a C-18, 250x4.6 mm, 5 µm. In Preti *et al*. (scenario B) that column have been substituted. The stationary phase is the same (C-18), length is reduced (10x4.6 mm). The column was also implemented with a core-shell technology, resulting in a lower expansion of bands, but maximizing the efficiency. Starting from a flow to 1.0 mL/min, it was achieved a 0.6 mL/min flow. The small length of the column, indeed, allows to reduce the analysis time, from 57 min to 13 min, by changing the solvent gradient. A decrease of solvent volume was achieved, so the ACN quantity involved in the method varies from 45.20 mL to 6.55 mL. This allows a reduction up to 6 times of ACN used. All these characteristics give the possibility to use a low quantity of solvents and to carried out more analysis in the same time spent. It was noteworthy that the optimized method doesn't show lose in sensibility.

Table 1. Experimental conditions scenario A and scenario B.

	SCENARIO A	SCENARIO B
COLOUMN	C-18 (250x4.6 mm, 5 µm)	C-18 (100x4,6 mm, 2,6 µm)
TEMPERATURE	40°C	50°C
MOBILE PHASE (GRADE)	A: H_20 B: ACN	A: H_20 B: ACN
	0 min.: 60% B	0 min.: 65% B
	40 min.: 100% B	3,5 min.: 75% B
	47 min.: 100% B	9 min.: 100% B
	48 min.: 60% B	11 min.: 100% B
	57 min.: 60% B	13 min.: 65% B
FLOW	1.0 mL/min	0.6 mL/min
ANALYSIS TIME	57 min	13 min
SOLVENT VOLUME	57 mL/analysis	7,8 mL/analysis
	(11,80mL H20; 45,20 mL ACN)	(1,25 mL H20; 6,55 mL ACN)

Table 2. System input and output

	Input / Output of production	Unit	Scenario A	Scenario B
Input	Water (HPLC grade)	g	1180.00	125.00
	Acetonitrile (HPLC grade)	g	3553.00	515.00
	Energy	KW/h	285.00	65.00
Output	Waste (disposed)	g	4733.00	640.00

Table 3. Cost allocation confront

	Scenario A	Scenario B
COST	Unit: €	Unit: €
Energy	17.67	4.03
Solvents	547.40	78.30
Operator	890.62	203.16
Waste Disposal	9.94	1,34
Σ 100 analyses	1465.63	286.83
Column	616.00	730.00
Total	2081.63	1016.83

Life Cycle Inventory

System data and information are studied to define the exact amount of input and output. In this research study the data derive from the information reported in literature (Liu, 2018 and Preti, 2015). The production unit is identified in 100 analyses. 100 analyses were considered as normal monthly laboratory routines. Input and output of the extraction procedure were not considered for comparison (identical for both methods). The HPLC system is considered equivalent for the two scenarios, except for the chromatographic column. Table 2 shows the input and output detail of both methods.

Life Cycle Impact Assessment

For the assessment of the environmental and social impact of methods, impact categories have been defined and chosen. The environmental variables were calculated by using Simapro 8 software (ReCIPe 2016 method) for both the systems, in order to compare the results of the two analytical methods. All three major impact fields have been considered to evaluate the environmental profile: human health effect, ecosystems impact and resources consumption. In Figure 1 are shown the results obtained from the conversion of relevant characterization factors of each impact field with the LCIA results. No treatment occurs because all the impact categories result significant. Scenario A was set as 100% of impact, and scenario B was compared to this. In the LCIA is highlighted that the optimization of the analysis method, achieved by the technological innovation (the use of the new column), has allowed a reduction of the impacts in all three fields. The new analysis methodology allows to use just 20.6% of resources, with an evident impact also on what will then be the disposal.

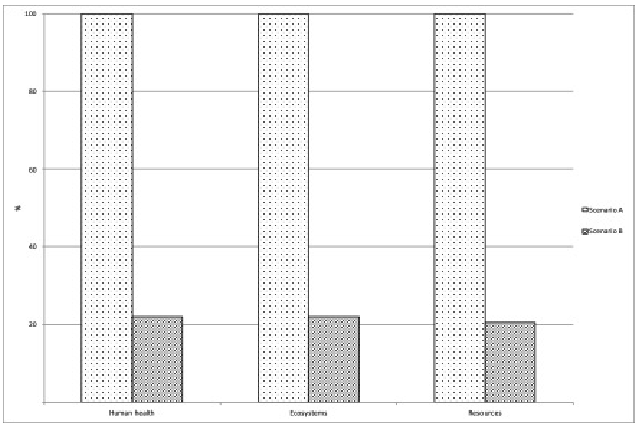

Fig. 2. Impact field comparison

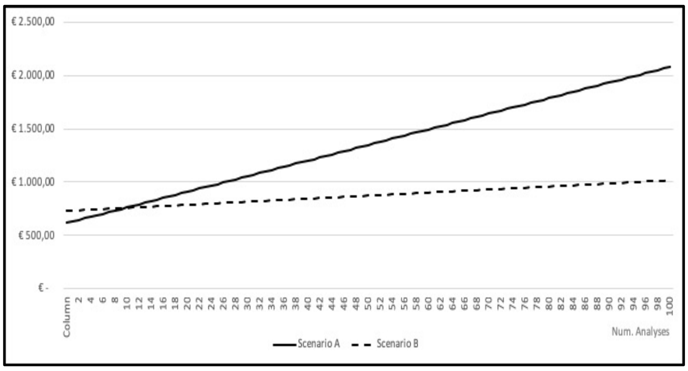

Fig. S.1. Investment Evaluation: Comparison between the two scenario

Life Cycle Costing analysis: The LCC is a valuation method that determines the overall cost of products and services, considering the entire life cycle (Zhang, 2011). This methodology is often used in industrial field, it can assist the decision makers about modification of some variables in the production process. Currently, there are very few applications of the LCC to laboratory experiments (Guinée, 2011). The comparison between the two different scenarios is shown in Table 3. The costs of columns and solvents are referred to the European retail market prices. The cost of waste disposal is referred to the rates applied in central Italy, according to European law (EWC 07 07 08). All costs are excluding taxes. Table 3 shows the cost of the individual components of the system studied in the scenario: energy, solvents and operator. In addition to analysis cost, the initial column cost was evaluated, resulting higher for Scenario B. The Scenario B save more than 50%, despite of the higher cost of the column. The optimized method results more efficient in terms of solvent expenditures (more of 80%). It also had a lower waste disposal cost. Figure 2 shows the evaluation of the investment, which gain to highlight the payback period. The high efficiency of the optimized scenario allows the recovery of the initial investment for the core-shell column after 10 analyses.

Conclusions

Sustainability is not a current topic in the food quality assessment field. The implementation of new methods of analysis improves the efficiency and sensitivity. To ensure consumer health, the impacts of inputs and outputs of the system have to be considered. The application of LCA and LCC methodologies allowed to evaluate the effect of the replacement of a classical HPLC column with Core-Shell technology column. The low flow rate and the reduced time analysis lead us to saving a great amount of solvents (up to 80 %), with a reduction up to 6 times of ACN volume. The new method shows an impact reduction up to 80% in the three major fields: human health, ecosystems and resources. The subsequent cost analysis showed a saving of 50%, even considering the cost of the investment, with a payback period of 10 analyses. This study therefore raises the evidence of how technological innovation can lead to greater sustainability, in an unexplored field such as food analysis.

Key Points

- Replacement of a classical HPLC column with Core-Shell technology column allowed to reduce flow rate and time analysis in BAs determination.
- LCA results suggests an impacts reduction in Human Health, Ecosystems and Resources fields for the optimized method.
- LCC shown that new analysis methodology lead to save more than 50% of resources.

Conflict of Interest statement: The authors state that there is no conflict of interests.

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