LIFE CYCLE ASSESSMENT OF THE EXTRACTION OF CONDENSED TANNINS FROM ACACIA BARK RESIDUES

Ricardo Simões [1], Carla L. Simões[1], Ricardo Ferreira[2] and Ana C. Rodrigues[2]
[1]School of Technology, Polytechnic Institute of Cavado and Ave
Campus do IPCA, Vila Frescaínha S. Martinho, 4750-810 Barcelos, Portugal
[2]PROMETHEUS, Unidade de Investigação em Materiais, Energia e Ambiente para a Sustentabilidade, Escola Superior Agrária, Instituto Politécnico de Viana do Castelo, 4900-347 Viana do Castelo, Portugal

ABSTRACT

The environmental impact of the production of condensed tannins from acacia bark was investigated from gate-to-gate perspective. Of the six process steps in the production system that were assessed, the spray drying and adsorption (purification) steps were identified as the main sources of the environmental impact of the whole system. This is due to intensive consumption of energy and consumption of makeup ethanol, respectively. The most important action to improve the environmental performance of the system is to reduce water consumption in the extraction, as it will reduce energy demand in the spray drying step. This LCA shows the most important steps to facilitate process development towards lower environmental impact.

KEYWORDS

Acacia Bark, Tannins, Extraction, Adsorption, Evaporation, Life Cycle Assessment

1. INTRODUCTION

Conventional water treatment using chemical coagulants always generates some kind of impact on the environment, therefore studies of alternative water treatments, especially with natural coagulants, are important. This is directly linked to the issue of sustainability and its development.

Natural coagulants are compounds that may or may not come from plants, which have the ability to add to contaminants and thus enable their removal. They are compounds easily found in nature and their use has a strong environmental, economic and social appeal, since they improve the quality of life of society and mitigate environmental damage or impact (Lima et al, 2020).

Among the most used natural coagulants is the group of tannins, which are organic compounds that can be extracted from plant barks such as Black Acacia, acting as coagulants and flocculants in water treatment (Fiorentini, 2005). Tannin is a phenolic substance with a complex molecular structure, classified as hydrolysable and condensed, it acts in colloidal systems, neutralizing charges and forming bridges between these particles, thus enabling the formation of flocs and their sedimentation (Coral et al, 2009). Tannins exhibit excellent properties in removing a wide range of metals. These metals can be removed by the tannins when they are adsorbed. In addition to metal adsorption, tannins can be used to coagulate and flocculate materials in wastewater. Tannins have many useful properties, such as biodegradability, interaction, low toxicity, low cost and easy application (Martins et al, 2014).

In this work, we are developing a new method to produce condensed tannins yield after post extraction treatment from bark residues to be applied in the process of water treatment. During the assessment of new production paths, it is important to understand the environmental impact of different choices making the best decisions possible and focusing development on potential improvements. An established method to evaluate a system's environmental performance is Life Cycle Assessment (LCA) (Bauman and Tillman, 2004; Finnveden et al., 2009; Pennington et al., 2004; Rebitzer et al., 2004). However, as far as we are aware, only one LCA study has been published on extraction of tannins from Norway spruce bark (Ding et al, 2017). The results of this study show that the extract drying process is the primary contributor to the environmental impact of tannin production. Another LCA study was performed, where it is analyzed the production of a flocculation agent based on actionized tannins from the bark of Norway spruce, including the production of spruce trees to the finished flocculation product ready to leave the factory gate (Carlqvist et al, 2020). This study shows that the main environmental impact stems from the reagents used in the cationization step. The purification step could also be a significant issue depending on the possibility of reusing the eluent (ethanol) and the lifetime of the resin used. Also, a LCA study was performed comparing in large-scale production scenario three different technologies: hot water extraction (HWE), ultrasound assisted extraction (UAE), and supercritical fluid extraction (SFE) for the extraction of phenolic compounds from spruce bark (Carlqvist et al, 2022). The LCA results show that the simpler HWE process has a lower environmental impact per amount of phenolic compound extracted than UAE and SFE unless the extraction yields of the latter are more than about 5 times that of HWE. The reason for this result is mainly the environmental burden caused by the consumption of ethanol in the UAE and SFE processes, which accounts for more than 70% of the total environmental burden in most impact categories. Other LCA studies have been published where extraction of tannins from softwood bark (such as maritime pine, mimosa) is also performed as a part of a system. However, the extracted tannins are used in the production of leather dyes, adhesives, resins, foams, etc (Arias et al., 2022; Conde et al., 2022; González-García et al., 2016). In this context it is noted a lack of studies in the application of the LCA methodology in the analysis of the environmental impact of the extraction of tannin-based natural coagulants for water treatment.

The present study aims to analyze the process of extraction and use of tannin-based natural coagulants for water treatment. This work provides a gate-to-gate LCA of the extraction and production of condensed tannins from acacia bark residues from the north Portugal region.

2. LIFE CYCLE ASSESSMENT

The main objective of the present work is to evaluate the potential environmental impact in the extraction and production of condensed tannins from acacia bark residues. Furthermore, it was defined as a secondary aim to identify the life cycle phase that contributes the most to its environmental impact. The LCA methodology, which includes all stages of a product's life (Bauman and Tillman, 2004) was used in accordance with the standards from the ISO 14040 and ISO 14044 (ISO, 2006a; ISO, 2006b).

2.1 Goal, Functional Unit and System Boundary

The objective of this LCA study is quantifying the environmental impacts of extraction and production of condensed tannins from acacia bark residues from the north Portugal region. The aim of the environmental assessment is to identify the most promising pathways and to identify optimization potential. The functional unit (FU) of this LCA is 1 kg of condensed tannins yield after post extraction treatment from bark residues.

Laboratory scale data was used to obtain data at pilot scale using SuperPro Design software simulation. It is assumed that extraction yield and extract composition on a pilot scale matches the laboratory results under the same process conditions. It was used a gate-to-gate approach, the acacia cultivation and acacia bark collection stages were excluded because it is assumed that it is a mandatory task of the forest management system and must be conducted in any circumstances. Also, the acacia bark is an invasive species therefore it grows without human help. Capital goods were also excluded.

The Acacia bark is assumed to be dried and shredded before being loaded to a tannin extraction unit. The extract in water is submitted to purification through adsorption and removal of solvent in an evaporation step. Finally, the extract is spray dried to remove remaining humidity (Figure 1).

2.2 Inventory Analysis

The Life Cycle Inventory and Life Cycle Impact Assessment were conducted with the SimaPro software. Unless otherwise specified, Ecoinvent was used as a main secondary data source, and missing data were collected from literature and laboratory data. An overview of mass and energy flows to produce the FU 1 kg of condensed tannins yield after post extraction treatment from bark residues is presented in Figure 1.

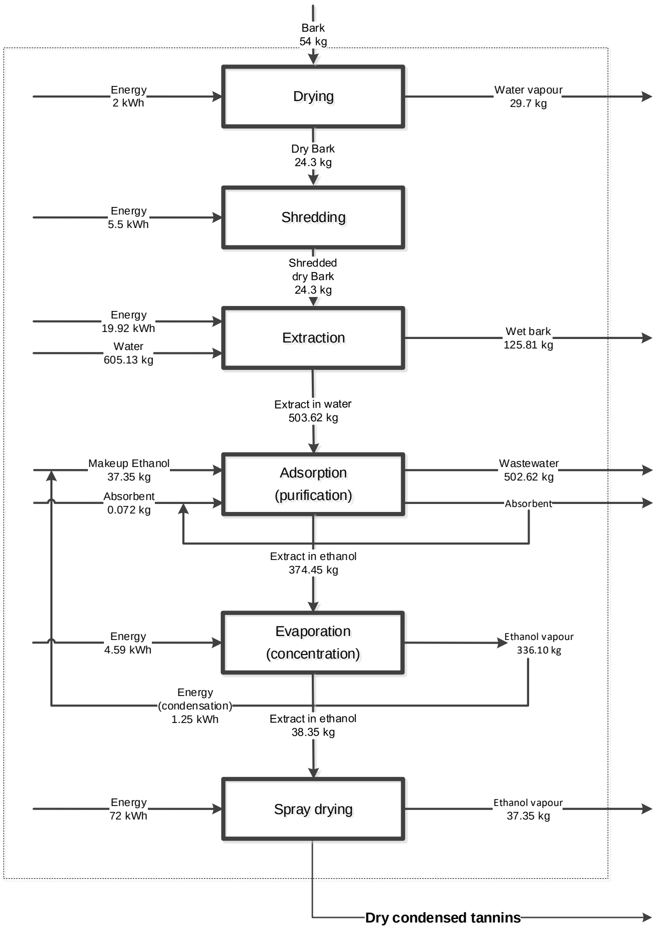

Figure 1. System boundary, showing the production system with mass and energy flows for 1 FU

2.3 Environmental Impact Assessment

Impact categories and characterization factors were obtained from the ReCiPe midpoint Hierarchist method. The ReCiPe model is well adapted to European conditions, which is consistent with the geographical scope of this LCA study. Of particular concern is the global warming potential (GWP), based on the current focus on environmental and sustainability goals. This category will therefore be evaluated first in detail and the others summarized in an overview.

An overview of the relative contribution of the potential impact on GWP, for each process step, is shown in Figure 2. The spray drying step has the largest potential impact on GWP in the present analysis and is the main hotspot in the overall process for many of the ReCiPe impact categories, as shown later in the summary of all 18 impact categories. This is due to intensive consumption of energy (the Portuguese country electricity mix is assumed). The second largest potential impact on GWP is the adsorption step, due to consumption of makeup ethanol and adsorption resin, even though bioethanol (based on lignocellulose) is assumed to be used. The remaining process steps (drying, shredding, extraction and evaporation) are also energy intensive.

In a broader perspective, the relative contribution to the impact categories of ReCiPe for the overall production of condensed tannins is shown in Figure 3. The pattern of the burden distribution is similar in many of the impact categories, dominated by the spray drying and adsorption processes. Except for Stratospheric ozone depletion, Marine eutrophication, Terrestrial ecotoxicity, Human non-carcinogenic toxicity and Land use, where the adsorption process is the main burden. These results are in line with previous published studies (Ding et al, 2017; Carlqvist et al, 2020), when taking in consideration the FU and system boundary. Hence a possible strategy to improve the environmental performance of the system is to try to reduce the water consumption in the extraction step since both the extraction and spray dying steps have high energy demands and by reducing the water content the energy demand will be reduced. Data for the adsorption step highlights the importance of re-using ethanol for elution and using a resin with long lifetime.

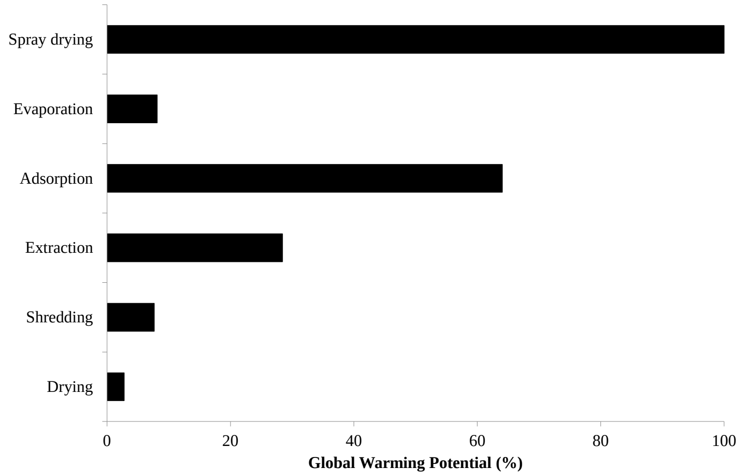

Figure 2. Relative contributions (in %) to the GWP for each process stage for the production of 1 FU

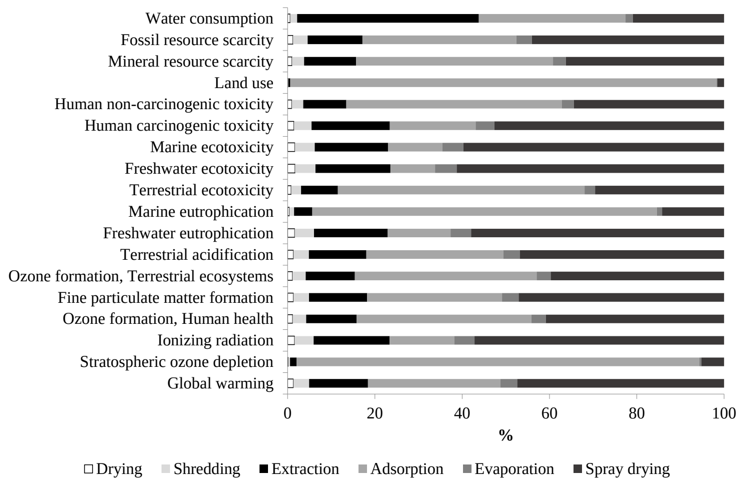

Figure 3. Relative contributions (in %) to the impact categories of ReCiPe per subsystem in the overall production of 1 FU

It should be mentioned that this work will be further developed in the future, in order to better understand the environmental impact of the new method proposed to produce condensed tannins yield after post extraction treatment from bark residues to be applied in the process of water treatment. Once the main hotspots of the production of condensed tannins from acacia bark have been identified, alternative formulation routes and a sensitivity analysis should be developed to determine the degree of improvement achievable in the environmental profiles. Possible aspects for future work include the possibility of eliminating the spray drying process step, to lower the energy consumption, since the main objective is to obtain condensed tannins to be used in the water treatment. Therefore, the drying process may be eliminated since the dry condensed tannins are hydrated again in subsequent steps. Also, the acacia cultivation and acacia bark collection stages were excluded from the study because it is assumed that this is a mandatory task of the forest management system and must be conducted anyway. However, on a larger scale, acacia will most likely have to be cultivated and not just collected from forests, in which case the acacia cultivation process could affect the environmental impact of the condensed tannins production and its potential impact on the system should be assessed.

3. CONCLUSION

In this study the environmental impact of the production of condensed tannins from acacia bark was investigated from gate-to-gate perspective. Of the six process steps in the assessed production system, spray drying and adsorption (purification) were identified as the main sources of the environmental impact of the whole system, respectively due to intensive consumption of energy and consumption of makeup ethanol.

The most important action to improve the environmental performance of the system is to improve the environmental profile of the extraction and spray dying steps. This LCA points towards a reduction in water consumption in the extraction as a way to reduce the environmental impact of the process. Both the extraction and spray dying steps have high energy demands and by reducing the water content the energy demand will be reduced. The analysis of the adsorption step highlights the importance of re-using the ethanol for elution and using a resin with a long lifetime. Through this LCA, it was possible to identify the most important steps that will facilitate process development towards a lower environmental impact.

ACKNOWLEDGEMENT

Project TECH (reference NORTE-01-0145-FEDER-000043), financed by the European Fund for Regional Development (FEDER) through Programa Operacional Regional do Norte (NORTE2020).

REFERENCES

Arias et al., 2022. Tannin-based bio-adhesives for the wood panel industry as sustainable alternatives to petrochemical resins, *Journal of Industrial Ecology*, Vol. 26, pp. 627-642.

Bauman H. and Tillman A.-M., 2004. *The Hitch Hiker's Guide to LCA - An orientation in LCA methodology and application*, Publisher: Studentlitteratur, Sweden.

Conde et al., 2022. Exploring the feasibility of substituting mimosa tannin for pine bark powder. A LCA perspective, *Cleaner Engineering and Technology*, Vol. 7, No. 100425.

Carlqvist K. et al, 2020. Life-cycle assessment of the production of cationized tannins from Norway spruce bark as flocculants in wastewater treatment. *Biofuels, Bioproducts and Biorefining*, Vol. 14, pp. 1270-1285.

Carlqvist K. et al, 2022. Life cycle assessment for identification of critical aspects in emerging technologies for the extraction of phenolic compounds from spruce bark. *Journal of Cleaner Production*, Vol. 333, No. 130093.

Coral L. A. et al, 2009. *Estudo da viabilidade de utilização do polímero natural (TANFLOC) em substituição ao sulfato de alumínio no tratamento de águas para consumo*. Key elements for a sustainable world. São Paulo - Brasil.

Ding T. et al, 2017. Life cycle assessment of tannin extraction from spruce bark. *iForest*, Vol. 10, pp. 807-814.

Finnveden et al., 2009. Recent developments in Life Cycle Assessment. *Journal of Environmental Management*, Vol. 91, pp. 1-21.

Fiorentini V., 2005. Uso do tanino no processo de tratamento de água como melhoria em sistema de gestão ambiental.

González-García et al., 2016. Environmental sustainability of bark valorisation into biofoam and syngas, *Journal of Cleaner Production*, Vol. 125, pp. 33-43.

ISO 14040: 2006, 2006a. Environmental Management – Life Cycle Assessment – Principles and Framework. ISO 14000 International Standards Compendium. Geneva, Switzerland: International Organization for Standardization (ISO).

ISO 14044: 2006, 2006b. Environmental Management – Life Cycle Assessment – Requirements and Guidelines. ISO 14000 International Standards Compendium. Geneva, Switzerland: International Organization for Standardization (ISO).

Lima P. R. et al, 2020. Os diferentes tipos de coagulantes naturais para tratamento de água. *Evidência*, Vol. 20, pp. 9-12.

Martins A. A. et al, 2014). Potencial de uso de compostos orgânicos como, coagulantes, floculantes e adsorventes no tratamento de água e efluentes. *Periódico Eletrônico Fórum Ambiental da Alta Paulista*, Vol. 10, No. 12.

Pennington et al., 2004. Life cycle assessment Part 2: Current impact assessment practice, *Environment International*, Vol. 30, pp. 701-720.

Rebitzer et al., 2004. Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications, *Environment International*, Vol. 30, pp. 721-739.