Life cycle assessment of the production of natural colourant extracts from *Curcuma longa*

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Abstract

The curcuminoids from *Curcuma longa* (*C. longa*) are broadly applied as a yellow colouring agent in the food sector, also coupling well-being benefits. Nevertheless, the extraction of curcuminoids from Curcuma rhizomes includes several chemical techniques, with high energy and materials needs. Thus, life cycle assessment (LCA) was applied to evaluate the sustainability of the processes involved in the curcuminoids extraction, at a bench scale. The impacts were assessed for 1 g of curcumin-based colourant extract, in eleven midpoint environmental categories, assuming a "cradle-to-gate" approach. In the present work, two scenarios were analysed: (1) curcumin-based colourant extract (without encapsulation) and (2) encapsulated curcumin-based extract. The results demonstrated that the most significant impacts occurred in the processes that involve the highest energy consumption, such as lyophilisation (95%) in the curcumin-based colourant extract (without encapsulation) scenario, and spray-drying (88%) in the encapsulated curcumin-based extract production.

Keywords: life cycle assessment, food colourants, energy, *Curcuma longa*

1. Introduction

There are more than seventy rhizomatous herbs from the genus Curcuma. These species can be found in subtropical and tropical areas, particularly in Asia. Curcuma has demonstrated important effects against inflammatory, bacterial (Dutra et al. 2021), allergic, oxidant, parasitic, mutagenic, and microbial conditions, having applications in several sectors (Degot et al. 2021).

The curcuminoids from *Curcuma Longa* (*C. longa*), are responsible for the yellow colour of these species, which are widely used as a powerful colouring agent in the food industry (Almeida et al. 2018). The separation of curcumin and curcuminoids from Curcuma rhizomes may involve diverse extraction techniques, such as conventional solvent extraction, hydrotrope, steam distillation, alkaline solution extraction, hot and cold percolation, and advanced techniques such as microwave-assisted (MAE), supercritical fluid (SFE), ultrasound-assisted (UAE), and highly efficient chromatography extractions (Shirsath et al. 2017).

Economic and environmental drawbacks of the natural product extraction have been highlighted, such as long extraction processes, low extraction efficiencies, the requirement of high energy needs, and large volumes of organic solvents (Shirsath et al. 2017). In this context, efforts should be made to turn the extraction techniques more sustainable, and in line with the Sustainable Development Goals of the United Nations (Mancini et al. 2019).

Currently, to evaluate the environmental impacts of products and/or services, the life cycle assessment (LCA) is a methodology widely applied to understand the environmental impacts that may emerge from raw materials acquisition to end-of-life alternatives, for instance (Monteiro et al. 2020; Moura et al., 2022a; 2022b).

Aiming to understand the critical unit processes of the production of *C. longa* colourant extracts regarding different extraction techniques and the development of sustainable development of colourants, an environmental LCA was performed at a bench scale.

2. Materials and methods

Based on standardized norms (ISO 2006a, b), this LCA study was performed using SimaPro (v9) software and the ReCiPe method (v1.03). A functional unit (FU) of 1 g of curcumin-based colourant extract was considered, assuming a "cradle-to-gate" approach. Herein, two different routes were considered to produce the extracts, as shown in Table 1.

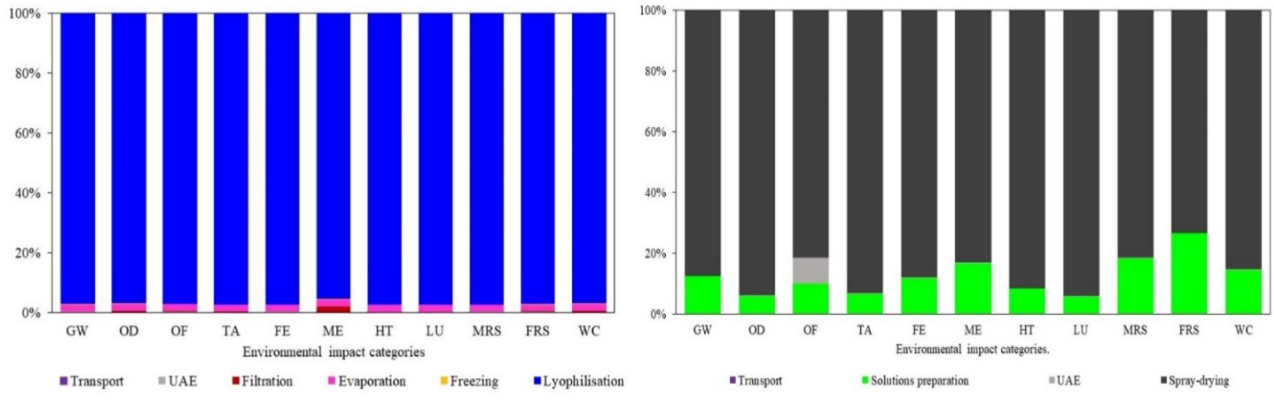
Table 1. Curcumin-based colourant extract production processes studied.

Product	Description	Processes involved
A. Curcumin-based colorant extract (without encapsulation)	The samples were collected from a Portuguese local store and transported to the laboratory, at room temperature. Afterwards, the samples were prepared and submitted to UAE. In this process, a mixture of ethanol/water (57.5:42.5) is used as a solvent. Then, the solution is filtrated to remove impurities and the ethanol is recovered by evaporation. The process finishes with freezing and lyophilization of the extract, to remove the water content.	(1) Transport; (2) ultrasound-assisted extraction (UAE); (3) filtration; (4) evaporation: (5) freezing and (6) lyophilisation.
B. Encapsulated curcumin-based extract	After the transportation, under the same conditions mentioned above, the samples were prepared and mixed joint with an aqueous and buffer solution. Then, they were submitted to the UAE process. At the end of the process, the extract is dried, using nitrogen during the spray-drying process.	(1) Transport; (2) Solution preparation; (3) UAE and (4) spray-drying in inert loop

In the life cycle impact assessment (LCIA) stage, eleven midpoint environmental impact categories were considered: global warming (GW), stratospheric ozone depletion (OD), ozone formation (OF), terrestrial acidification (TA), freshwater eutrophication (FE), marine eutrophication (ME), human toxicity (HT), land use (LU), mineral resource scarcity (MRS), fossil resource scarcity (FRS) and water consumption (WC).

3. Results and discussion

The environmental impacts of C.*longa*-based extract production were evaluated for unit process and extraction route. The LCIA results demonstrated the highest impacts were obtained for the processes that involved the highest energy consumption. Thus, in alternative A (Figure 1 (a)), the lyophilisation process contributed to above 95% of the environmental impacts, followed by the evaporation stage (0.7%). Transport and freezing presented neglectable environmental impacts. Regarding the encapsulated extract (Figure 1(b)), the spray-drying phase contributed to 88% of the environmental impacts due to the energy requirements of the equipment used. The solution preparation accounted for 12% of environmental impacts, due to the use of solvents, namely ethanol, citric acid, and PVP40.



(a) (b)

Figure 1. Environmental impacts from the processing phases of (a) *C. longa* and (b) *C. longa* with encapsulation.

In the OF category, a higher contribution of the UAE (7 %) was observed. This may be related to the release of solvents (e.g., ethanol) into the atmosphere, during the process. The shipping of the virgin material presented the lowest environmental burden (below 0.1 %), considering the impacts from all the midpoints analysed.

Comparing the of curcumin-based extracts, 1g of extract without encapsulation presented a global warming potential of 36 kg CO_2-eq, whereas to produce the encapsulated extract only 0.6 kg CO_2-eq, were required, per gram. Generally, the encapsulated extract shows up as an environmentally promising alternative, since it mitigated 99% of the environmental impacts associated with extraction route A (with no encapsulation).

4. Conclusions

The power sector decarbonisation and the implementation of innovative strategies are key factors towards net-zero carbon emissions, in the food industry. This study showed the electricity embodied impact is quite relevant for the curcumin extracts under development. Comparing the extraction of curcumin with and without encapsulation, it is possible to conclude that encapsulation presented an environmental benefit per gram, since an average environmental impact reduction of 99% was observed. Bio-additives are still in an early-stage of development. Thus, to improve the sustainability of extraction processes, an environmental life cycle perspective is key to support the selection of the more sustainable techniques for scaling up.

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