

Banana peel as a Source of Polyphenols: Perspectives of Sustainability

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ABSTRACT

The case of banana peel as a rich source of pharmaceutically important polyphenols is well-known. Our research focuses on techno-economic and environmental impact assessment of sourcing polyphenols from banana peel. Firstly, phenolic acids and flavonoids, the two major classes of polyphenols, are extracted from dried banana peel powder. The extraction process is carried out with different solvents with varying properties and different extraction techniques with differences in their working mechanism. These extraction protocols were compared on the basis of techno-economics. Distilled water was the most favored solvent in that regard. On the other hand, from the perspective of carbon dioxide emission potential, ethanol stood out as the best. Recovery of extraction solvent was considered and its impact, on techno-economics and emission potential of the protocols was analyzed. The exact nature of the impact was a strong function of the specific protocol and the target polyphenols.

Keywords: Extraction, Food & Agricultural Processes, Batch Process, Polyphenols, Techno-economics, Emission potential

INTRODUCTION

Valorization of agro-food waste is key to waste management in a sustainable manner. While such waste products, so commonly available world-wide, has great value as fuel and fertilizer, they are also useful source of important chemicals, many of which have critical pharmaceutical applications owing to their anti-oxidant properties [1, 2]. Among pharmaceutically active intra-cellular metabolites of plants, polyphenols are most abundant of which phenolic acids and flavonoids are the major subclasses [3]. Accordingly, in this work, the aim is to evaluate various extraction strategies for obtaining phenolic acids and flavonoids from banana peel.

While there exists rich literature on evaluating performance of different extraction techniques, solvents as well as other factors (such as time, temperature, parameters of extraction agents such as microwave power, ultrasound power etc.) for polyphenols extraction from various natural sources [4, 5], studies on analyzing their sustainability perspectives are very rare. Thus, in this work, we aim to bridge this gap by performing analysis based on techno-economic and environmental impact for production of phenolics and flavonoids from banana peel.

EXTRACTION PROTOCOLS

Banana peels, freshly obtained from the whole fruit was cut into pieces and dried in microwave oven to remove moisture (to around 85 %) which otherwise might interfere with solvent extraction efficiency. Our study involved optimizing critical extraction decisions in terms of techno-economics and environmental impact. With this motivation, the microwave-dried banana peel powder (BPP) was subjected to solvent extraction using five different solvents – distilled water (DW), methanol (Me), ethanol (Et), acetone (Ac) and acetic acid (AA). In terms of extraction solvent, the chosen solvents varied in terms of the key properties relevant for leaching – such as polarity (which impacts the type of polyphenols a solvent would extract), surface tension, viscosity, vapor pressure (these properties of solvent determine how good a solvent would perform in presence of ultrasound), dielectric properties (which impact suitability of solvents in microwave).

The extraction process was carried out with five different methods. Only these two factors which would fundamentally alter the extraction performance were varied.

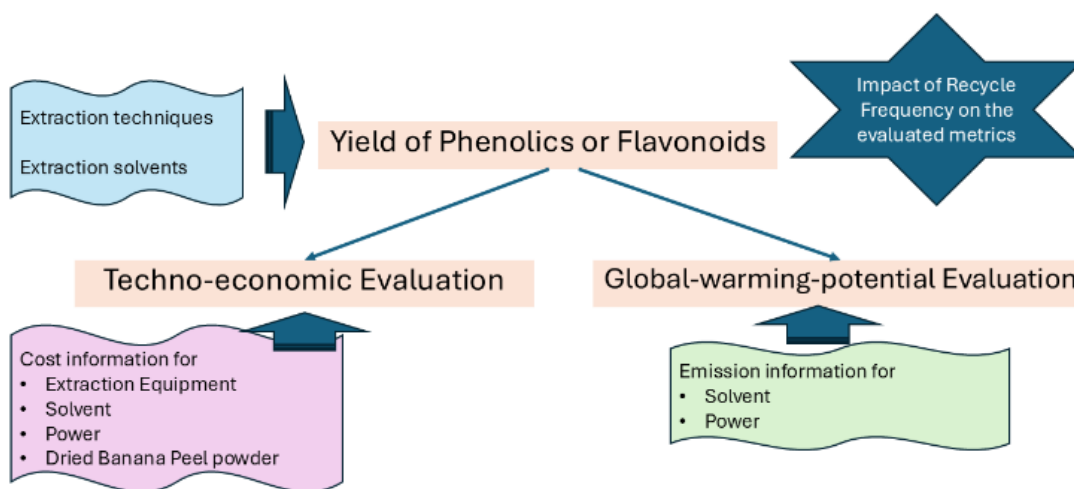


Figure 1. Scope of the Present Work and its Correlation with the Yield of Polyphenols and the Relevant Input Parameters.

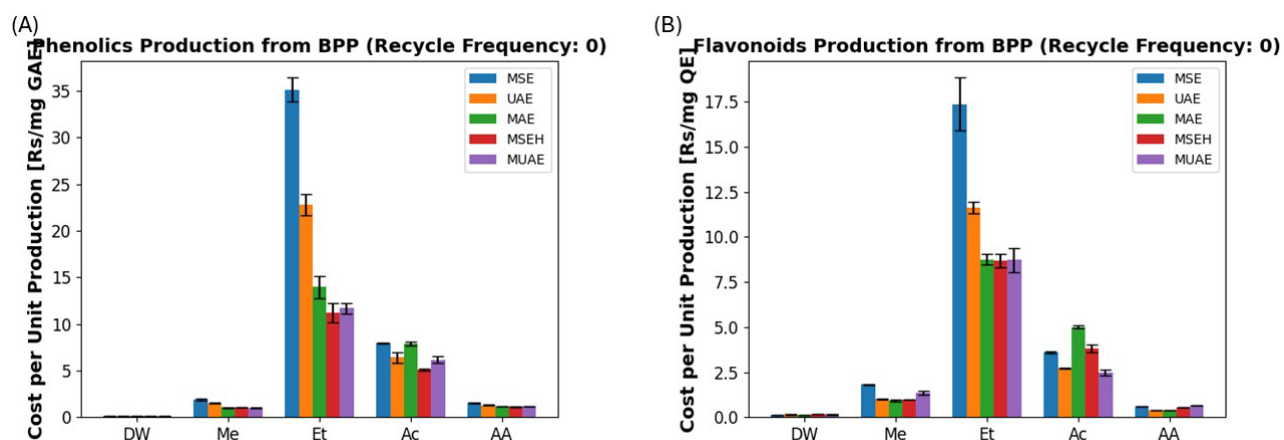


Figure 2. Variation in Cost per Unit Production of either type of Polyphenols for all the different Extraction Protocols: (A): Phenolics and (B): Flavonoids

Other potential factors like temperature, solvent amount, US power etc. were not independently varied. Among the five extraction techniques, for Magnetic Stirred-based Extraction (MSE), a simple leaching was conducted at room temperature (around 25°C). Ultrasound and microwave have been reported to enhance the yield by helping rupture the cell walls of BPP [6, 7], thereby allowing the solvents an easy access to dissolve them. Thus, two of our techniques (UAE and MAE) employed these to incorporate these impacts. While temperature of extraction was maintained at 25°C for UAE, microwave also increased the temperature of medium. The extraction temperature was maintained at 50°C for MAE. Thus, we also had an extraction technique (Magnetic Stirred-based Extraction with Heating, i.e., MSEH) that would ensure 50°C operation with conventional heating – for a fair comparison between two modes of heating. Finally, for the case of MUAE operated at 50°C, both the ultrasound and

microwave effects acted in parallel. Extraction time was 30 times for all the scenarios and solvent to solid ratio was 10 mL/g. Total Phenolics Content (TPC) and Total Flavonoids Content (TFC) were computed with UV-Visible Spectrophotometer. While the lab-scale experiments were conducted using 50 mL solvent, for computations in this work, a scaling of 10 times was considered since 500 mL was maximum capacity of equipment with which we performed MAE and MUAE. Accordingly, for the scaled scenario, electricity demand was considered to be also 10 times (as against lab scale one) to ensure identical profile for stirring, US, MW, heating to keep efficiency of extraction same.

METRIC FOR COMPARING VARIOUS EXTRACTION DECISION-ALTERNATIVES

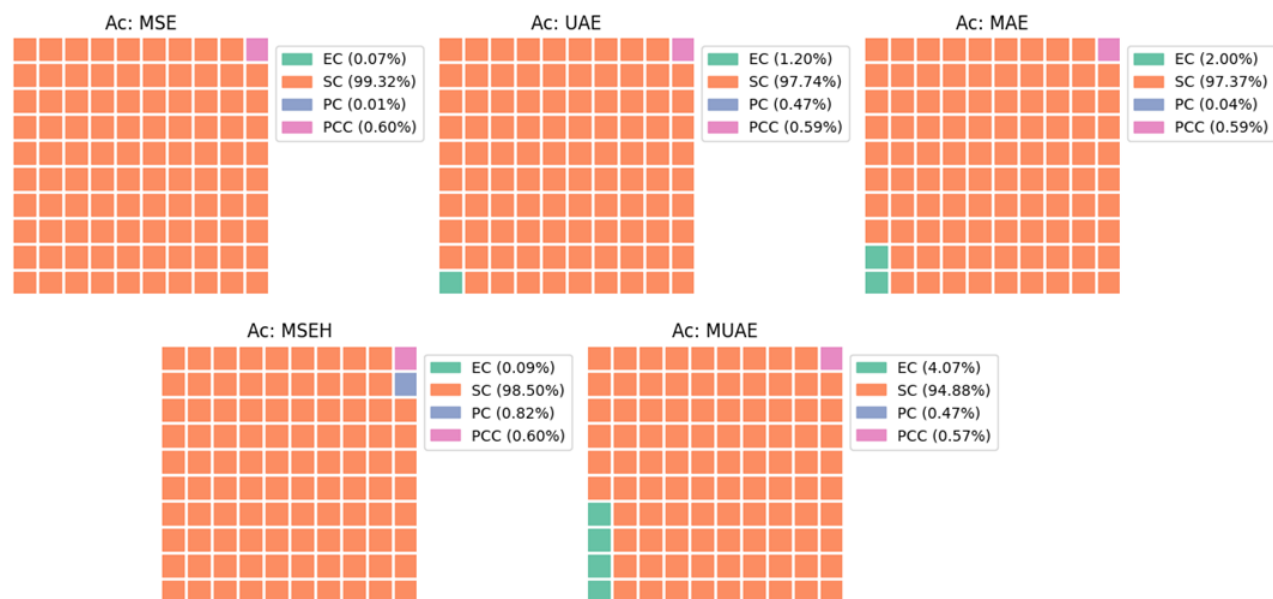


Figure 3. Relative Contribution of various cost components for various extraction techniques with acetone as solvent (for the use of fresh solvent, i.e., recycle frequency = 0)

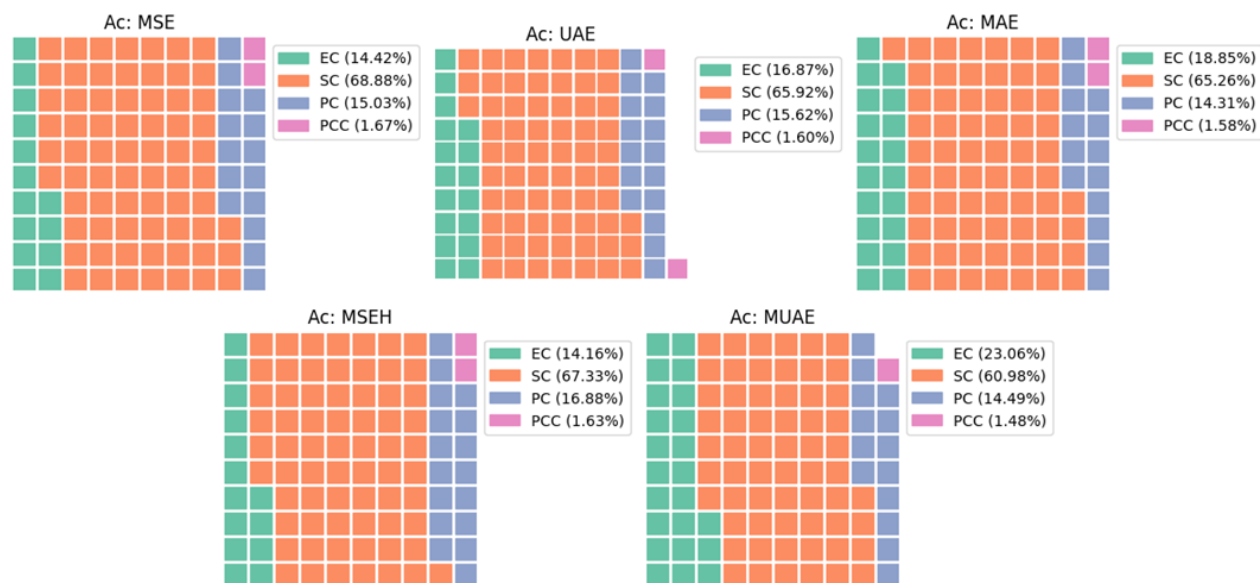


Figure 4. Relative Contribution of various cost components for various extraction techniques with acetone as solvent (for recycle frequency = 5)

In this section, we present and discuss about the basis on which techno-economic analysis was performed. We define Techno-Economic Metric (TEM) as a function of total cost incurred over a year for unit production of phenolics or flavonoids. Total cost was assumed to have four components – equipment cost (EC) required to procure extraction equipment as per the specific technique, solvent cost (SC) required to purchase necessary

amount of a specific solvent, power cost (PC) necessary to meet the demand of electricity for stirring, heating, introducing ultrasound and microwave, as the case may be, and BPP cost (BPPC) incurred to procure the necessary amount of raw material. Among the four components, EC, being a capital cost, was annualized as per capital recovery factor. 300 days of operation was assumed over one year and 16 batches, over one day with each batch,

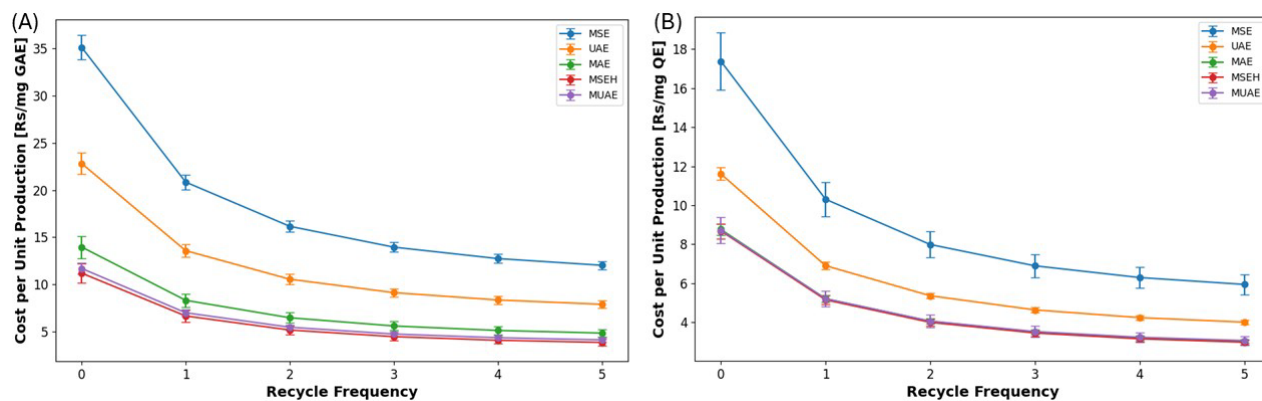


Figure 5. Variation in Cost per Unit Production of Polyphenols with Increase in Recycle Frequency: (A): Phenolics, (B): Flavonoids, considering ethanol as an example solvent

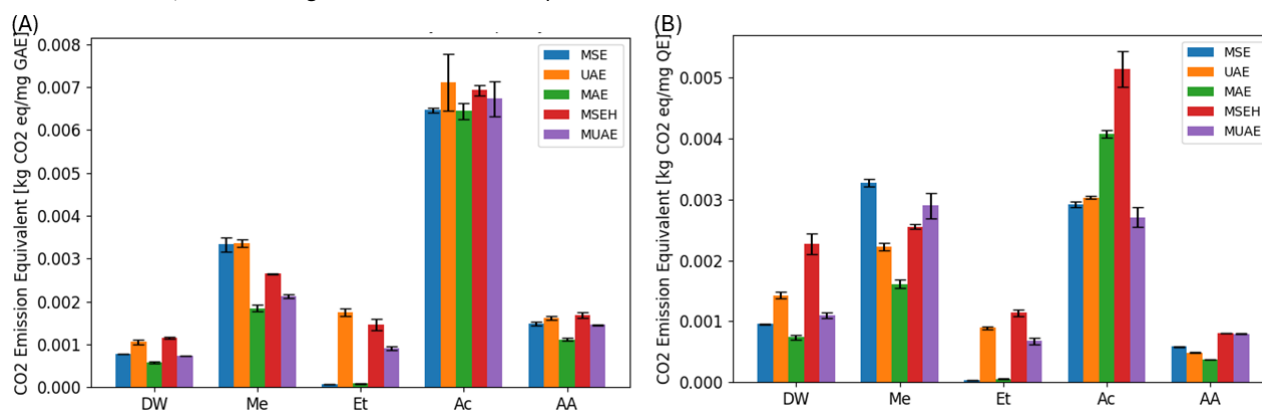


Figure 6. Variation in Emission per Unit Production of either type of Polyphenols for all the different Extraction Protocols: (A): Phenolics and (B): Flavonoids, using fresh solvent (n: 0).

employing 500 mL of a specific extraction solvent at a relative ratio of 10 ml/g solid.

Instances of solvent recovery was also considered. For such cases, the extra terms for cost for recovery scenario involved the purchase of a rotary evaporator, vacuum pump and recirculating chiller as well as the electricity needed for the recovery operation, while cost for fresh solvent got reduced. Detailed scheduling of extraction and recovery operation was ignored since labor cost was ignored.

Figure 1 presents a schematic of the scope of this study. Extraction yield of polyphenols is a strong function of the extraction protocols, i.e., technique and solvent. In conjunction with yield and relevant inputs related to cost of various contributing factors, we obtain cost of production (CP) per unit of a specific type of polyphenols, and that is considered as a metric of evaluation. Similarly, the CO₂ emission potential for production of the organic solvents (as per standard values in literature [8-10] in addition with the electricity required during extraction, in conjunction with yield provide us a mean to compare the protocols as per emission from production (EP) for unit

production of a specific type of polyphenols over the same operation period, as stated above. For DW, the emission was based on power demand in the distillation equipment. DW was not recovered as it would always be available in any lab facility at minimal cost.

It is to be noted that the recycle frequency plays an important role in our study. We consider six scenarios in this regard – recycle frequency of zero defining use of fresh solvent daily. For recycle frequency of ‘n’, the scenario assumes that extraction starts with fresh solvent on day 1 and then, for n consecutive days, solvents are continued to be recovered after each extraction operation. After n days, again the process is repeated with one day of operation with fresh solvent and n days again, with recovered solvent. Yield is assumed to be dropping similar to that reported in literature [11] by a factor of 0.9 for each recovery frequency. The trade-off that all these factors bear on CP and EP per unit production is important and discussed in due course.

RESULTS AND DISCUSSIONS

Based on yield, it was noticed that for phenolics, DW

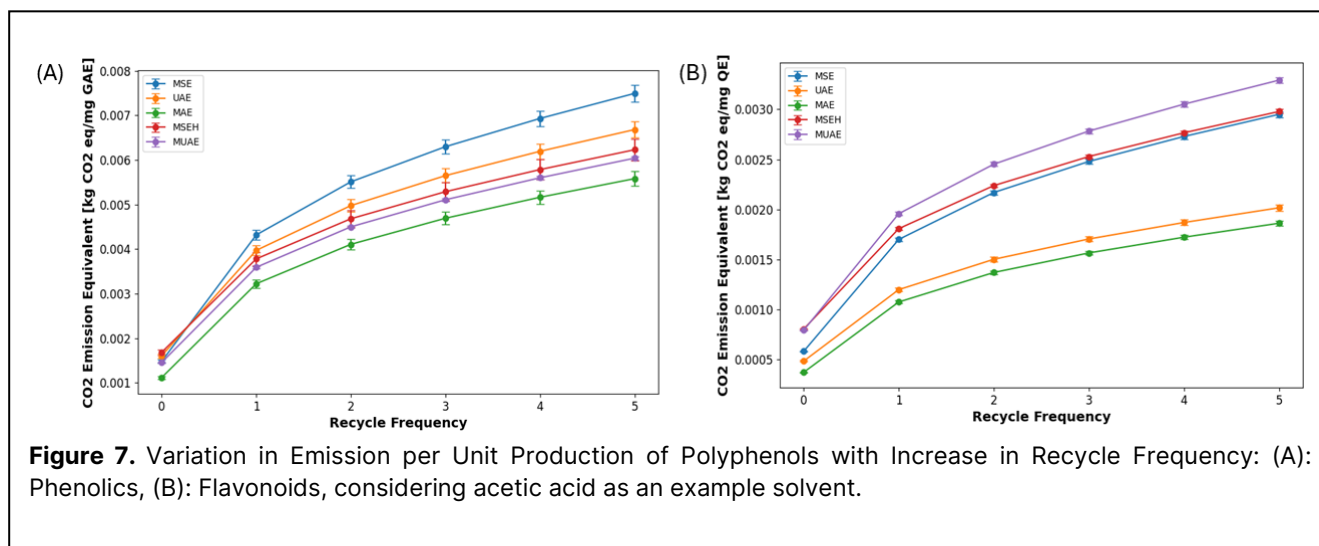


Figure 7. Variation in Emission per Unit Production of Polyphenols with Increase in Recycle Frequency: (A): Phenolics, (B): Flavonoids, considering acetic acid as an example solvent.

with MUAJAE was the most efficient, while for flavonoids, it was AA, with MAE. Variation in yield with extraction protocols closely followed prospective impact of most critical solvent properties, as relevant for a specific extraction technique. As stated earlier, the major focus of this present work is comparative evaluation of five extraction techniques and those many solvents from the perspectives of sustainability.

Techno-economic Analysis

We firstly focus on the findings from a techno-economic evaluation. The trade-off between yield obtained by a certain protocol and the associated cost incurred is studied here. This study is important since without this, one would not know whether a protocol with low yield with a low cost is preferred over one with high yield at high cost.

From Figure 2, we notice that DW was the most favoured solvent for all the extraction techniques from the perspective of achieving a high enough yield of either type of polyphenols at low enough expenditure. Ethanol, being the most expensive solvent among all (for the AR/ACS grade, in India), was the least favoured. Among the extraction techniques, the relative superiority varied with the choice of solvent as well as the target polyphenol and there was no clear trend identical for all the solvents for either of the polyphenols. Figure 3 presents the relative contribution of the four cost components – for acetone, as an example. We notice that for all the techniques, solvent cost was the most dominant cost components. The findings were same (with difference only in % contribution values) for the other solvents. These % contribution were same for both the types of polyphenols since the cost for utilizing 500 mL solvent in extraction over one year as stated before would be same for either type of polyphenols.

Impact of Recovery of Solvent

As the frequency of recycle increases, fresh solvent amount drops – this, its cost and emission would also drop. However, recycle of solvent also requires equipment for solvent recovery – thereby increasing equipment cost and power cost (for power, operating those extra equipment).

With the yield dropping and cost also majorly dropping (as solvent contribution was so dominant on process economics for extraction with fresh solvent), the net impact can be seen in Figure 5, wherein we noticed a drop in cost as n increases for all the scenarios. In terms of relative cost contribution, equipment and power now had more foothold as expected (Figure 4 as against Figure 3, for acetone as an example).

Emission Potential of the Extraction Protocols

We also evaluated the EP for unit amount of polyphenols as shown in Figure 6 for fresh solvent. Like CP, EP was also, as expected, a strong function of extraction protocol. However, percentage change in EP was not that much significant across the techniques for any solvent, for majority of the instances. Among all the scenario, acetone's outlook was the poorest for phenolics and also for MAE and MSEH for flavonoids extraction. Ethanol with MSE was the most superior among all options.

Figure 7 reflects relative change in EP with increase in recycle frequency for acetic acid, as an example solvent. Even though emission due to solvent production dropped (for use of lower amount of fresh solvent), that due to power demand for solvent recovery increased. Moreover, with increase in recycle frequency, production of polyphenols also took a hit. As a result, we notice an increase in EP with recycle frequency for all the extraction techniques. A similar trend was observed for other solvents, as well.

CONCLUSIONS

Comparative evaluation of extraction protocols

(technique and solvent) from the critical perspectives of techno-economics and emission potential was the major focus of this study. We found that the relative superiority of extraction protocols as per either of these perspectives differed as per choice of target polyphenols. While this work is an important step towards sustainability assessment for phytochemical extraction from agro-food waste, consideration of other environmental impact assessment indicators would be an important next step. Moreover, pareto-optimality of this two-objective (cost and environmental impact) would enable us to have a sounder decision-making for extraction protocol. Moreover, while this work has highlighted important findings for polyphenols extraction from a given quantity of banana peel (since volume of solution per batch was same), it would also be very informative to explore the optimal decisions for a certain demand profile of polyphenols.

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