International Journal of Food Science +Technology



Original article

# A potential of banana flower and pseudo-stem as novel ingredients rich in phenolic compounds

**Sara Ramírez-Bolaños,[1]* Jara Pérez-Jiménez,[2] Sara Díaz[3] & Lidia Robaina[1]**

1 Grupo de Investigación en Acuicultura (GIA), IU-ECOAQUA, Universidad de Las Palmas de Gran Canaria, Crta. Taliarte s/n, Telde 35214, Spain

2 Department of Metabolism and Nutrition, Institute of Food Science, Technology and Nutrition (ICTAN-CSIC), José Antonio Novais 10, Madrid 28040, Spain

3 Fabricación Integrada y Avanzada Research Group, Departamento de Ingeniería de Procesos, Universidad de Las Palmas de Gran Canaria, Las Palmas de Gran Canaria 35017, Spain

*(Received 28 January 2021; Accepted in revised form 27 April 2021)*

**Keywords** Banana flower, banana pseudo-stem, extractable polyphenols, non-extractable polyphenols.

## Introduction

World banana production in 2017–2019 reached 116 million tonnes, making it the most important fruit production worldwide (FAO, 2020). Due to the way bananas are harvested, the amount of waste generated in the plantations reaches 80% of the total biomass (Padam *et al*., 2014), constituting both an environmental problem related to soil toxicity and elevated carbon print (Adsal *et al*., 2020) and a food safety problem derived from food waste management (Campos *et al*., 2020). Interest in banana residues has been renewed in recent times mostly due to their variety of bioactive compounds (Lau *et al*., 2020), apart from the emerging uses of banana plant fibre in several industries (Ortega *et al*., 2016; Rodríguez *et al*., 2020); all these usages and its processes generate waste as a secondary by-product after processing. The utilisation of these secondary by-products fit with the current FAO ODS actions on the Circular Economy (FAO, 2018).

Polyphenols are the most common bioactive compounds in plant residues (Singh *et al*., 2016; Lau *et al*., 2020). They are secondary metabolites with biological activities such as radical scavenging ability or microbiota modulation, which results in health benefits related to glucose homeostasis, obesity, type II diabetes, systemic inflammation or lipid metabolism, besides their use as a natural preservative (Cao *et al*., 2019; Fraga *et al*., 2019; Lau *et al*., 2020). Interest in polyphenols have been traditionally focussed on the so-called extractable polyphenols (EPP), that is, low molecular weight compounds present free in vegetal cells, although increasing evidence is showing the relevance of non-extractable polyphenols (NEPP) or macromolecular antioxidants, which are high molecular weight polyphenols or small ones associated with macromolecules such as protein or dietary fibre (Pérez-Jiménez *et al*., 2013).

Among agricultural residues from banana production are the banana flowers, which arise upon the bracts axis of the inflorescence (Ram *et al*., 1962) and cut down when they reach a specific size so that they do not interfere with the ripening and growth of the fruit (Lau *et al*., 2020), and the whole pseudo-stem, which is left on the ground of the plantation. These by-products have been widely used in traditional medicine (Mathew & Negi, 2017; Lau *et al*., 2020). There are currently several studies on the inclusion of banana by-products in animal and human diets. For instance, banana leftovers were used to replace up to 75% of the cornmeal in lamb diets without causing adverse effects (Menezes *et al*., 2018). Likewise, several studies with pseudo-stem show that it can be considered as an alternative source to traditional livestock fodder (Wang *et al*., 2016). The banana flower has been studied for its antioxidant and anti-diabetic capacity (Lau *et al*., 2020); thus Bhaskar *et al*. (2012) showed that both, banana pseudo-stem and banana flower used as a dietary supplement in patients with diabetes may reduce associated complications.

Nevertheless, studies on the phytochemical characterisation of banana flower or banana pseudo-stem are still scarce. Thus, Bashkar *et al*. (2012) is the only found study with these two banana by-products

*Correspondent: E-mail: sara.ramirez@ulpgc.es

doi:10.1111/ijfs.15072

from *Musa sp. elakki bale*, where HPLC analysis was performed. Also, Schmidt *et al.* (2015) have reported some characterisation of banana male flower and bracts from *Musa cavendish* in which EPP content by spectrophotometry was measured. Moreover, most of the studies performed with banana residues do not differentiate the banana flower from the inflorescence being the composition and effects indistinctly attributed to both parts of the plant (Lau *et al.*, 2020).

The present study aims to perform a preliminary approach to evaluate the potential of the use of banana flower and pseudo-stem as novel food ingredients, for which a nutritional characterisation of both materials was performed, including HPLC-MS analysis of polyphenol fractions.

## Material and methods

### Chemicals

The Folin-Ciocalteu reagent was from Panreac (Castellar del Vallés, Barcelona, Spain). Gallic acid, kaempferol, myricetin, ferulic acid, 2-hydroxybenzoic acid, protocatechuic acid, 1-caffeoylquinic acid, *p*-coumaric acid, (+)-catechin and (-)-epicatechin were all obtained from Sigma-Aldrich (St. Louis, MO). All the reagents used for the preparation of phenolic compounds fractions and spectrophotometric determinations were of analytical grade, while for MS analysis, they were of MS grade. Condensed tannin concentrate from Mediterranean carob pods (*Ceratonia siliqua L*) was supplied by Nestlé Ltd. (Vers-chez-les Blancs, Switzerland).

### Samples

Pseudo-stem and flowers were supplied by local producers of banana cultivars (*Musa accuminata cavendish*) from the 2017 and 2018 harvests. Pseudo-stem was processed at University of Las Palmas de Gran Canaria facilities to mechanically separate the external long fibre for other studies (patent: WO2014/174115), the residue that remained in the machine was the pseudo-stem fibre considered for the present study. Dried banana flower (DBF) and dried pseudo-stem (DBPS) were freeze-dried and ground in a mill (Ultra Centrifugal Mill ZM200, Retsch, Germany) to a particle size of 0.5mm. All the analysis were performed in triplicates for each harvest; results are given on a dry weight (dw) basis and are expressed as the mean of the two harvest ± standard deviation.

### Proximate composition and fatty acids profile

Moisture, crude protein and ash content were determined according to AOAC (1995). Lipids were determined according to Folch *et al.* (1957). The total carbohydrate content was calculated by the difference method. FAMEs (Fatty Acid Methyl Esters) were obtained by transmethylation of total lipids following Christie (1982) protocol and separated and quantified by liquid chromatography (Izquierdo *et al.*, 1989).

### Extractable polyphenols (EPP)

0.5 g of sample was extracted by shaking at room temperature with 20 mL of methanol/water (50:50 v/v, pH 2) and then with 20 mL of acetone/water (70:30, v/v) for 1 hour. The two supernatants were combined, which corresponded to the extractable phenolic compounds fraction (Pérez-Jiménez *et al.*, 2008).

### Hydrolyzable polyphenols (HPP)

The residue from the extractable phenolic compounds extraction was treated with 20 mL of methanol and 2 mL of sulfuric acid (12 M) at 85 °C for 20 h. After washing with distilled water, an aliquot of the extract was adjusted to pH 5.5 (Hartzfeld *et al.*, 2002; Arranz *et al.*, 2009).

### Nonextractable proanthocyanidins (NEPA)

The residue from the extractable phenolic compounds extraction was treated with butanol/HCl (97.5:2.5, v/v) with 0.1% FeCl3 at 100 °C for 1h (Pérez-Jiménez *et al.*, 2009).

### Determination of EPP, HPP and NEPA content

The total content of phenolic compounds was determined by spectrophotometry. The Folin-Ciocalteau assay (Singleton *et al.*, 1999) was applied to EPP and HPP, the results being expressed as g of gallic acid equivalents/100 g dw. NEPA content was determined by measuring the sum of absorbance at 450 and 555 nm (Zurita *et al.*, 2012) and the results were expressed as mg NEPA/100g dw, using a standard curve from carob pod concentrate. The total percentage of non-extractable polyphenols was determined by the formula (HP+NEPA)/total polyphenols x100. All these measurements were carried out in a 96-well plate reader (Synergy MX, Bio Tek, Winooski, Vermont, USA).

### Phenolic profile by HPLC−ESI−QTOF

The EPP and HPP fractions from DBF, as well as HPP fraction of DBPS, were concentrated (6:1) with an $N_2$ stream; EPP fraction of pseudo-stem was discarded after previous evaluation of spectrophotometry results. For separation, the HPLC apparatus (Agilent

 

1200, Agilent Technologies, Santa Clara, CA) with DAD (Agilent G1315B) and a QTOF mass analyzer (Agilent G6530A) with an atmospheric pressure electrospray ionization (ESI) was used. The column used was a 100A 50 mm × 2 mm i.d., 5 μm, Luna C18 (Phenomenex, Torrance, CA) at 25°C. Gradient elution was performed with a binary system consisting of 0.1% aqueous formic acid (solvent A) and 0.1% formic acid in acetonitrile (solvent B). The following gradient was applied at a flow rate of 0.4 mL/min: 0 min, 8% B; 10 min, 23% B; 15 min, 50% B; 20 min, 50% B; 23 min, 100% B; followed by a re-equilibration step. The injection volume was 20 μL. Data were acquired using negative ion mode with a mass range of 100 − 1200 Da and using a source temperature of 325 °C and a gas flow of 10 L/h. Peak identity was established by comparison with the retention times of commercial standards when available. Also, the molecular formula proposed by the MassHunter Workstation software version 4.0 for the different signals obtained in the MS experiments were compared with previously reported phenolic compounds in banana and other vegetal materials, and a maximum error of 10 ppm was accepted. For MS/MS experiments, the auto MS/MS acquisition mode was used; the main fragments were compared with the fragmentation patterns reported for phenolic compounds.

A relative quantitation was performed based on UV signals, using the calibration curve of a commercial standard for each class of phenolic compounds. Hydroxybenzoic acid was monitored at 280 nm and directly quantified, other hydroxybenzoic acids were monitored at 280 nm and quantified with protocatechuic acid, *p*-coumaric acid was monitored at 320 nm and directly quantified, other hydroxycinnamic acids were monitored at 320 nm and quantified with ferulic acid, flavonols were monitored at 365 nm and quantified with kaempferol.

### Statistical analysis

The distribution of the results obtained in each batch was analysed with Rcmdr: R Commander (R package version 2.6-2, Fox J, Bouchet-Valat M, 2020) with Shapiro-– test to determine the normality and also the descriptive statistics were performed.

## Results and discussion

This study aims to explore the potential of DBF and DBPS as possible new functional ingredients, as a way to valorise these by-products in a circular economy context. For this, the proximate composition of these materials was obtained, completing previous data and, especially, a comprehensive analysis of polyphenols was performed.

The proximate composition of DBF and DBPS are provided in Table 1. There were some differences with previous studies, which reported lower values in proteins and ash content (Bhaskar *et al*., 2012; Wang *et al*., 2016) in pseudo-stem, or proteins, lipids and ash in the flower (Sheng *et al*., 2010). This may be related to the differences between varieties and the samples that were taken; for instance, the part of the pseudo-stem that was analysed in the present study was the remain fibrous pulp after the extraction of most of the fibre, instead of the whole pseudo-stem.

The detailed composition of the fat fraction of each material was evaluated (Table 2). The two samples presented marked different fatty acid profile. The overall profile for DBF agreed with that described in another study (Lau *et al*., 2020), although other authors described a lower proportion of unsaturated fatty acids (Vilela *et al*., 2014). DBPS composition differs from the one described by Ramu *et al*. (2017), where palmitic acid content was lower while linoleic acid was higher than in this preliminary study. Regarding the potential benefits of fatty acids present in these residues, since DBPS exhibits a low amount of lipids in this product, the actual impact on health would be irrelevant. On the contrary, the DBF does present an appreciable quantity of lipids that can influence health. Thus, a portion of 20g of DBF can provide 197.3 mg of linoleic acid, which is 18% of the recommended dietary amount; DHA quantity present in 20g of DBF is the equivalent of half DHA present in 100g of salmon; also, the content of n-3 fatty acid is similar to the recommended portion which is 450 mg/day (Kris-Etherton *et al*., 2009; Ytrestøyl *et al*., 2015). Furthermore, eicosadienoic acid, a precursor of DHA (Lupette & Benning, 2020), is present with 157.2 mg/portion. The benefits of MUFA and PUFA are widely described in the literature, such as mediation in the innate immune system, reduction of cardiovascular disease risk and the redistribution of adipose tissue (Tvrzicka *et al*., 2011; Lau *et al*., 2020).

Therefore, these results show that both DBF and DBPS may have an interesting nutritional

**Table 1** Proximate composition of dried banana flower and dried banana pseudo-stem

| | Banana flower | Banana pseudo-stem |
|---|---|---|
| *(% dw)* | | |
| Lipids | 8.66 ± 0.23 | 1.01 ± 0.32 |
| Ash | 18.07 ± 0.76 | 15.97 ± 2.67 |
| Protein | 13.59 ± 0.41 | 7.25 ± 2.48 |
| Moisture | 7.23 ± 1.89 | 8.97 ± 1.01 |
| Carbohydrates | 59.68 ± 1.26 | 76.09 ± 5.58 |

(mean ± sd deviation of the two harvest).

**Table 2** Fatty acid profile from dried banana flower and dried banana pseudo-stem

| FAA (%) | Banana flower | Banana pseudo-stem |
|---|---|---|
| 14:00 | 0.16 | 1.55 |
| 14:1n-5 | 0.06 | 0.77 |
| 15:00 | 0.26 | 2.29 |
| 15:1n-5 | 0.03 | 0.11 |
| 16:00 | 12.90 | 39.89 |
| 16:1n-7 | 0.21 | 1.04 |
| 16:1n-5 | 0.03 | 0.08 |
| 16:2n-6 | 0.62 | 0.00 |
| 17:00 | 0.04 | 0.30 |
| 16:3n-4 | 0.03 | 0.21 |
| 16:3n-3 | 0.02 | 0.05 |
| 16:3n-1 | 0.03 | 0.10 |
| 16:4n-3 | 0.26 | 0.16 |
| 18:00 | 2.19 | 6.17 |
| 18:1n-9 | 2.04 | 9.21 |
| 18:1n-7 | 0.73 | 3.93 |
| 18.1n-5 | 0.04 | 0.18 |
| 18:2n-9 | 0.03 | 0.09 |
| 18:2n-6 | 11.47 | 15.46 |
| 18:2n-4 | 1.02 | 0.25 |
| 18:3n-6 | 0.46 | 0.90 |
| 18:3n-3 | 5.68 | 0.22 |
| 18:4n-3 | 0.37 | 8.39 |
| 20:00 | 1.15 | 1.92 |
| 20:1n-9 | 0.12 | 0.39 |
| 20:1n-7 | 1.55 | 0.48 |
| 20.1n-5 | 0.20 | 0.09 |
| 20:2n-9 | 0.09 | 0.07 |
| 20:2n-6 | 9.14 | 0.46 |
| 20:3n-6 | 1.24 | 1.02 |
| 20:4n-6 | 0.00 | 0.46 |
| 20:3n-3 | 0.41 | 0.07 |
| 20:4n-3 | 0.23 | 0.12 |
| 20:5n-3 | 0.17 | 0.16 |
| 22:1n-11 | 0.41 | 0.25 |
| 22:1n-9 | 19.11 | 1.10 |
| 22:4n-6 | 0.79 | 0.15 |
| 22:5n-6 | 0.31 | 0.40 |
| 22:5n-3 | 0.36 | 0.00 |
| 22:6n-3 | 26.04 | 0.94 |
| ∑SFA | 16.70 | 52.12 |
| ∑MUFA | 24.47 | 16.86 |
| ∑PUFA | 58.77 | 29.68 |
| n-3 | 33.54 | 10.11 |
| n-6 | 24.03 | 18.85 |
| n-9 | 21.39 | 10.86 |

MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; SFA, saturated fatty acid.

composition, especially regarding proteins and lipids, which could make them suitable to be tested in different formulations.

From phenolic compound analysis (Table 3), DBF emerged as a potentially relevant source of these compounds. Regarding EPP fraction (not detected in DBPS), the number of phenolic compounds in the flower agreed with that reported by Padam *et al.* (2012) and, interestingly, was much higher than that described in the fruit (Pico *et al.*, 2019). In agreement with this higher phenolic compound content in DBF than in DBPS, HPP fraction was between 6-fold and 8-fold higher in the latter. Previous data showed that a relevant fraction of phenolic compounds in DBF was associated with hemicellulose A (Bhaskar *et al.*, 2012), thus corresponding to the HPP fraction. But the most relevant fact of phenolic compounds analysis in these by-products was the determination, by the first time, of NEPA content. A very high content (about 10% dw) was determined in DBF, indeed constituting 90% of the total phenolic compound content in this material. This novel result is in concordance with previous descriptions of a very high NEPA content in banana fruit (Pérez-Jiménez & Saura-Calixto, 2015) and banana peel (Pérez-Jiménez & Saura-Calixto, 2018), being commonly underestimated. The difference observed between the spectrophotometry and the HPLC-MS determination was within the ranges observed in other characterisations of vegetal materials (Pérez-Ramírez *et al.*, 2018), where the spectrophotometry determinations were higher due to the unspecific of the technique and are not directly comparable techniques.

**Table 3** Total content (mg/100 g dw) for extractable polyphenols (EP), hydrolysable polyphenols (HP) and non-extractable proanthocyanins (NEPA), and percentage of non-extractable polyphenols (NEPP) in dried banana flower and dried banana pseudo-stem

| | Banana flower | Banana pseudo-stem |
|---|---|---|
| Fraction | | |
| EP | 1075.02 ± 20.60 | nd |
| HP | 735.23 ± 103.91 | 150.75 ± 53.54 |
| NEPA | 11200.00 ± 3357.61 | nd |
| %NEPP | 91.73 | 100 |

(mean ± sd. deviation of the two harvest).

Detailed phenolic compounds profile was evaluated by HPLC-ES-QTOF MS technique analysis in EPP fraction of DBF (Table 4), and HPP fractions in DBF (Table 5) and DBPS (Table 6). NEPA, due to the butanol medium, exhibit problems for HPLC analysis and, besides, due to the depolymerization process information about original structures would be completely lost (Pérez-Jiménez & Torres, 2011).

The identity of individual phenolic compounds in DBF and DBPS was performed for the first time by MS.

In BBF EPP fraction (Table 4) and both HPP fractions (Table 5, Table 6), phenolic acids were the most

 

**Table 4** Phenolic compounds identified by HPLC-ESI QTOF MS analysis in the extractable polyphenols (EPP) fraction of dried banana flower of the two harvest

| ID | Compound | Formula | (M-H)-teo | (M-H)-cal | Diff | Concentration (mg/100 g dw) |
|---|---|---|---|---|---|---|
| Hydroxybenzoic acids | | | | | | |
| 1 | 3,5-Dihydroxybenzoic acid | $C_7H_6O_4$ | 153.0187 | 153.0195 | 2.17 | 0.44 ± 0.02 |
| | Gentisic acid | $C_7H_6O_4$ | 153.0187 | 153.0195 | 2.17 | 0.44 ± 0.02 |
| 2 | Protocatechuic acid* | $C_7H_6O_4$ | 153.0187 | 153.0185 | 4.28 | 0.43 ± 0.04 |
| 3 | Hydroxybenzoic acid* | $C_7H_6O_3$ | 137.0238 | 137.0237 | 4.86 | 6.61 ± 2.74 |
| Hydroxybenzaldehydes | | | | | | |
| *4* | 4-Hydroxybenzaldehyde | $C_7H_6O_2$ | 121.0289 | 121.0291 | 2.98 | 0.24 ± 0.02 |
| | Benzoic acid | $C_7H_6O_2$ | 121.0289 | 121.0291 | 2.98 | 0.24 ± 0.02 |
| Hydroxycinnamic acids | | | | | | |
| 5 | Caffeic acid | $C_9H_8O_4$ | 179.0344 | 179.0345 | 2.78 | 10 ± 3.38 |
| 6 | *p*-Coumaric acid* | $C_9H_8O_3$ | 163.0398 | 163.0395 | 1.54 | 0.38 ± 0.05 |
| 7 | Ferulic acid* | $C_{10}H_{10}O_4$ | 193.0507 | 193.0500 | 4.11 | 1.64 ± 0.57 |
| Flavonols | | | | | | |
| 8 | Quercetin 3,4′-O-diglucoside | $C_{27}H_{30}O_{17}$ | 625.1404 | 625.1440 | -4.24 | 1.01 ± 0.83 |
| | Quercetin 3-O-sophoroside | $C_{27}H_{30}O_{17}$ | 625.1404 | 625.1440 | -4.24 | 1.01 ± 0.83 |

*Identified by standard. cal, calculated; exp, experimental.

**Table 5** Phenolic compounds identified by HPLC-ESI-QTOF MS analysis in the hydrolizable polyphenols (HPP) fraction of dried banana flower of the two harvest

| ID | Compound | Formula | (M-H)-teo | (M-H)-cal | Diff | Concentration (mg/100g dw) |
|---|---|---|---|---|---|---|
| Hydroxybenzoic acids | | | | | | |
| 2 | Protocatechuic acid* | $C_7H_6O_4$ | 153.0187 | 153.0195 | 1.16 | 48.68 ± 0.62 |
| 9 | Gallic acid 3-o-gallate | $C_{14}H_{10}O_9$ | 321.0246 | 321.0227 | 7.68 | 0.43 ± 0.01 |
| Hydroxycinnamic acids | | | | | | |
| 7 | Ferulic acid* | $C_{10}H_{10}O_4$ | 193.0500 | 193.0498 | 4.4 | 0.71 ± 0.17 |
| 10 | Isoferulic acid | $C_{10}H_{10}O_4$ | 193.0500 | 193.0505 | 0.64 | 5.74 ± 0.16 |

*Identified by standard. cal. calculated; exp. experimental. nd, non-detected.

**Table 6** Phenolic compounds identified by HPLC-ESI-QTOF MS analysis in the hydrolizable polyphenols (HPP) fraction of dried banana pseudo-stem of the two harvest

| ID | Compound | Formula | (M-H)-cal | (M-H)-exp | Diff | Concentration (mg/100g dw) |
|---|---|---|---|---|---|---|
| Hydroxybenzoic acids | | | | | | |
| 2 | Protocatechuic acid* | $C_7H_6O_4$ | 153.0187 | 153.0191 | 4.24 | 49.02 ± 27.64 |
| Hydroxycinnamic acids | | | | | | |
| 6 | *p*-Coumaric acid* | $C_9H_8O_3$ | 163.0395 | 163.0395 | 3.34 | 0.48 ± 0.12 |
| 7 | Ferulic acid* | $C_{10}H_{10}O_4$ | 193.0500 | 193.0508 | -1.4 | 1.26 ± 0.29 |
| 11 | *p*-Coumaric acid ethyl ester | $C_{11}H_{12}O_3$ | 191.0708 | 191.0720 | -3.76 | 0.05 ± 0.01 |

*Identified by standard; cal. calculated; exp. experimental. nd, non-detected.

relevant constituents, although some flavonol was also detected, which agrees with previous results in banana fruit and peel (Tsamo *et al.*, 2015). Previous studies also identified epicatechin and gallic acid in the banana flower associated with hemicellulose and in green banana flour (Bhaskar *et al.*, 2012; Pico *et al.*, 2019) or protocatechuic acid in the banana rhizome (Kandasamy & Aradhya, 2014). Nevertheless, for most detected phenolic compounds, identity could not be assigned, since they corresponded to structures not present in common databases nor literature on banana. In the EPP fraction from DBF, 45 non-

identified compounds were detected, and 28 compounds in HPP fraction. In the HPP fraction from DBPS 12 non-identified were detected (data not shown). The wide diversity of structures in the phenolic compounds family makes that new structures are still being identified (Nguyen *et al*., 2019); this indicates the need for further structural analysis in DBF and DBPS.

Due to the total concentration and profile of individual phenolic compounds in DBF, this product, as an additional source of phenolic compounds in the context of the whole diet, might have health benefits. For instance, protocatechuic acid, for which health effects related to cancer, type I and II diabetes and neuroprotection have been reported (Adedara *et al*., 2019; Al Olayan *et al*., 2020), was detected in DBF at a concentration higher than that observed in most common foods, according to the Phenol-Explorer database (Neveu *et al*., 2010). Although the potential effects would be mostly derived from the combination of all phenolic compounds present in this product, as shown in a study in diabetic rats where phenolic extracts of banana pseudo-stem and flowers modulated the antioxidant defence enzymes, decreasing the complications associated with diabetes (Bhaskar *et al*., 2011). Also, regarding the high NEPA content detected in DBF, it should be remarked that other products rich in this phenolic compound fraction, such as grape pomace, have shown several health-related properties, for instance regarding fasting insulin (Martínez-Maqueda *et al*., 2018).

In conclusion, this study provides preliminary new data on proximate composition and, especially, phenolic compounds profile, in DBF and DBPS, two by-products from the banana industry currently neglected. In the light of the results obtained, future comprehensive studies need to be performed to establish an accepted range of the main constituent of these by-products, taking into account the possible difference between batches of the same species due to environmental growing conditions (Vinson *et al*., 2018; Lau *et al*., 2020); and thus, the real potential of the DBF and DBPS as novel food ingredients as well as the technological aspects for their incorporation into foods and their potential health effects.

## Acknowledgment

This research was partially funded by the EU Environment and Climate Action LIFE Programme (European Union), under the LIFEBAQUA project (code: LIFE15 ENV/ES/000157). We are grateful to the ICTAN Analysis Services Unit for providing facilities for chromatography analysis and in particular to Dr Inmaculada Álvarez-Acero for technical assistance.

## Author Contribution

**Sara Ramírez-Bolaños:** Data curation (lead); Formal analysis (lead); Investigation (equal); Writing-original draft (lead). **Jara Pérez-Jiménez:** Conceptualization (equal); Resources (equal); Supervision (lead); Validation (lead); Writing-review & editing (lead). **Sara Díaz:** Formal analysis (supporting). **Lidia Robaina:** Conceptualization (equal); Funding acquisition (equal); Project administration (lead); Resources (equal); Supervision (supporting); Writing-review & editing (supporting).

## Conflict of interest

We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with this manuscript.

## Ethical Approval

Ethics approval was not required for this research.

## Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## References

Adedara, I.A., Okpara, E.S., Busari, E.O., Omole, O., Owumi, S.E. & Farombi, E.O. (2019). Dietary protocatechuic acid abrogates male reproductive dysfunction in streptozotocin-induced diabetic rats via suppression of oxidative damage, inflammation and caspase-3 activity. *European Journal of Pharmacology*, **849**, 30–42.

Adsal, K.A., Üçtuğ, F.G. & Arikan, O.A. (2020). Environmental life cycle assessment of utilizing stem waste for banana production in greenhouses in Turkey. *Sustainable Production and Consumption*, **22**, 110–125.

Al Olayan, E.M., Aloufi, A.S., Alamri, O.D., Ola, H. & Moneim, A.E.A. (2020). Protocatechuic acid mitigates cadmium-induced neurotoxicity in rats: role of oxidative stress, inflammation and apoptosis. *Science of The Total Environment*, **723**, 137969.

Arranz, S., Saura-Calixto, F., Shaha, S. & Kroon, P.A. (2009). High contents of nonextractable polyphenols in fruits suggest that polyphenol contents of plant foods have been underestimated. *Journal of Agricultural and Food Chemistry*, **57**, 7298–7303.

Association of Analytical Communities (1995). *Official methods of analysis of AOAC International*. Association of Analytical Communities.

Bhaskar, J.J., Chilkunda, N.D. & Salimath, P.V. (2012). Banana (Musa sp. var. elakki bale) flower and pseudostem: dietary fiber and associated antioxidant capacity. *Journal of Agricultural and Food Chemistry*, **60**, 427–432.

Bhaskar, J.J., Shobha, M.S., Sambaiah, K. & Salimath, P.V. (2011). Beneficial effects of banana (Musa sp. var. elakki bale) flower and pseudostem on hyperglycemia and advanced glycation end-products (AGEs) in streptozotocin-induced diabetic rats. *Journal of Physiology and Biochemistry*, **67**, 415–425.

 

Campos, D.A., Gómez-García, R., Vilas-Boas, A.A., Madureira, A.R. & Pintado, M.M. (2020). Management of fruit industrial by-products—A case study on circular economy approach. *Molecules*, **25**, 320.

Cao, H., Ou, J., Chen, L. *et al.* (2019). Dietary polyphenols and type 2 diabetes: human study and clinical trial. *Critical Reviews in Food Science and Nutrition*, **59**, 3371–3379.

Christie, W.W.(1982). *Lipid Analysis*, vol. **207**. Pp 207. Oxford: Pergamon Press.

Folch, J., Lees, M. & Stanley, G.H.S.A. (1957). A simple method for total lipid extraction and purification. *Journal of Biological Chemistry*, **226**(497–509), 18.

Food and Agriculture Organization of the United Nations. (2018). Transforming Food and Agriculture to Achieve the SDGs: 20 interconnected actions to guide decision-makers. Technical Reference Document. Pp. 132. Rome, Italy.

Food and Agriculture Organization of the United Nations (2020). *Banana Market Review: February 2020 snapshot*. Rome: Food and Agriculture Organization of the United Nations.

Fraga, C.G., Croft, K.D., Kennedy, D.O. & Tomás-Barberán, F.A. (2019). The effects of polyphenols and other bioactives on human health. *Food & Function*, **10**, 514–528.

Hartzfeld, P.W., Forkner, R., Hunter, M.D. & Hagerman, A.E. (2002). Determination of hydrolyzable tannins (gallotannins and ellagitannins) after reaction with potassium iodate. *Journal of Agricultural and Food Chemistry*, **50**, 1785–1790.

Izquierdo, M.S., Watanabe, T., Takeuchi, T., Arakawa, T. & Kitajima, C. (1989). Requirement of larval red seabream *Pagrus major* for essential fatty acids. *Nippon Suisan Gakk*., **55**, 859–867.

Kandasamy, S. & Aradhya, S.M. (2014). Polyphenolic profile and antioxidant properties of rhizome of commercial banana cultivars grown in India. *Food Bioscience*, **8**, 22–32.

Kris-Etherton, P.M., Grieger, J.A. & Etherton, T.D. (2009). Dietary reference intakes for DHA and EPA. *Prostaglandins, Leukotrienes and Essential Fatty Acids*, **81**(2–3), 99–104.

Lau, B.F., Kong, K.W., Leong, K.H. *et al.* (2020). Banana inflorescence: Its bio-prospects as an ingredient for functional foods. *Trends in Food Science & Technology*, **97**, 14–28.

Lupette, J. & Benning, C. (2020). Human health benefits of very-long-chain polyunsaturated fatty acids from microalgae. *Biochimie*, **178**, 15–25.

Martínez-Maqueda, D., Zapatera, B., Gallego-Narbón, A., Vaquero, M.P., Saura-Calixto, F. & Pérez-Jiménez, J. (2018). A 6-week supplementation with grape pomace to subjects at cardiometabolic risk ameliorates insulin sensitivity, without affecting other metabolic syndrome markers. *Food & Function*, **9**, 6010–6019.

Mathew, N.S. & Negi, P.S. (2017). Traditional uses, phytochemistry and pharmacology of wild banana (Musa acuminata Colla): A review. *Journal of Ethnopharmacology*, **196**, 124–140.

Menezes, A.M.D., Peripolli, V., Esteves, G.I.F. *et al.* (2018). Carcass characteristics and fatty acid profile of Santa Inês lamb fed banana leftovers. *Scientia Agricola*, **77**, 1–11.

Neveu, V., Pérez-Jiménez, J., Vos, F. *et al.* (2010). Phenol-Explorer: an online comprehensive database on polyphenol contents in foods. *Database*, **2010**, bap024

Nguyen, H.X., Nguyen, L.T., Van Do, T.N. *et al.* (2019). A new phenolic acid from the wood of Mangifera gedebe. *Natural Product Research*, 1–4.

Ortega, Z., Morón, M., Monzón, M.D., Badalló, P. & Paz, R. (2016). Production of banana fiber yarns for technical textile reinforced composites. *Materials*, **9**, 370.

Padam, B.S., Tin, H.S., Chye, F.Y. & Abdullah, M.I. (2012). Antibacterial and antioxidative activities of the various solvent extracts of banana (Musa paradisiaca cv. Mysore) inflorescences. *Journal of Biological sciences*, **12**, 62–73.

Padam, B.S., Tin, H.S., Chye, F.Y. & Abdullah, M.I. (2014). Banana by-products: an under-utilized renewable food biomass with great potential. *Journal of Food Science and Technology*, **51**, 3527–3545.

Pérez-Jiménez, J., Arranz, S., Tabernero, M. *et al.* (2008). Updated methodology to determine antioxidant capacity in plant foods, oils and beverages: Extraction, measurement and expression of results. *Food Research International*, **41**, 274–285.

Pérez-Jiménez, J., Arranz, S. & Saura-Calixto, F. (2009). Proanthocyanidin content in foods is largely underestimated in the literature data: an approach to quantification of the missing proanthocyanidins. *Food Research International*, **42**, 1381–1388.

Pérez-Jiménez, J., Díaz-Rubio, M.E. & Saura-Calixto, F. (2013). Non-extractable polyphenols, a major dietary antioxidant: occurrence, metabolic fate and health effects. *Nutrition Research Reviews*, **26**, 118–129.

Pérez-Jiménez, J. & Saura-Calixto, F. (2015). Macromolecular antioxidants or non-extractable polyphenols in fruit and vegetables: intake in four European countries. *Food Research International*, **74**, 315–323.

Pérez-Jiménez, J. & Saura-Calixto, F. (2018). Fruit peels as sources of non-extractable polyphenols or macromolecular antioxidants: analysis and nutritional implications. *Food Research International*, **111**, 148–152.

Pérez-Jiménez, J. & Torres, J.L. (2011). Analysis of non-extractable polyphenols in foods: the current state of the art. *Journal of Agricultural and Food Chemistry*, **59**, 12713–12724.

Pérez-Ramírez, I.F., Reynoso-Camacho, R., Saura-Calixto, F. & Pérez-Jiménez, J. (2018). Comprehensive characterization of extractable and nonextractable phenolic compounds by high-performance liquid chromatography–electrospray ionization–quadrupole time-of-flight of a grape/pomegranate pomace dietary supplement. *Journal of Agricultural and Food Chemistry*, **66**, 661–673.

Pico, J., Xu, K., Guo, M., Mohamedshah, Z., Ferruzzi, M.G. & Martinez, M.M. (2019). Manufacturing the ultimate green banana flour: Impact of drying and extrusion on phenolic profile and starch bioaccessibility. *Food chemistry*, **297**, 124990.

Ram, H.M., Ram, M. & Steward, F.C. (1962). Growth and development of the banana plant: 3. A. The origin of the inflorescence and the development of the flowers: B. The structure and development of the fruit. *Annals of Botany*, **26**, 657–673.

Ramu, R., Shirahatti, P.S., Anilakumar, K.R. *et al.* (2017). Assessment of nutritional quality and global antioxidant response of banana (Musa sp. CV. Nanjangud Rasa Bale) pseudostem and flower. *Pharmacognosy research*, **9**(Suppl 1), S74.

Rodríguez, L.J., Fabbri, S., Orrego, C.E. & Owsianiak, M. (2020). Comparative life cycle assessment of coffee jar lids made from biocomposites containing poly (lactic acid) and banana fiber. *Journal of Environmental Management*, **266**, 110493.

Schmidt, M.M., Prestes, R.C., Kubota, E.H., Scapin, G. & Mazutti, M.A. (2015). Evaluation of antioxidant activity of extracts of banana inflorescences (Musa Cavendishii). *CyTA-Journal of Food*, **13**, 498–505.

Sheng, Z.W., Ma, W.H., Jin, Z.Q. *et al.* (2010). Investigation of dietary fiber, protein, vitamin E and other nutritional compounds of banana flower of two cultivars grown in China. *African Journal of Biotechnology*, **9**, 3888–3895.

Singh, B., Singh, J.P., Kaur, A. & Singh, N. (2016). Bioactive compounds in banana and their associated health benefits–A review. *Food Chemistry*, **206**, 1–11.

Singleton, V.L., Orthofer, R. & Lamuela-Raventós, R.M. (1999). [14] Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent. *Methods in Enzymology*, **299**, 152–178.

Tsamo, C.V.P., Herent, M.F., Tomekpe, K. *et al.* (2015). Phenolic profiling in the pulp and peel of nine plantain cultivars (Musa sp.). *Food Chemistry*, **167**, 197–204.

Tvrzicka, E., Kremmyda, L.S., Stankova, B. & Zak, A. (2011). Fatty acids as biocompounds: their role in human metabolism, health and disease-a review. part 1: classification, dietary sources and

biological functions. *Biomedical Papers of the Medical Faculty of Palacky University in Olomouc*, **155**.
Vilela, C., Santos, S.A., Villaverde, J.J. *et al.* (2014). Lipophilic phytochemicals from banana fruits of several Musa species. *Food Chemistry*, **162**, 247–252.
Vinson, E.L., Coneva, E.D., Kemble, J.M. *et al.* (2018). Prediction of flower emergence and evaluation of cropping potential in selected banana cultivars (Musa sp.) cultivated in subtropical conditions of coastal Alabama. *HortScience*, **53**, 1634–1639.
Wang, C.F., Muhammad, A.U.R., Liu, Z.Y., Huang, B.Z. & Cao, B.H. (2016). Effects of ensiling time on banana pseudo-stem silage chemical composition, fermentation and in sacco rumen degradation. *The Journal of Animal & Plant Sciences*, **26**, 339–346.
Ytrestøyl, T., Aas, T.S. & Åsgård, T. (2015). Utilisation of feed resources in production of Atlantic salmon (Salmo salar) in Norway. *Aquaculture*, **448**, 365–374.
Zurita, J., Díaz-Rubio, M.E. & Saura-Calixto, F. (2012). Improved procedure to determine non-extractable polymeric proanthocyanidins in plant foods. *International Journal of Food Sciences and Nutrition*, **63**, 936–939.

 