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# Artificial neural network modelling of the antioxidant activity and phenolic compounds of bananas submitted to different drying treatments

**Running title:**
**MODELLING BY ANN OF THE ANTIOXIDANT ACTIVITY AND PHENOLIC COMPOUNDS OF BANANAS**

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## ABSTRACT

Bananas (cv. *Musa nana* and *Musa cavendishii*) fresh and dried by hot air at 50 and 70 ºC and lyophilisation were analysed for phenolic contents and antioxidant activity. All samples were subject to six extractions (three with methanol followed by three with acetone/water solution). The experimental data served to train a neural network adequate to describe the experimental observations for both output variables studied: total phenols and antioxidant activity. The results show that both bananas are similar and air drying decreased total phenols and antioxidant activity for both temperatures, whereas lyophilisation decreased the phenolic content in a lesser extent.

Neural network experiments showed that antioxidant activity and phenolic compounds can be predicted accurately from the input variables: banana variety,

dryness state and type and order of extract. Drying state and extract order were found to have larger impact in the values of antioxidant activity and phenolic compounds.

**Keywords:** antioxidant activity, banana, drying, neural network, phenolic compounds.

## 1. Introduction

The antioxidant compounds can be defined as substances that in small concentrations, compared to the oxidizable substrate, significantly delay or prevent the initiation or propagation of oxidizing chain reactions. These natural chemical compounds are generally aromatic and contain at least one hydroxyl group and are called bioactive substances, including, among others, phenolic compounds that are part of the constitution of various foods. Phenolic compounds are widely present in the plant kingdom, have simple or complex structures, and are essential for growth and reproduction of plants, besides being responsible for the colour, astringency and aroma in several foods (Sharma, 2014). These compounds, being antioxidants, fight free radicals (Rodrigo & Gil-Becerra, 2014), prevent heart diseases (Jiang, 2014; Khoo & Falk, 2014), neurodegenerative disorders (Hamaguchi, Ono, Murase, & Yamada, 2009), circulatory problems (Medina-Remón, Tresserra-Rimbau, Valderas-Martinez, Estruch, & Lamuela-Raventos, 2014), cancer (Fernández-Arroyo et al., 2012), inflammation (Wen, Chen, & Yang, 2012), and inhibit lipid oxidation (Maqsood & Benjakul, 2010). Thermal processing may destroy the amount or the bioavailability of these compounds, thus reducing beneficial health effects (Agcam, Akyıldız, & Akdemir Evrendilek, 2014; Al Bittar, Périno-Issartier, Dangles, & Chemat, 2013).

Bananas belong to the genus *Musa* from the family Musaceae and are one of the most popular fruits worldwide. They have a strong ability to protect themselves from the oxidative stress caused by intense sunshine and high temperature by increasing their antioxidant levels. Bananas contain vitamins (A, B, C and E), β-carotene and phenolic compounds, such as catechin, epicatechin, lignin, tannins and anthocyanins (Huang et al., 2014; Sulaiman et al., 2011), and are notably perishable, as they ripen rapidly causing significant changes of physicochemical, biochemical and sensory attributes (Huang et al., 2014). Hence drying represents one of the possible preservation methods to prevent deterioration and extend the shelf life.

Drying is a very ancient way of preserving foods, and is still in use nowadays due to its ability to inhibit microbial growth and enzymatic modifications, owing to the low moisture and water activity of the dried products. However, the advantages of drying surpass the preservation capacity (Guiné, Pinho, & Barroca, 2011). Drying, and particularly air drying, usually implies an exposure to high temperature for some time, and that may affect the product properties, either at the physical or chemical levels (Coimbra, Nunes, Cunha, & Guiné, 2011; Guiné, 2011). Polyphenols, which are sensitive to high temperatures, may be affected by heat treatment, leading to some reduction on their content and antioxidant capacity (Ahmad-Qasem et al., 2013).

Artificial neural networks have been used in the past years for modelling many processes in food engineering. Behroozi Khazaeia et al. (2013) used neural networks to model and control the drying process of grapes. Aghbashlo et al. (2012) used artificial neural networks to predict exergetic performance of the spray drying process for fish oil and skimmed milk powder. Kerdpiboon et al. (2006) used artificial neural network analysis to predict shrinkage and rehydration of dried carrots. Hernández-Pérez et al. (2004) proposed a predictive model for heat and mass transfer using artificial neural networks to obtain on-line prediction of temperature and moisture kinetics during the drying of cassava and mango.

The present study was undertaken to investigate the impact of drying conditions on the total phenolic compounds and antioxidant activity in bananas from two cultivars, as well as to model the process variables by means of artificial neural networks.

## 2. Materials and methods

### *2.1. Sampling*

In this work samples from two varieties of banana, *Musa nana* (MN) and *Musa cavendishii* (MC) were used. The bananas were obtained from a local supermarket and then were peeled and cut into slices 8 mm thick before submitting them to the drying process. The initial moisture content of the bananas was calculated as an average of three tests made with a halogen Moisture Analyser (Operating parameters: temperature = 130 ºC, rate = 3). For *Musa nana* the initial moisture content was 67.37±2.65 % (wet basis), and for *Musa cavendishii* it was 72.32±2.36 % (wet basis).

### *2.2. Processing*

The convective drying was undertaken in an electrical FD 155 Binder drying chamber with an air flow of 0.2 m/s and over perforated trays. The samples were dried until a final moisture content lower than 10% (wet basis) was reached, in order to ensure good preservation characteristics as well as good final physical and chemical properties. The drying experiments were conducted at a constant temperature, having been tested two different temperatures: 50 and 70 ºC. The drying of the bananas of cv. *Musa nana* at 50 ºC lasted 525 min and the obtained final moisture content (wet basis) was 9.36%, whereas the drying a 70 ºC was faster, lasting only 270 min and the final moisture obtained was 4.71%. For *Musa cavendishii* dried at 50 ºC the process lasted 450 min and the final moisture content (wet basis) was 6.37%, while at 70 ºC the process lasted 300 min and the final moisture was 8.83%.

Lyophilization was made using a Freeze Dryer TDF 5505 (Uniequip, Germany). The samples were frozen in a conventional kitchen freezer, and then left in the freeze-drier for 96 hours at a temperature ranging from -52 ºC to -49 ºC and a pressure 0.7 Pa. The final moisture content was 2.32 and 2.14 % (wet basis) for *Musa nana* and *Musa cavendishii*, respectively.

*2.3. Analysis of total phenolic compounds and antioxidant activity*

In the present work the extraction of phenolic compounds was performed in multiple successive steps, namely three times with methanol solutions followed by three times with acetone/water solutions. This procedure was adopted so as to extract the highest possible quantity of the phenolic compounds present in the original sample. Each sample was used to obtain extracts, rich in phenolic compounds, according to the method described by Soutinho, Guiné, Jordão, & Gonçalves, (2013). Each of the samples was macerated and successively submitted to multiple extractions: first with a solution of methanol: three times with acetic acid (98:2), and following with an acetone/water solution (60:40) also three times. For each of the 6 extractions performed, the sample was left for 1 hour in an ultrasonic bath at room temperature. This procedure resulted in three methanol extracts (M1, M2 and M3) and three acetone extracts (A1, A2 and A3).

The phenolic compounds were determined by means of the Folin-Ciocalteu reagent, using gallic acid as a standard, according to the conditions described by Gonçalves et al. (2012). The results were expressed as milligrams of gallic acid equivalents (GAE) per gram of dried sample mass. The expression of the results in

terms of dry mass instead of whole sample allows the direct comparisons of the results of the different samples, because in that way the effect of water content was eliminated.

The antioxidant activity was determined by the method based on the radical ABTS (2,2'-azino-bis(3-ethylbenzthiazoline-6-sulphonic acid)), as described by Miller et al. (1993). The results were expressed as micromoles of Trolox per gram of dried sample mass.

### *2.4. Artificial neural network modelling*

Artificial Neural Networks (ANN) models come from Artificial Intelligence, where they were first proposed for learning and function approximation. ANNs are an interconnected assembly of simple processing elements, known as artificial neurons. Each artificial neuron aims to mimic the functioning of a human neuron. The input for each neuron is one or more weighted variables, and the output is a linear or non-linear function of the weighted inputs. Neurons learn by adjusting the weights of the input variables. Those weights are adjusted in a way to minimise the error between the neuron's expected output and the measured output value.

In the present work, experimental data were modelled using artificial neural networks, trained and simulated in Matlab™ [1].

#### *2.4.1. Data encoding and modelling*

For ANN modelling, the data were first encoded in a manner suitable for ANN processing. Variety *Musa nana* was encoded as 1, variety *Musa cavendishii* was encoded as 2. Banana state values 'fresh', 'dehydrated at 50 ºC', 'dehydrated at 70 ºC' and 'lyophilized' were encoded with integers from 1 to 4. Methanol and acetone extracts were encoded as 1 and 2, respectively.

The number of samples available from the experimental data to train and validate the neural networks was 264 for the output variable 'antioxidant activity' and 277 for the output variable 'phenolic compounds content'. To facilitate training and the analysis of the results, each output variable was processed separately. This simplification does not imply any loss of generality, for it is always possible to simulate a smaller neural network using a larger neural network with sufficient neurons.

[1] Matlab is a registered trademark of Mathworks. www.mathworks.com.

The ANN used was a feed forward model, created using the Matlab fitnet function in a Matlab script. The ANN used the Levenberg-Marquartd method for training and the Mean Squared Error (MSE) method for performance assessment.

Each network was created with just four inputs (variety, state/dehydration method, extract type and extract order) and one output, for each of the variables separately. Each network had just one hidden layer with ten neurons and one output neuron. There is no general rule accepted for calculating the number of neurons in the hidden layer, although the common recommendation $N_{hidden} = 2/3\ (N_{inputs} + N_{outputs})$ is often followed. In the present work, empirical evidence showed that 10 neurons could produce better results than smaller numbers, without over fitting. Thus, all the results shown in Table 3 (section 3.4) were obtained using ten neurons in the hidden layer.

For training and testing the neural networks, two smaller datasets were created, one for each output variable. Invalid rows, i.e., rows where there was no valid output, were removed from the smaller datasets. For each run, the Matlab script randomly selected 70% of the samples for the train subset and 15% for the validate subset. The remainder samples were used for the test subset.

## 3. Results and discussion

### *3.1. Phenolic compounds*

Table 1 shows the amount of phenolic compounds present in the three methanol extracts and in the three acetone extracts, for all samples at study: fresh, dried at 50 and 70 ºC and lyophilized. Regarding variety *M. nana*, the amount of phenolic compounds present in the first methanol and acetone extracts represented between 52 and 60%, and between 53 and 76% of the sum of compounds extracted with methanol and with acetone, respectively. For variety *M. cavendishii*, the amount of phenolics present in the first methanol and acetone extracts represented between 43 and 69% and between 42 and 64% relative to the total extracted with methanol and with acetone, respectively. The results showed that the amount of compounds extracted diminished from the first to the second and again to the third extracts, either in methanol or in acetone, for both varieties and all stages (fresh or processed). Although most of the compounds were effectively recovered in the first extraction, the results also show that the first extract itself would account for an insufficient amount of the phenolics present (42-69%), the

second extraction accounting for 13-32% and the third still recovering 11-26%. This confirms the usefulness of the procedure adopted, by performing successive extractions with each of the solvents used. The relative percentage of phenolics extracted with methanol is on average higher (60.0%) than that of the acetone extracts (40.0%). The type of phenols soluble in each of the solvents tested is different, because phenols include one or more hydroxyl groups (polar part) attached directly to an aromatic ring (non polar part). This stereochemistry distinguishes phenols according to their polarity variance, which influences the recovery of phenols from natural sources, when accomplished with solvent extraction, being the yield of the process strongly dependent on the nature of the solvent (Meneses, Martins, Teixeira, & Mussatto, 2013).

Flavonoids are in the soluble polar fraction and can therefore easily be extracted with a polar solvent such as methanol (Rispail, Morris, & Webb, 2005). Methanol has been generally found to be more efficient in the extraction of lower molecular weight polyphenols while the higher molecular weight flavonols are better extracted with aqueous acetone (Dai & Mumper, 2010). However, the solubility of the phenols in each solvent is very much dependent on the food matrix at study (Michiels, Kevers, Pincemail, Defraigne, & Dommes, 2012; Tomsone, Kruma, & Galoburda, 2012; Zhou & Yu, 2004).

Figure 1 shows the amount of phenolic compounds present in the extracts of methanol and acetone, as a whole, expressed as gallic acid equivalents (GAE) per gram of dry matter, for the fresh samples and after the different drying treatments. Looking at the graph, it can be seen that, in general, the amount of phenolic compounds in the methanol extracts was higher than in the acetone extracts. The only exception was the lyophilized sample of the variety *Musa cavendishii*. Considering the total phenolic compounds quantified in the two groups, the sample *M. nana* fresh had the largest quantified amount, 6.91 mg GAE/g (dry basis), 60% more than in sample *M. cavendishii* fresh (4.17 mg GAE/g db). These values stand in the same range of those reported by Sulaiman et al. (2011) for total phenolic content in eight banana cultivars, varying from 3.98 to 13.00 mg GAE/g dry weight.

For variety *M. nana*, the amount of total phenolic compounds of the dried samples ranged between 3.79 and 6.91 mg GAE/g dry matter, in all extracts. For variety *M. cavendishii*, the amount of total phenolic compounds of the dried samples ranged between 3.52 and 6.27 mg GAE/g dry matter, in all extracts. The convective drying originated in all cases a reduction in the total phenolic compounds present, relatively to

the fresh sample. For bananas of variety *M. cavendishii* the reduction was 20% at 50 ºC and 15% at 70ºC, while for variety *M. nana* the reduction was larger, 43% at 50 ºC and 45% at 70ºC. The lyophilized samples showed a better preservation of the phenolic compounds in the bananas of variety *M. nana* (4.71 mg GAE/g dry matter), even increasing in the case of variety *M. cavendishii* (6.27 mg GAE/g dry matter).

Many authors have previously reported that polyphenolics are heat sensitive and that prolonged heat treatment causes irreversible chemical changes to phenol contents (Lin, D. Durance, & Scaman, 1998; Mejia-Meza et al., 2008), this being attributed to different phenomena occurring during heat treatment. According to Martín-Cabrejas *et al.* (2009) and Qu et *al.* (2010), this may be attributed to the binding of polyphenols with other compounds or to alterations in the chemical structure of polyphenols. Julkunen-Tiitto and Sorsa (2001) observed a destruction of flavonoids and tannins during drying. Other authors suggested that another factor contributing to the degradation of polyphenols may be the activity of polyphenol oxidase, organic acid content, sugar concentration, and pH (de Ancos, Ibañez, Reglero, & Cano, 2000; Nicolas, Richard-Forget, Goupy, Amiot, & Aubert, 1994; Yousif, Durance, Scaman, & Girard, 2000).

*3.2. Antioxidant activity*

Table 2 shows values of the antioxidant activity for the three extracts of methanol and acetone. The values for the antioxidant activity of the first methanol extract of fresh samples represent 74 and 65% of the sum of the three extracts, respectively for *M. nana* and *M. cavendishii*. Dehydration of the samples resulted in a decrease of this value to about 50%, on average. As to the acetone extracts, the first represents 53% on average of all samples and both varieties, while the second extract represents 31% and the third 17%. Once again the results show that the procedure of making multiple extractions is adequate since the last extract still represented 19% and 17% of the total antioxidant activity measured in the methanol and acetone extracts.

Figure 2 shows the antioxidant activity in μmol Trolox/g (expressed on dry basis) as determined by the ABTS method in the banana samples subjected to different treatments. The results show that the antioxidant activity for the fresh bananas, and for those dried at 50 and 70 ºC, is always higher in the methanol extracts than in the acetone extracts. On the other hand, the lyophilized samples from both varieties show an

opposite trend, with the antioxidant activity quantified in the acetone extracts larger than in the methanol extracts. These results indicate that the phenolic compounds present in the acetone extract of the freeze-dried samples had higher antioxidant activity when compared with those present in the methanol extracts. The antioxidant capacity of phenolic compounds depends on their conformational chemical structure, namely on their ability to donate a hydrogen or an electron as well as on their ability to delocalise the unpaired electron within the aromatic structure. For instance, procyanidins are the most protective when the oxidant agent is the thermo-labile free radical ABTS (Lotito et al., 2000).

Comparing the two varieties under study, it was found that the fresh sample of *M. nana* had an antioxidant activity of 16.0 µmol Trolox/g dry matter, higher than that of the *M. cavendishii*, 13.7 µmol Trolox/g dry matter. Sulaiman et al. (2011) reported values of antioxidant activity for pulp of eight banana cultivars ranging between 1.12 and 12.83 mgTE/g dry weight.

The convective drying at both temperatures induced a decrease in the phenolic compound, up to 40% in the methanol extracts and 22% in the acetone extracts. Furthermore, the extension of the reduction in antioxidant activity was higher for variety *M. nana* than *M. cavendishii.* Lyophilization did not induce a reduction in the total antioxidant activity, so that the values in the lyophilized samples were 14.1 and 16.4 µmol Trolox/g respectively for *M. nana* and *M. cavendishii*.

### *3.3. Correlation between antioxidant activity and phenolic compounds*

The concentrations of the phenolic compounds in the extracts were correlated with the antioxidant activity, this being done for the methanol and acetone extracts separately and for the whole data together. The results obtained are expressed by the following equations:

For methanol extracts data: $AA = 0.4490 + 2.1325\ TP$ ; $R = 0.8258$ (1)

For acetone extracts data: $AA = 0.4472 + 2.9597\ TP$ ; $R = 0.7992$ (2)

For all data: $AA = 0.6563 + 2.1452\ TP$ ; $R = 0.7638$ (3)

where AA is antioxidant activity (µmol Trolox/g dry basis) and TP is total phenols content (mg GAE/g dry basis).

The results show a good correlation between the two parameters, with correlation coefficients ranging from 0.7638 to 0.8258, being the correlation stronger in the methanol extracts than in the acetone extracts. These results are consistent with those described by different authors that reported a positive correlation between the concentration of phenolic compounds and antioxidant activity in foods (Katalinić, Milos, Modun, Musić, & Boban, 2004; Sulaiman et al., 2011).

Empirical evidence showed that it is possible to train a neural network, with the same characteristics as described in Section 2.4 and one neuron in the hidden layer, to predict antioxidant activity based on the phenolic content with R = 0.90 for the whole dataset. Predicting phenolic contents from antioxidant activity is a harder problem, as the neural network with the same characteristics can only predict with R = 0.85.

### *3.4. Artificial neural network modelling*

Table 3 shows the results obtained for function approximation using the neural networks. Columns 2 to 5 show the R value for the linear regression between the ANN predicted values and the experimental results, for train, validation and test sets and for the whole datasets of each variable. Column 6 shows the performance as measured Mean Squared Error (MSE). Columns 7 and 8 show the average and standard deviation (STD) calculated for each variable, using the experimental data.

As the results in Table 3 show, the artificial neural network learns to predict the phenolic content and antioxidant activity with very high accuracy, approximating the experimental data with a very small error. Training was performed based on experimental data, which is not free from noise and outliers. Even so, it is clear from the results that the neural network was able to abstract an accurate model. Further comparison of the values predicted by the neural network with the experimental values showed, for the whole dataset, four errors greater than 75% for the antioxidant activity and two errors greater than 75% for the phenolic contents. These are with high probability outliers in the experimental data. This is mentioned just for completeness, since the impact of those apparent outliers seems negligible, for the present work they were not removed from the datasets.

### *3.5. Neuron weights analysis*

One interesting characteristic of neural networks is that some information about the data can be discovered by analysis of the weights of each input. In the present work, a simplified version of the neural network was implemented. The neural networks were reconfigured with just one neuron in the hidden layer. Those simplified networks are not as stable as the networks with 10 neurons in the hidden layer, which showed to be excellent predictors, as described in the previous section. However, it was still possible to make the simplified neural networks converge and fit the data with $R > 0.85$ for most of the experiments. The advantage of approximating the variables with these simplified networks is that they have only one weight for each input variable, to weigh the value fed to the hidden neuron. That weight is a direct indication of the relevance of each variable to the neuron and, further, to the output function.

Table 4 shows the weights of each input for the single neuron in the hidden layer of the neural networks used, for selected experiments where data was fit with $R > 0.85$. As the table shows, the order of the extract is the most important predictor both for antioxidant activity and phenolic content. In other words, the variables drying method, extract type and variety are all less important than extract order. Still, the state is the second best predictor, which confirms that both phenolic content and antioxidant activity are greatly affected when the fruits are dried.

The weights also show that both banana types are very similar: the weight of the variety variable is negligible, compared to their state and extract order. Variety is actually the least important predictor of all.

Another important confirmation is that the extract type indeed affects the results, specially the amount of phenolic contents measured. For the antioxidant activity, it is the least important predictor, but for the phenolic contents it is more important than variety by a factor of almost 6.

## 4. Conclusions

In general, the phenolic compounds present in all banana samples were recovered preferentially in the methanol extracts.

The results obtained during the present study showed that the drying processes resulted in bananas with lower phenolic compounds content and antioxidant activity expressed in a dry basis, when compared with the fresh fruits.

The lyophilization process showed to be a drying process that preserves in higher extent the original properties of fresh bananas than the drying in a ventilated chamber.

Neural network modelling showed that the antioxidant activity and phenolic compounds contents can be predicted with high accuracy from banana variety, drying state and extract type, using simple neural networks. Antioxidant activity can also be predicted from the phenolic contents. Neuron weight analysis indicated that the order of the extract is the most important factor to predict the amount of phenolic contents and antioxidant activity measured, and both banana varieties show similar properties in the analysis.

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**Tale captions**

**Table 1.** Phenolic compounds in the different methanol and acetone extracts for both varieties of banana studied.

**Table 2.** Antioxidant activity in the different methanol and acetone extracts for both varieties of banana studied.

**Table 3.** Results obtained for approximating the variables using neural networks with ten neurons in the hidden layer.

**Table 4.** Input variable weights for each variable, obtained for networks with just 1 neuron in the hidden layer and which fit the output variables with R = 0.86.

**Figure captions**

**Figure 1.** Total phenolic compounds considering the total among the methanol and acetone extracts for both varieties of banana studied.

**Figure 2.** Antioxidant activity considering the total among the methanol and acetone extracts for both varieties of banana studied.

585
586 **Table 1.** Phenolic compounds in the different methanol and acetone extracts for both
587 varieties of banana studied.
588

| Total phenolic compounds (mg GAE/g dry solids) | | | | | | |
|---|---|---|---|---|---|---|
| ***Musa nana*** | | | | | | |
| | **M1** | **M2** | **M3** | **A1** | **A2** | **A3** |
| Fresh | 2.82±0.15 | 1.07±0.05 | 0.82±0.03 | 1.25±0.05 | 0.69±0,19 | 0.25±0.03 |
| 50 ºC | 1.25±0.04 | 0.66±0.04 | 0.49±0.05 | 1.17±0.07 | 0.20±0,07 | 0.17±0.01 |
| 70 ºC | 1.29±0.10 | 0.63±0.03 | 0.47±0.02 | 0.87±0.04 | 0.33±0,01 | 0.21±0.03 |
| Lyophilized | 1.57±0.07 | 0.75±0.01 | 0.51±0.04 | 1.00±0.16 | 0.57±0,09 | 0.31±0.04 |
| ***Musa cavendishii*** | | | | | | |
| | **M1** | **M2** | **M3** | **A1** | **A2** | **A3** |
| Fresh | 1.81±0.20 | 0.44±0.15 | 0.39±0.10 | 0.64±0.08 | 0.49±0.07 | 0.41±0.10 |
| 50 ºC | 0.85±0.03 | 0.63±0.05 | 0.52±0.16 | 0.79±0.03 | 0.34±0.08 | 0.17±0.02 |
| 70 ºC | 1.16±0.02 | 0.61±0.12 | 0.44±0.15 | 0.84±0.04 | 0.30±0.03 | 0.17±0.08 |
| Lyophilized | 1.66±0.12 | 0.75±0.18 | 0.33±0.07 | 2.04±0.16 | 0.91±0.10 | 0.58±0.07 |

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593 **Table 2.** Antioxidant activity in the different methanol and acetone extracts for both
594 varieties of banana studied.
595

| Antioxidant activity (µmol Trolox/g dry solids) | | | | | | |
|---|---|---|---|---|---|---|
| ***Musa nana*** | | | | | | |
| | **M1** | **M2** | **M3** | **A1** | **A2** | **A3** |
| Fresh | 6.8±0.6 | 1.5±0.1 | 0.9±0.2 | 3.6±0.2 | 2.6±0.9 | 0.7±0.2 |
| 50 ºC | 3.4±0.1 | 1.6±0.1 | 1.2±0.1 | 3.6±0.4 | 1.1±0.0 | 0.6±0.1 |
| 70 ºC | 2.6±0.3 | 1.7±0.1 | 1.3±0.2 | 3.1±0.2 | 1.4±0.1 | 0.8±0.1 |
| Lyophilized | 3.3±0.5 | 2.1±0.1 | 1.2±0.1 | 3.4±0.4 | 2.9±0.0 | 1.2±0.3 |
| ***Musa cavendishii*** | | | | | | |
| | **M1** | **M2** | **M3** | **A1** | **A2** | **A3** |
| Fresh | 4.8±0.3 | 1.4±0.4 | 1.2±0.2 | 3.2±0.2 | 2.0±0.9 | 1.2±0.4 |
| 50 ºC | 2.7±0.1 | 2.8±0.3 | 2.0±0.1 | 2.5±0.3 | 1.6±0.3 | 0.8±0.1 |
| 70 ºC | 3.8±0.2 | 1.8±0.1 | 1.4±0.2 | 3.7±0.2 | 1.4±0.2 | 0.9±0.3 |
| Lyophilized | 3.5±0.4 | 2.1±0.1 | 1.3±0.4 | 3.3±0.2 | 3.3±0.0 | 2.8±0.1 |

596
597

598 **Table 3.** Results obtained for approximating the variables using neural networks with
599 ten neurons in the hidden layer.
600

| | *R value for each subset* | | | | *Train error* | *Whole Dataset* | |
|---|---|---|---|---|---|---|---|
| | **Train** | **Validation** | **Test** | **All** | | **Average*** | **STD*** |
| Phenolic content | 0.99 | 0.98 | 0.98 | 0.99 | 57.85 | 56.80 | 40.51 |
| Antioxidant activity | 0.98 | 0.97 | 0.97 | 0.98 | 721.06 | 176.01 | 102.68 |

601 *The Average and STD shown refer to all the samples in the dataset and are useful to interpret the train
602 MSE shown in column 6.
603
604

605

606 **Table 4.** Input variable weights for each variable, obtained for networks with just 1
607 neuron in the hidden layer and which fit the output variables with R = 0.86.

608

| *Output variable* / *Input variable* | *Phenolic content* | *Antioxidant activity* |
|---|---|---|
| Variety | -0.034 | -0.034 |
| State | 0.556 | -0.669 |
| Extract type | -0.199 | 0.032 |
| Extract order | -0.923 | 0.780 |

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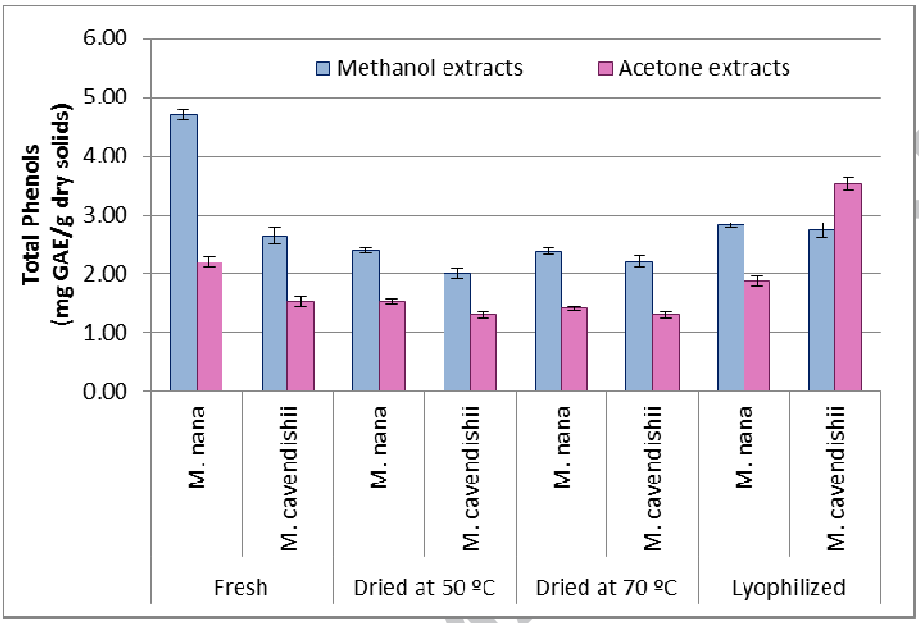


616

617 **Figure 1.** Total phenolic compounds considering the total among the methanol and
618 acetone extracts for both varieties of banana studied.

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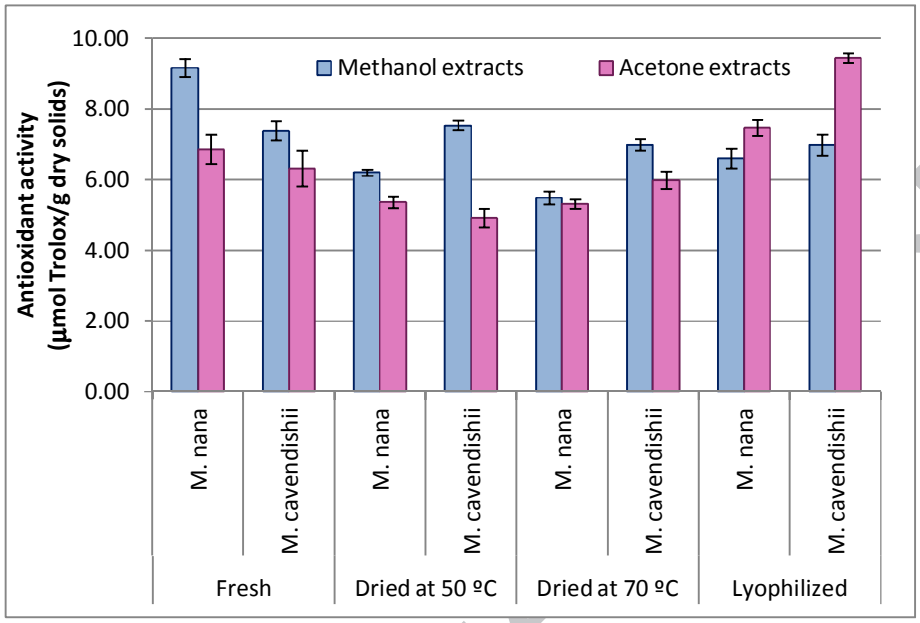


623

624 **Figure 2.** Antioxidant activity considering the total among the methanol and acetone

625 extracts for both varieties of banana studied.

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627

**ARTIFICIAL NEURAL NETWORK MODELLING OF THE ANTIOXIDANT ACTIVITY AND PHENOLIC COMPOUNDS OF BANANAS SUBMITTED TO DIFFERENT DRYING TREATMENTS**

- Bananas fresh and dried were analysed for phenols (TP) and antioxidant activity (AA)
- Different consecutive extraction solutions were used
- The data trained a neural network (ANN) for data analysis and variable prediction
- Phenols and antioxidant activity decreased with drying for al treatments
- ANN showed that TP and AA can be predicted from the input variables tested