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NUTRACEUTICALS COMPOUNDS EXTRACTION OPTIMIZATION FROM OPEN AIR AND SWELL-DRIED BANANA PEEL POWDERS

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ABSTRACT

The aim of this study was to optimize the operating conditions of two drying processes on banana peels: open air and Instant Controlled Pressure Drop technique (DIC) assisted Swell-Drying at 40°C in order to obtain high quality final powders. The optimization of three extraction conditions including extraction temperature (40-100°C), extraction time (10 – 60 min) and particle size (60 – 363 µm) from open air banana peel powder was investigated). Additionally, three DIC texturing conditions were improved. DIC involves maintaining banana peels at a high temperature for 20 to 220s, high steam pressure (p=0.3 to 0.6 MPa) and varying the Number of cycles from 1 to 7. Modelling of some nutraceutical compounds (Total Flavonoids Content and carotenoids) from open air and Swell-Dried banana peels powders by applying experiments design using Response Surface Methodology and Desirability Function. The antioxidant activity was also investigated by the determination of the % of DPPH inhibition.

The optimal conditions derived from the multi-Responses-Desirability Function were as follows: 60.47°C; 10min; and particle size Φ= 348.648 µm yielding a TFC=5.13 (mg QE/g d.b), TCC=0.48 (mg /g d.b) and % of DPPH inhibition=73.05%, with an optimal desirability coefficient d=0.7 (open air process). The following optimized DIC operating parameters with maximum desirability coefficient d=1, t=24.46s P=0.59MPa and number of cycles N=6.38 yielding a TFC=4.07 (mg QE/g d.b), a TCC= 1.37 (mg /g d.b) and a % of DPPH inhibition=75.97 %. Banana peel could be a good source of bioactive substances, which could be further used as a natural antioxidant.

1.Introduction

The production of banana fruit, a tropical perishable fruit, amounts to 119 million tonnes per year (FAO, 2022), with around 36 million tonnes of peel as a waste product. Banana peel contains a variety of bioactive compounds, including flavonoids, tannins, carotenoids, vitamins, and other elements with anti-inflammatory and antioxidant properties (Havsteen, 1983; Toh et *al*., 2016; Pereira et *al*., 2017). According to (Iman and Akter, 2011), the eucocyanidin flavonoid is gaining popularity as medication for stomach ulcers.

Banana peel contains mucilages, which are naturally occurring polysaccharides that are chemically linked to proteins and minerals (Gemede et *al*., 2015). These substances have a range of medicinal effects including anticancer, antioxidant, antimicrobial, hypoglycemic, and antiulcer properties (Dantas et *al*., 2021).

Proteins and other compounds have the ability to form phenolic insoluble complexes. Dopamine is the only phenolic amino acid found in banana peels according to Happy (Emaga et *al*., 2007).

In terms of applications, the banana's peel has long been used in traditional medicine to cure many health disorders such as burns, anemia, and diarrhoea (Vu et *al*., 2018).

In Algerian traditional medicine, dried banana peel infusion is used to cure gastric disorders.

Furthermore, a water extract of *Musa acuminata* peel dried in the open air could be deemed an efficient treatment for reducing gastrointestinal inflammation in rats after 30 days. This work was conducted at Pasteur Institute in Algeria and is currently being published.

The impact of pre-treatment on the availability of phenolic chemicals recovered from banana peels have been reported in a number of studies. These pre-treatments include, among others, blanching (Hernandez-Carranza, 2016), and freezing (ISO, 2000).

To our knowledge, no scientific research has been conducted to investigate the impact of the two drying processes -open air drying and Swell-Drying using DIC- on the availability of nutraceutical compounds of banana peel and determine the parameters under which it can be used.

The current research was carried out in order to analyse the biochemical composition of banana peels and to optimize the extraction conditions of some nutraceutical compounds (flavonoids and carotenoids) and to evaluate their antioxidant activity by determination of the % of DPPH inhibition from open air and DIC Swell-dried banana peels powders by applying experiments design using Response Surface Methodology (RSM) and Desirability Function (DF).

2. Materials and methods

2.1. Plant material

Banana fruits of the *Musa acuminate* species were acquired at a French market in La Rochelle (France). Table 1 summarizes some physicochemical properties of fresh Musa acuminate peels.

Table 1. Some physicochemical composition of fresh *Musa acuminate* peels (n=3)

Parameters	Average contents
pH at 22°C	5.45±0.07
Humidity level (%)	7.76±0.18
Ash rate (%)	14.18±4.14
Organic matter (%)	85.82±4.14
Titratable acidity (g of citric acid /100g of sample)	0.09±0.01
Total sugars (g/l)	17.11±0.02
Reducing sugars (g/l)	0.36±0.01
Sucrose (g/l)	15.91±1.64

2.2. Methods

2.2.1. Drying processes of banana peels

Two drying processes were used in this study: open air under dark condition and Instant Controlled Pressure Drop process DIC assisted Swell-Drying at 40°C. This work was conducted at the Unit Laboratory of Materials, Processes & Environment (UR-MPE), M'Hamed Bougara University of Boumerdes (Algeria) with the collaboration of the laboratory of Engineering Science for

Environment (LaSIE) UMRER7356 CNRS, La Rochelle University (France).

All banana fruits were washed under tap water to remove impurities, then the peels were manually recovered and cut into small pieces before being dried in the open air under dark condition and textured with DIC using equipment from ABCAR-DIC Process (La Rochelle, France) followed by Swell-Drying at 40°C until the final weight was constant.

The DIC treatment involves four steps, which are as follows: 1): a primary vacuum is created; 2): high saturated steam pressure is injected and maintained for a short time (10 to 30 s); 3): pressure is abruptly dropped toward a vacuum within few milliseconds, and finally released to atmospheric pressure.

The dried peels were crushed in an electric grinder and sieved using an ORTO ALRESA sieve between 60 and 363 µm. The final powders were stored in hermetic glass bottle at room temperature until their analysis

2.2.2. Experimental design

Using a banana peel that had been dried in the open air and DIC assisted Swell-Drying, the extraction of nutraceutical compounds (Total of flavonoids and carotenoids) and antioxidant activity were improved as revealed by the response optimizer function of Statgraphics Centurion 18 software. The independent variables used in the RSM design of a banana peel that had been dried in the open air are listed in Table 2. Three DIC operating conditions optimization of banana peel: treatment time (X_1) from 20 to 220s**,** steam pressure P (X_2) from 0.3 to 0.6 MPa, and the number of cycles (X_3) adjusted from 1 to 7 were also investigated (Table 3).

The response for nutraceutical components (TFC and TCC) and the percentage of DPPH inhibition of water extract from banana peels dried in open air and DIC-assisted Swell-Drying were assessed using a Central Composite Design (CCD) with four central points (Tables 4, 5).

A second-order polynomial of the following form was employed to express the responses using multiple regressions:

$$Y = a_0 + \sum_{i=1}^{3} a_i X_i + \sum_{i=1}^{3} a_i X_i^2 + \sum_{i=1}^{3}\sum_{j=1}^{3} a_{ij} X_i X_j \quad (1)$$

Where Y is the predicted responses used as dependent variables, $X_i (i = 1, 2\ and\ 3)$ are the independent variables, and a_0 and $a_{ij} (i = 1, 2, 3;\ j = i, \ldots, 3)$ are the model coefficient parameters.

All water extracts were prepared from open air and DIC-assisted Swell- Dried banana peels powders at 5%.

Only the textured banana peels powders underwent a one-night maceration in distilled water at 4°C.

All measurements were made in triplicate, and the results were reported as mean standard deviation. Except for the pivot points matching the experiments run N° 4, 7, 10, 13, 16 and 19 in Table 5, nothing else was repeated.

Table 2. Central Composite Design independent variables and their levels (Case of open air)

Variables	Coded level				
	-1.68	-1	0	1	1.68
$\mathbf{X_1}$	40	52	70	88	100
$\mathbf{X_2}$	60	122	212	302	363
$\mathbf{X_3}$	10	20	35	50	60

X_1= Extraction Temperature T (°C); X_2= Particle size (µm); X_3= Extraction time t (min)

Table 3. Central Composite Design independent variables and their levels (case of DIC)

Variables	Coded level				
	-1.68	-1	0	1	1.68
X_1	20	60,54	120	179,46	220
X_2	0.3	0,36	0.45	0,54	0.6
X_3	1	2,22	4	5,78	7

X_1= Treatment time t (s); X_2= Steam Pressure P (MPa); X_3= Number of cycles (-)

Table 4. Central composite design and observed response for nutraceutical compounds and the % of DPPH inhibition of banana peel dried in open air

	Coded variable levels			Uncoded variable levels			Responses		
Run	X_1	X_2	X_3	X_1	X_2	X_3	TFC (mg QE/g d.b)	TCC (mg/g d.b)	% of DDPH inhibition (Water extract)
1(C)*	0	0	0	70	212	35	2.57±0.03	0.398±0.005	75.14±0.417
2	-1	-1	-1	52	122	20	4.00±0.12	0.632±0.010	67.23±0.11
3	+1	-1	-1	88	122	20	3.5±0.27	0.446±0.031	72.05±0.298
4	-1	+1	-1	52	302	20	3.69±0.08	0.530±0.005	63.23±0.468
5	+1	+1	-1	88	302	20	3.55±0.02	0.365±0.011	76.35±0.192
6	-1	-1	+1	52	122	50	3.80±0.10	0.524±0.018	64.7±0.358
7	+1	-1	+1	88	122	50	3.38±0.08	0.400±0.019	70.45±0.298
8	-1	+1	+1	52	302	50	3.16±0.08	0.422±0.005	69.11±0.063
9	+1	+1	+1	88	302	50	2.93±0.19	0.302±0.057	67.05±0.298
10(C)*	0	0	0	70	212	35	2.36±0.01	0.414±0.017	64.7±0.358
11(C)*	0	0	0	70	212	35	2.52±0.02	0.428±0.013	72.23±0.11
12	-1.68	0	0	40	212	35	2.81±0.10	0.482±0.006	62.57±0.415
13	+1.68	0	0	100	212	35	2.01±0.02	0.430±0.039	61.6±0.032
14	0	-1.68	0	70	60	35	3.33±0.16	0.299±0.021	67.35±0.192
15	0	+1.68	0	70	363	35	5.13±0.32	0.356±0.007	75.58±0.405
16	0	0	-1.68	70	212	10	2.76±0.11	0.487±0.037	68.23±0.468
17	0	0	+1.68	70	212	60	2.06±0.01	0.377±0.044	81.03±0.308
18(C)*	0	0	0	70	212	35	2.61±0.03	0.474±0.041	64.56±0.421

X_1: Extraction Temperature T (°C); X_2: Particle size Ps (µm); X_3: Extraction Time t (min); TFC: Total Flavonoids Content (mg QE/g d.b); TCC: Total Carotenoids Content (mg/g d.b); % of DPPH inhibition (water extract); (C)*: Central point

Table 5. Central composite design and observed response for nutraceutical compounds and % of DPPH inhibition from Swell-dried textured banana peels by DIC

	Coded variable levels			Uncoded variable levels			Responses		
Run	X_1	X_2	X_3	X_1	X_2	X_3	TFC (mg QE/g d.b)	TCC (mg/g d.b)	% of DDPH inhibition (Water extract)
1(C)*	0	0	0	120.00	0.45	4.00	1.42 ± 0.071	0.43± 0.004	66.11± 0.685
2	+1.68	0	0	220.00	0.45	4.00	2.3 ± 0.045	0.78± 0.007	71.34± 6.219
3	0	0	+1.68	120.00	0.45	7.00	1.79 ± 0.105	0.59± 0.004	68.20± 0.117
4(C)*	0	0	0	120.00	0.45	4.00	1.42 ± 0.071	0.43± 0.004	66.11± 0.685
5	0	+1.68	0	120.00	0.60	4.00	1.11 ± 0.17	0.8± 0.007	67.46± 0.462
6	0	-1.68	0	120.00	0.30	4.00	1.67 ± 0.032	1.23± 0.063	66.41± 0.491
7(C)*	0	0	0	120.00	0.45	4.00	1.42 ± 0.071	0.43± 0.004	66.11± 0.685
8	+1	-1	+1	179.46	0.36	5.78	1.74 ± 0.126	0.46± 0.008	62.23± 0.498
9	-1	-1	-1	60.54	0.36	2.22	1.26 ± 0.084	0.42± 0.008	62.38± 0.534
10(C)*	0	0	0	120.00	0.45	4.00	1.42 ± 0.071	0.43± 0.004	66.11± 0.685
11	+1	+1	-1	179.46	0.54	2.22	1.19 ± 0.21	0.99± 0.01	66.56± 0.471
12	-1	+1	+1	60.54	0.54	5.78	2.01 ± 0.155	1.06± 0.004	70.29± 0.222
13(C)*	0	0	0	120.00	0.45	4.00	1.42 ± 0.071	0.43± 0.004	66.11± 0.685
14	-1	+1	-1	60.54	0.54	2.22	2.32 ± 0.182	1.19± 0.005	69.55± 0.448
15	-1	-1	+1	60.54	0.36	5.78	2.07 ± 0.195	0.42± 0.004	74.77± 0.249

16(C)*	0	0	0	120.00	0.45	4.00	1.42 ± 0.071	0.43± 0.004	66.11± 0.685
17	-1.68	0	0	20.00	0.45	4.00	3.09 ± 0.371	0.44± 0.004	67.76± 0.249
18	+1	+1	+1	179.46	0.54	5.78	2.04 ± 0.351	0.54± 0.006	68.65± 0.241
19(C)*	0	0	0	120.00	0.45	4.00	1.42 ± 0.071	0.43± 0.004	66.11± 0.685
20	+1	-1	-1	179.46	0.36	2.22	3.65 ± 0.138	0.49± 0.003	69.10± 0.132
21	0	0	-1.68	120.00	0.45	1.00	3 ± 0.184	0.48± 0.003	69.25± 0.209
22(C)*	0	0	0	120.00	0.45	4.00	2.89 ± 0.032	0.64± 0.003	70.14± 1.053

X_1: Treatment time t (s); X_2: Steam pressure P (MPa); X_3: Number of cycles (−); TFC: Total Flavonoids Content (mg QE/g d.b); TCC: Total Carotenoids Content (mg/g d.b); % of DPPH inhibition (water extract); (C)*: Central point

2.2.3. Physicochemical analysis

- Hexane extraction was used to extract the oil from banana peels. The fatty acid profile (Table 6) was determined using CHROMPACK CP 9002 gas phase chromatography. The methyl esters were produced by esterification using the ISO 5509 technique (ISO, 2000).
- An Atomizer (VARIAN AA 240, Australia) was used to determine the mineral composition (Table 7) of banana peels. This measurement is based on dissolving 1g of ashes in 5mL of HCL acid (0.5N) (Adrian, et *al*. 1995).
- The mucilage was extracted from banana peel powder according to the method described by Dick et *al*. (2019). 30 g of banana peel powder were mixed with 100mL of distilled water and heated for 54 to 96 minutes at 50°C. The mucilage was lyophilized after being precipitated with 35mL of ethanol.
- A colorometric method was used to determine the Total Flavonoids Content (TFC) (Bahorun et *al*. 1996). 1mL of the water extract was mixed with 1mL of a 2% AlCl3 solution. After a 10 minutes incubation period, the absorbance was measured using a spectrophotometer at 430nm. The TFC in different banana peel water extracts was estimated using a regression equation that used Quercetin as a standard and was estimated in milligrams of Quercetin Equivalent per gram dry basis (mg QE/g d.b).
- The Total Carotenoids Contents TCC was extracted using the Sass-Kiss et *al*. (2005) method. 20 mL of a solvent mixture of hexane-acetone-ethanol (2V: 1V: 1V) were added to 0.5g of banana peel powder. After 30 minutes of agitation, the upper phase was recovered. For a second extraction, 10 mL of hexane were added. The absorbance was measured using a spectrophotometer at 450nm. Carotenoid concentrations were estimated by referring to the regression equation with carotene as a standard and were expressed in milligrams per gram dry basis (mg /g d.b).
- The DPPH free radical scavenging method was employed to assess the antioxidant activity of aqueous extracts of banana peels dried in the open air and DIC-assisted Swell–drying (Kroyer, and Hegedus, 2001). A volume of 0.1mL of extract was added to 3.9mL of DPPH (60mM). After 30 minutes of incubation in the dark, the absorbance was measured at 517 nm. The percentage of DPPH radical inhibition is expressed as follows:

$$\text{\% of DPPH radical inhibition} = \frac{(\text{OD517 of Reference} - \text{OD517 of water extract})}{\text{OD517 of Reference}} \times 100 \quad (2)$$

Table 6. Fatty acids (%) of *Musa acuminate* peel powder

Fatty Acids	Names	Content (%)
C12 :0	Lauric A.	1.32
C16 :0	Palmitic A.	28.32
C16 :1ω7	Palmitoleic A.	1.53
C18 :0	Stearic A.	5.54
C18 : 1ω9	Oleic A.	3.93
C18 : 2ω6	Linoleic A.	19.35
C18 : 3ω3	Linolenic A.	22.13
C22 :0	Behenic A.	3.13
C14 : 0	Myristic A.	1.50
C24: 0	Lignoceric	2.81

Table 7. Mineral composition of *Musa acuminate* peel powder

Minerals	Content (g/Kg d.b)
Ca	30.254
Mg	25.836
Na	54.701
K	24.178
Fe	0.441
Cu	0.019
Zn	0.018
Cr	-
Cd	-
Pb	-

2.2.4. Statistical analysis

Using Statgraphics Centurion 18 software, the Response Surface Methodology (RSM) was utilized to define the relationship between independent variables and to deduce the optimum extraction conditions of bioactive substances from banana peel powders. A quadratic model to predict the response (TFC, TCC and percentage of the DPPH radical inhibition) was determined from all the experiments, and the regression coefficients for the linear, quadratic and interaction factor were calculated and statistically examined using variance analysis (ANOVA). The multi-response optimization was defined using the desirability approach (Response Optimizer function in Statistica). The desirability function is a multi-criteria approach for assessing the overall desirability that considers each response's desirable value or the best accepted.

The Surface Responses were generated using the polynomial equations regressions coefficients. These were utilized to analyse the variables under investigation as a function and to present the most favourable acceptance.

To highlight the interaction effects of independent variables of each drying process, one variable remained constant at its centre level while the other two variables changed within the experimental range.

3.Results and discussions

3.1. Physicochemical analysis

Musa acuminata peel dried in the open air studied here contains oil with a yield of 10±0.5%. This oil is rich in unsaturated fatty acids such as palmitic acid (28.32%), linolenic acid (22.13%), linoleic acid (19.35%) and oleic acid (3.39%) (Table 6). These fatty acids are beneficial to people's health and are thought to help in the prevention of cancer, atherosclerosis and obesity (Kaleem, 2013).

High levels of macro-metals (30.02; 5.47; 2.583 g/Kg d.b) for Ca, Na and Mg respectively and low levels of trace metals (Fe, K) were found in *Musa acuminata* peel (Table 7). Heavy metals like Cr and Cd are not present.

Banana peel, which is rich in minerals, could be used as a powder to correct mineral deficiencies.

The size of the particle determines how much mucilage can be produced from banana peels powder 21.25±12.37% (for a particle size Φ=363µm); 17.25±3.181% (Φ=208µm); 14±5.656% (Φ=69µm).

The amount of mucilage is higher than that of flaxseed, which Mazza and Biliaderis, (1989), and Benahmed Djilali et *al.* (2022) reported to yield, respectively, 7.08 and 9.4%.

Additional factors, such as the temperature and extraction time, have also an impact on the mucilage content (Mazza, and Biliaderis, 1989).

The mucilage of banana peels was verified using the FT-IR method (Fig.1). A strong band is visible at 3438 cm-1 (-OH stretching) and 2935 cm-1 (-CH stretching) is observed (Sawut et *al.* 2014).

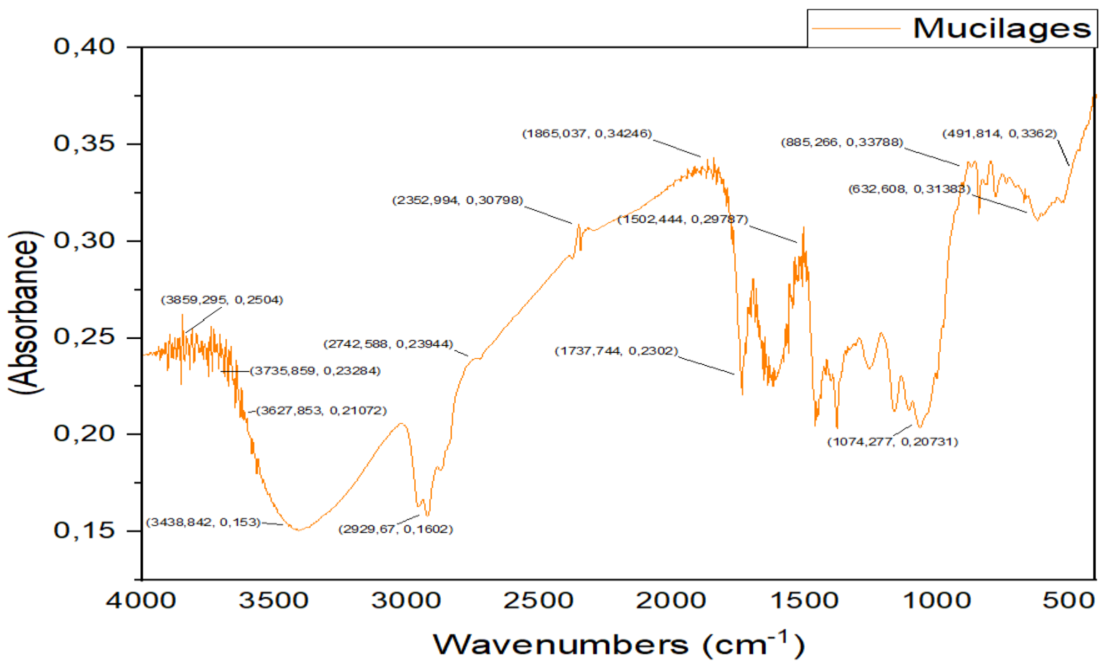


Figure 1. FT-IR spectrum of banana peel mucilage

The vibrational peaks at 1215 and 1074 cm-1 (CO, ether) and (C-C of pyrenoids), respectively, indicate the presence of polysaccharides (mucilage) in banana peel (Pereira et *al.* 2017).

The peaks at 1750 and 1733 cm-1 are caused by stretching vibrations of the C=O group (Kpodo et *al.* 2017).

The carboxyl group COOH of Galacturonic Acid (GalA) is responsible for the peaks between 1650 and 1733 cm-1 (Nejatzadeh-Barandozi, and Enferadi, 2012 ; Kpodo et *al.* 2017).

In the food industry, this polysaccharide can be used for stabilizing beverages and adding texture to dairy desserts, among other uses (Qin et *al.* 2005).

3.2. Fitting the models

3.2.1. Case of open air drying

The following empirical models for the Total Flavonoids Content, Total Carotenoids Content and % of the DPPH inhibition from open air banana peels powder and their regression (Table 8).

Where X_1: Extraction Temperature T (°C); X_2: Particle size Ps (μm); X_3: Extraction Time t (min).

$$\text{Total Flavonoids Content}\left(\text{mg}\frac{\text{QE}}{\text{g}}\text{d.b}\right) \quad (3)$$

$$= 8.661 – 0.047X1 – 0.036X2 - 0.016X3 + 0.0002X1^2 + 0.00004X1X2 - 0.000005X1X3 + 0.00009X2^2 - 0.00008X2X3 + 0.0003X3^2$$

$$\text{Total Carotenoids Content}(\text{mg QE/g d.b}) \quad (4)$$

$$= 1.136 – 0.014X1 + 0.001X2 – 0.009X3 + 0.00006X1^2 + 0.000002X1X2 + 0.00005X1X3 - 0.000003X2^2 - 0.000002X2X3 + 0.00005X3^2$$

$$\%\ \text{of DPPH radical inhibition (water extract)} \quad (5)$$

$$= 22.172 + 1.358X1 - 0.041X2 – 0.131X3 - 0.007X1^2 + 0.000038X1X2 - 0.0066X1X3 + 0.00011X2^2 + 0.000066X2X3 + 0.0092X3^2$$

The fitted models for TFC and TCC (Eq.2 and Eq.3) using the open-air drying process were satisfactory, with significant regressions responsible for residual values and satisfactory determination coefficients R^2 (76 and 68%), which represents acceptable equation fitting. However, the percentage of DPPH inhibition, presents a low value of R^2 (54%) (Table 8).

Statistical analysis of the experimental design shows that the Total Flavonoids Content extract from open air banana peels powder is only affected by DIC operating parameters (particle size); the quadratic second-order effect was significant (P< .05) as observed in Fig.2.

Fig. 3 and Eq. 3 allow noting the extraction temperature T has an impact on the quantity of Total Carotenoids extracted from open air banana peels powder (a negative linear first-order effect was significant (P< .05)). When the extraction temperature decreases the TCC increases.

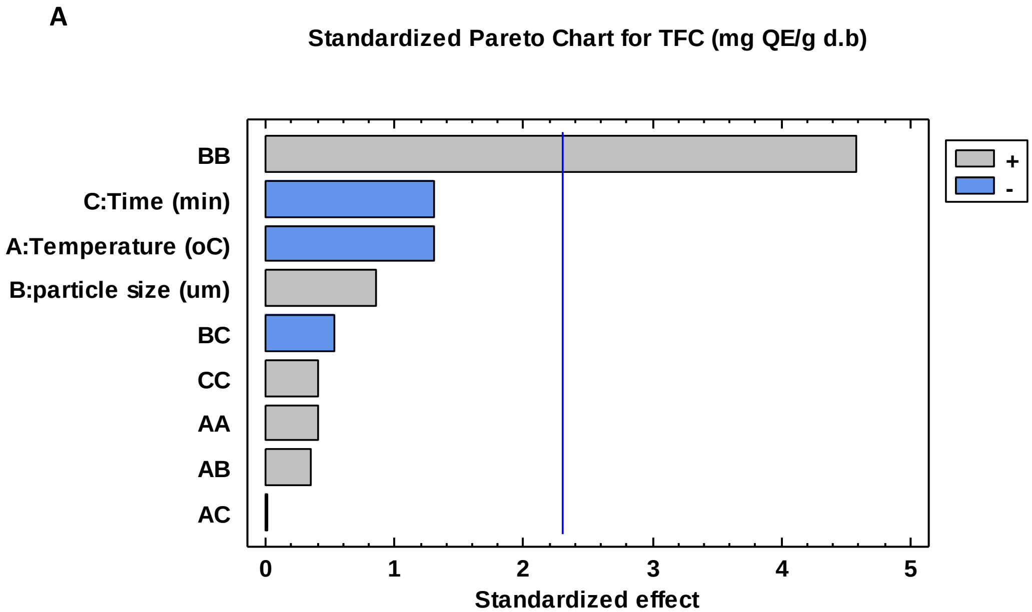
Here too, statistical analysis showed that the percentage of DPPH inhibition was not affected by any of the studied parameters (Temperature, Particle size and time), and the other terms from eq.4 are not statistically significant (P>05) (Fig.4).

The absence of interaction effects for TFC, TCC, and the percentage of DPPH inhibition suggests that there is no synergistic interaction between the components being studied.

Table 8 Regression coefficients of the second-order polynomial and their significance (open air)

	TFC		TCC		% of DPPH inhibition (Water extract)	
Regression coefficients	Values	*P*-value	Values	*P*-value	Values	*P*-value
a_0	8,66179		1,13642		22,1717	
a_1	-0,0472928	0,2291	-0,0139118	0,0247	1,35838	0,3235
a_2	-0,0356211	0,4181	0,00101351	0,2785	-0,0407254	0,4486
a_3	-0,0162992	0,2269	-0,00940816	0,0736	-0,130885	0,4893

a_{11}	0,000197904	0,6917	6,41098E-05	0,3089	-0,0075248	0,1363
a_{22}	8,6661E-05	0,0018	-3,13178E-06	0,2143	0,00011356	0,543
a_{33}	0,000284981	0,6917	0,0000539181	0,5434	0,00923629	0,1957
a_{12}	4,24383E-05	0,7315	1,92901E-06	0,8984	3,78086E-05	0,9741
a_{23}	-7,68519E-05	0,6063	-1,57407E-06	0,9308	6,57407E-05	0,9624
a_{13}	-4,62963E-06	0,995	4,9537E-05	0,5883	-0,00659722	0,358
R^2	76,43 percent		68,97 percent		54,62 percent	



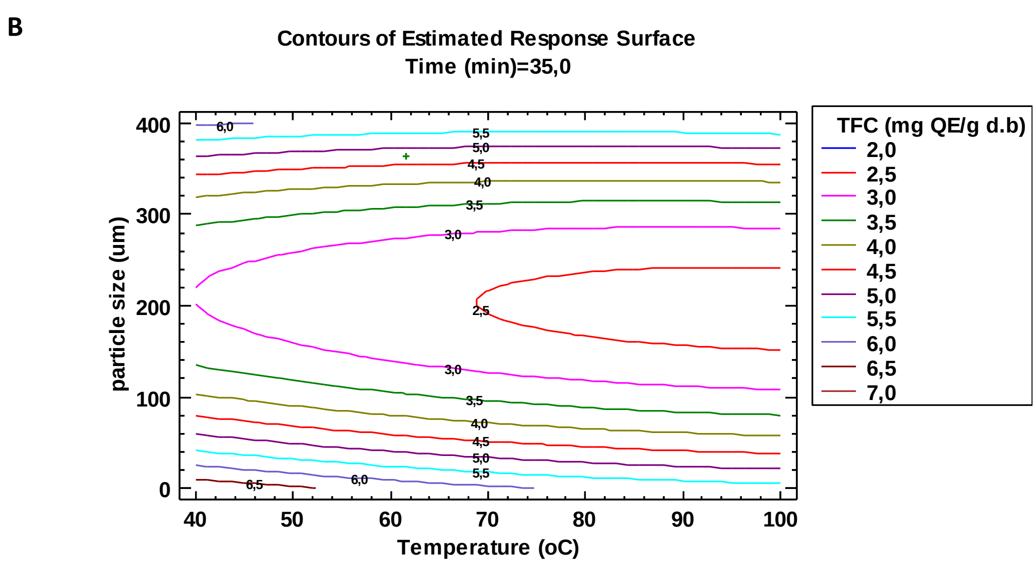


Figure 2. Effect of open-air extraction parameters (temperature (oC), particle size (µm) and extraction time (min)) on the Total Flavonoids Content: (a) Pareto Chart; (b) Response surface

C

D

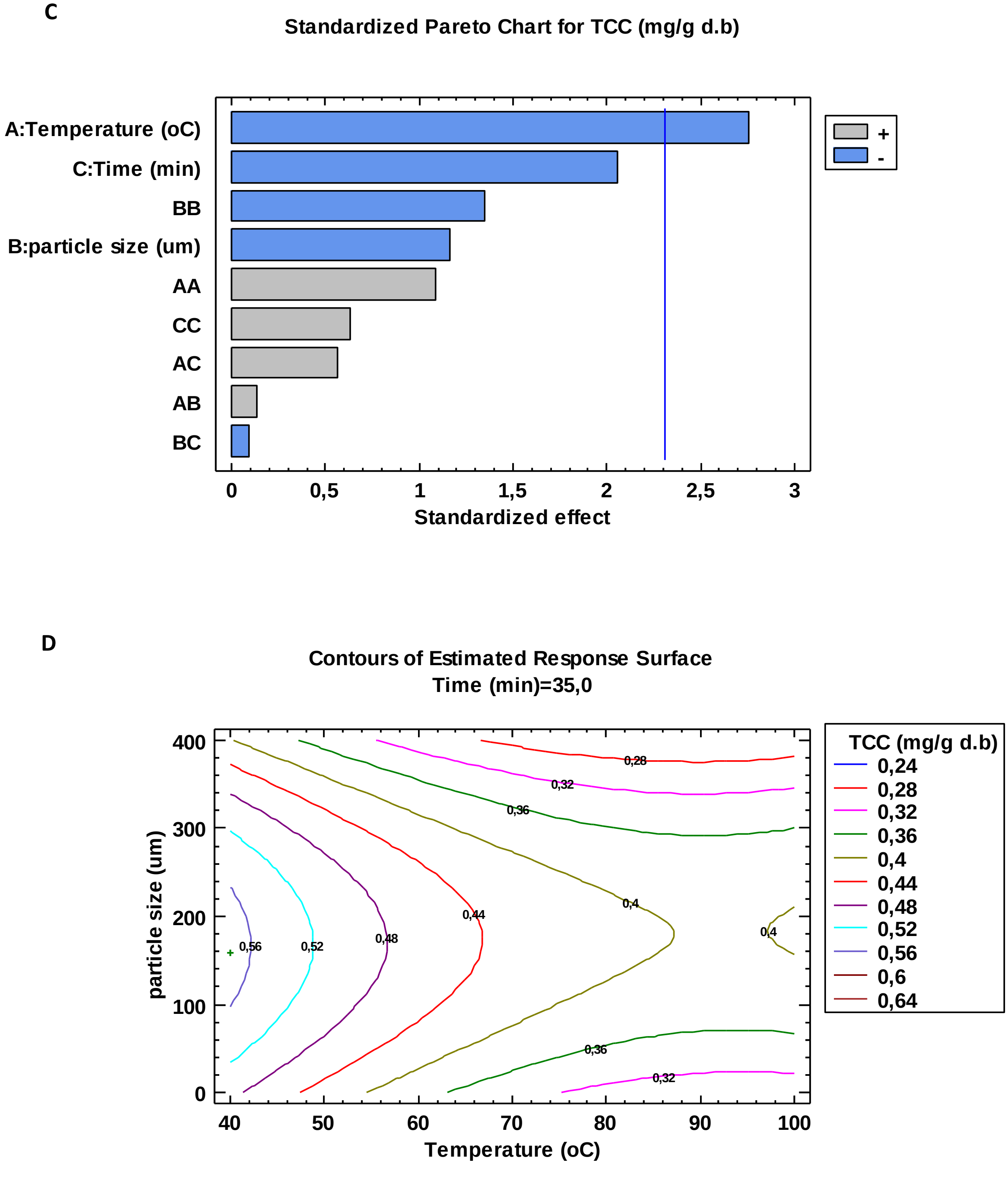
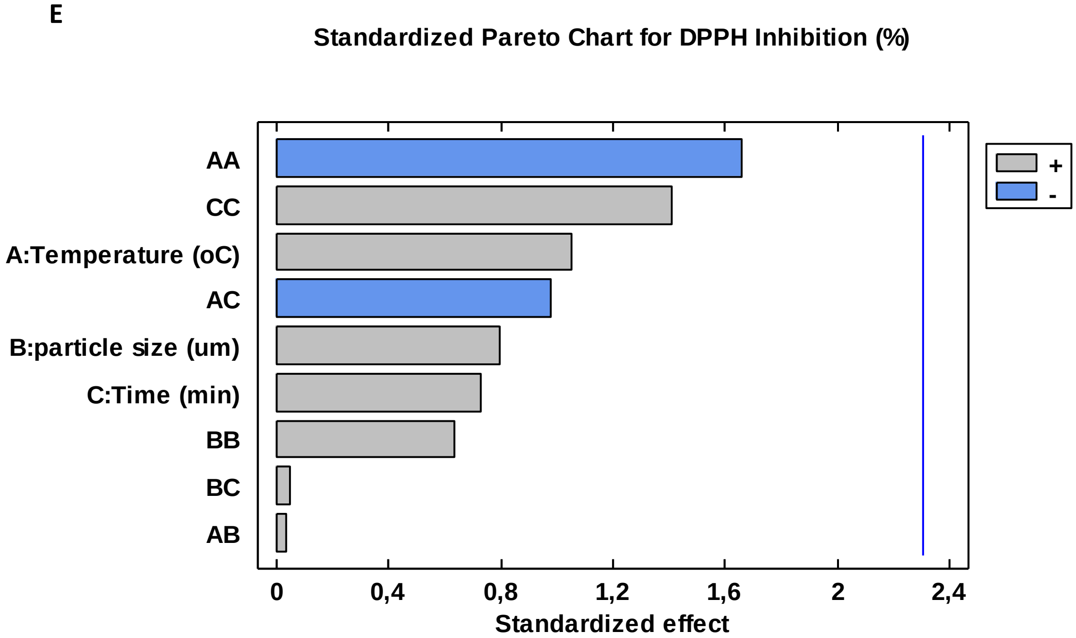


Figure 3. Effect of open-air extraction parameters (temperature T(oC), particle size Ps (μm) and extraction time t(min)) on the Total Carotenoids Content: (c) Pareto Chart; (d) Response surface

E



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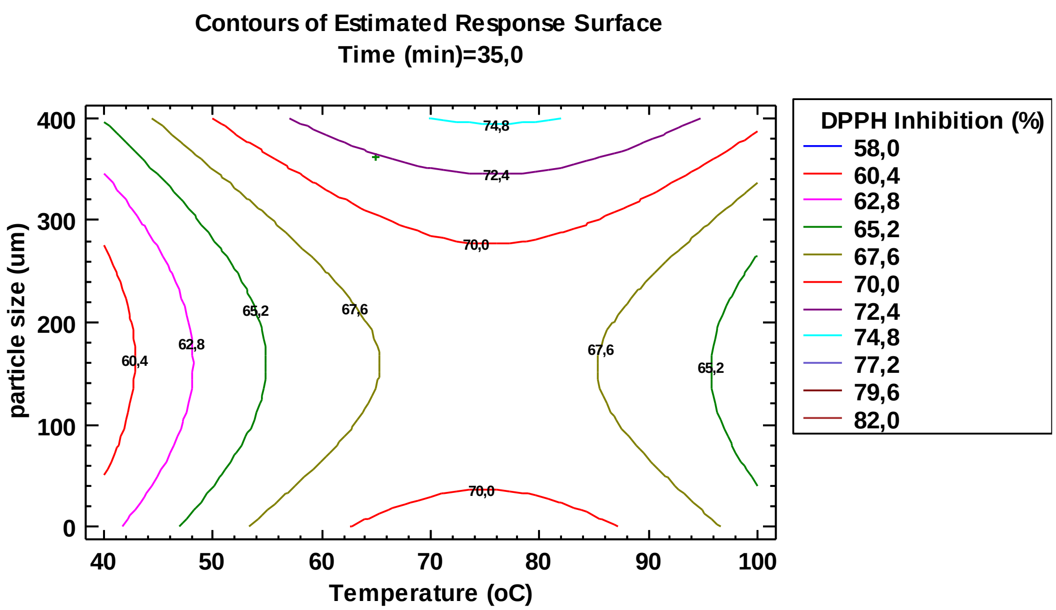


Figure 4. Effect of open-air extraction parameters (temperature T(oC), particle size Ps (µm) and extraction time t(min)) on the Total Carotenoids Content: (e) Pareto Chart; (f) Response surface

3.2.2. Case DIC assisted Swell-drying

The following responses form of a second-order polynomial for TFC, TCC and % of the DPPH inhibition from Swell-Dried banana peels powders and their regression (Table 9).

Where X_1: Treatment time t (s); X_2: Steam pressure P (MPa); X_3: Number of cycles (−).

$$\text{Total Flavonoids Content}\left(\text{mg}\frac{\text{QE}}{\text{g}}\text{d.b}\right) = 0{,}258343 + 0{,}0161853X1 + 14{,}0994X2 - 1{,}08437X3 + 0{,}0000997754X1^2 - 0{,}0738125X1X2 - 0{,}00184242X1X3 - 13{,}4117X2^2 + 1{,}27965X2X3 + 0{,}0778587X3^2 \quad (6)$$

$$\text{Total Carotenoids Content}\left(\text{mg}\frac{\text{QE}}{\text{g}}\text{d.b}\right) = 3{,}0694 + 0{,}00720274X1 - 15{,}9562X2 + 0{,}175842X3 + 0{,}0000130335X1^2 - 0{,}0193875X1X2 - 0{,}000413364X1X3 + 23{,}3667X2^2 - 0{,}429151X2X3 + 0{,}00617456X3^2 \quad (7)$$

$$\%\ \text{inhibition of DPPH radical of water extract} = 57{,}4982 + 0{,}00424404X1 + 0{,}00424404X2 + 2{,}16904X3 + 0{,}000260012X1^2 + 0{,}0277965X1X2 - 0{,}0211525X1X3 - 0{,}650717X2^2 - 2{,}09894X2X3 + 0{,}198078X3^2 \quad (8)$$

The DIC technique was used to successfully fit the TFC and TCC (Eq.5 and Eq.6). The resulting models were suitable with acceptable determination coefficients R^2, with similar values (~ 56%), indicating satisfactory equation fitting and appropriate adjustment models, except for the percentage of DPPH inhibition, which had a low value of R^2 (42.55%) (Table 9).

Table 9 Regression coefficients of the second-order polynomial and their significance (DIC)

	TFC		TCC		% of DPPH inhibition (Water extract)	
Regression coefficients	Values	*P*-value	Values	*P*-value	Values	*P*-value
a_0	0,258343		3,0694		57,4982	
a_1	0,0161853	0,874	0,00720274	0,9658	0,00424404	0,6759
a_2	14,0994	0,3739	-15,9562	0,1718	12,4278	0,4358
a_3	-1,08437	0,2764	0,175842	0,6346	2,16904	0,5362
a_{11}	9,97754E-05	0,0436	1,3034E-05	0,4568	0,00026001	0,2202
a_{22}	-13,4117	0,5007	23,3667	0,0082	-0,650717	0,9942
a_{33}	0,0778587	0,1408	0,00617456	0,7497	0,198078	0,3946
a_{12}	-0,0738125	0,0947	-0,0193875	0,2372	0,0277965	0,883
a_{23}	1,27965	0,365	-0,429151	0,4258	-2,09894	0,7398
a_{13}	-0,00184242	0,388	-0,00041336	0,6094	-0,0211525	0,0429
R^2	55,84 percent		56,07 percent		42,55 percent	

According to the study of the variance, Fig. 5 and Eq.5 allow noting that DIC treatment time t is only significant for the increase of Total Flavonoids Content (a positive quadratic effect was significant ($P< .05$)).

Statistical analysis of the experimental design showed the steam pressure P to be the only significant DIC operating condition affecting the increase of Total Carotenoids recovered from DIC swell-dried banana peels powder (a positive quadratic second-order effect was significant ($P< .05$)) (Fig.6).

Statistical analysis of the experimental design allowed obtaining Pareto Chart and Response surface (Fig.7), as well as the empirical model (Eq.7), which show that treatment time t and number of cycles are the main significant operating parameters. (a negative linear effect was significant ($P< .05$)). When the treatment time t and the Number of cycles increase, the percentage of DPPH inhibition decreases.

3.3.Optimization of extraction conditions

3.3.1. Case of open air

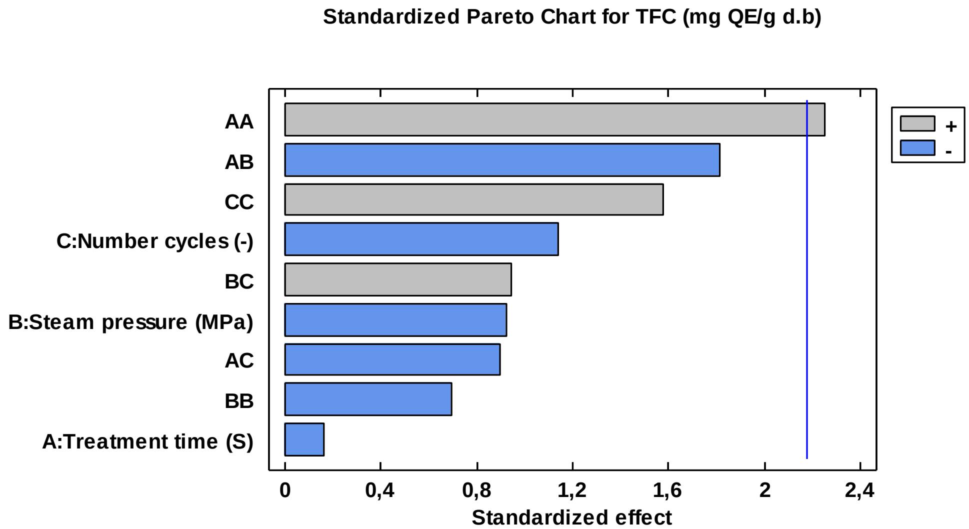
The optimal values for the variables used in the open air drying of banana peels, with maximum desirability were found to be as follows: temperature, 60.47°C; extraction time, 10min; and particle size, 348.648μm. The predicted values are satisfactory because the optimal desirability d=0.7.

The values for the responses at the optimized point were as follows (Fig.8):

Total Flavonoids Content= 5.13 (mg QE/g d.b) with a desirability d=1;

Total Carotenoids Content = 0.48 (mg /g d.b) with a desirability d=0.54;

% of DPPH inhibition=73.05% with a desirability d=0.63.



H

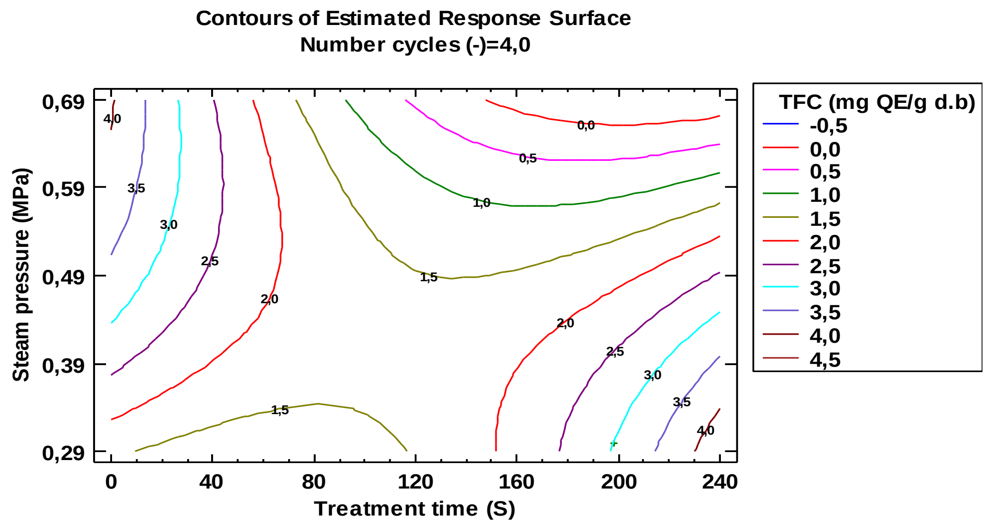
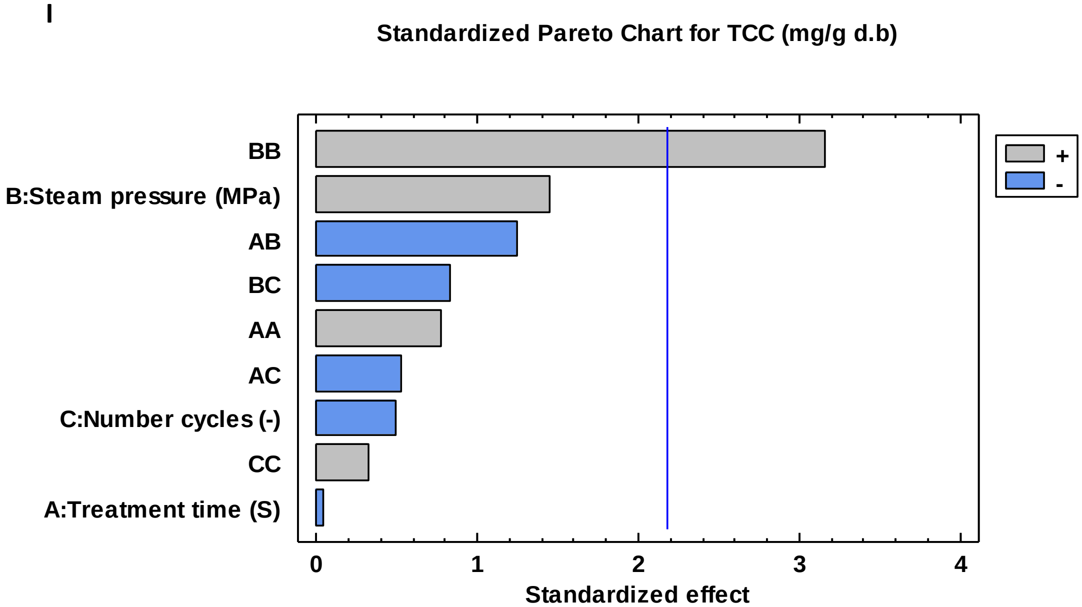


Figure 5. Effect of Swell-Drying with DIC parameters (Treatment time t(s), steam Pressure P (Mpa) and Number of Cycles)) on the Total Flavonoids Content: (g) Pareto Chart; (h) Response surface

I



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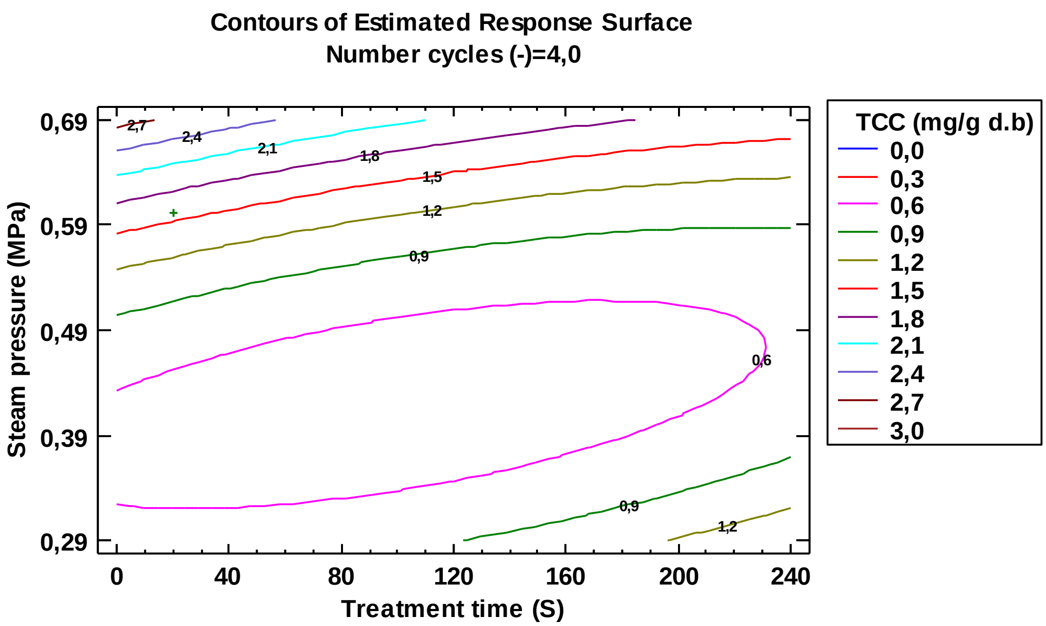

Figure 6. Effect Swell-Drying with DIC parameters (Treatment time t(s), steam Pressure P(Mpa) and Number of Cycles)) on the Total Carotenoids Content: (i) Pareto Chart; (k) Response surface

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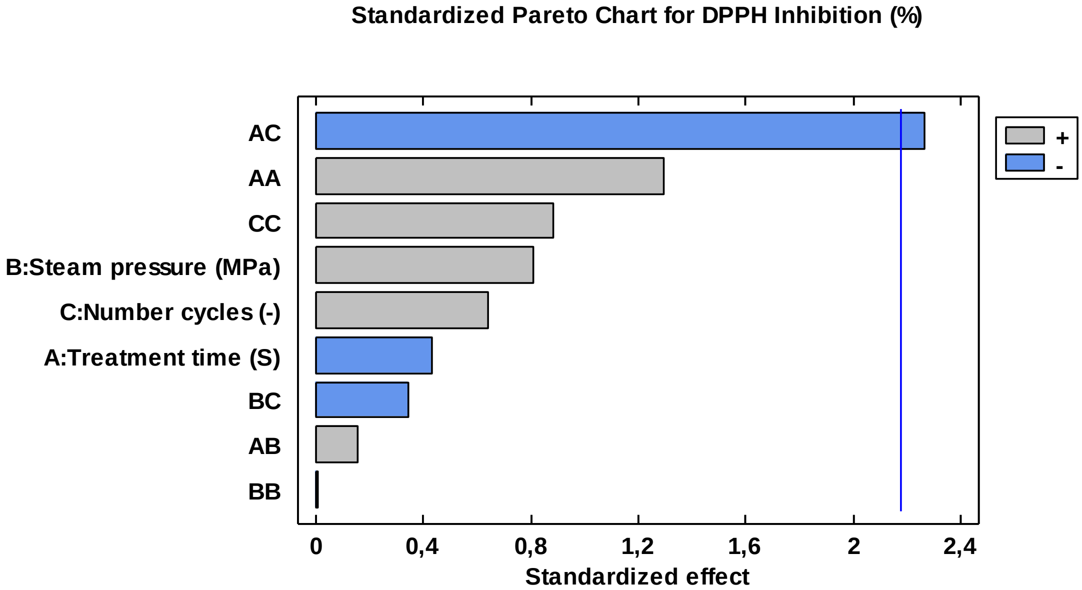
L



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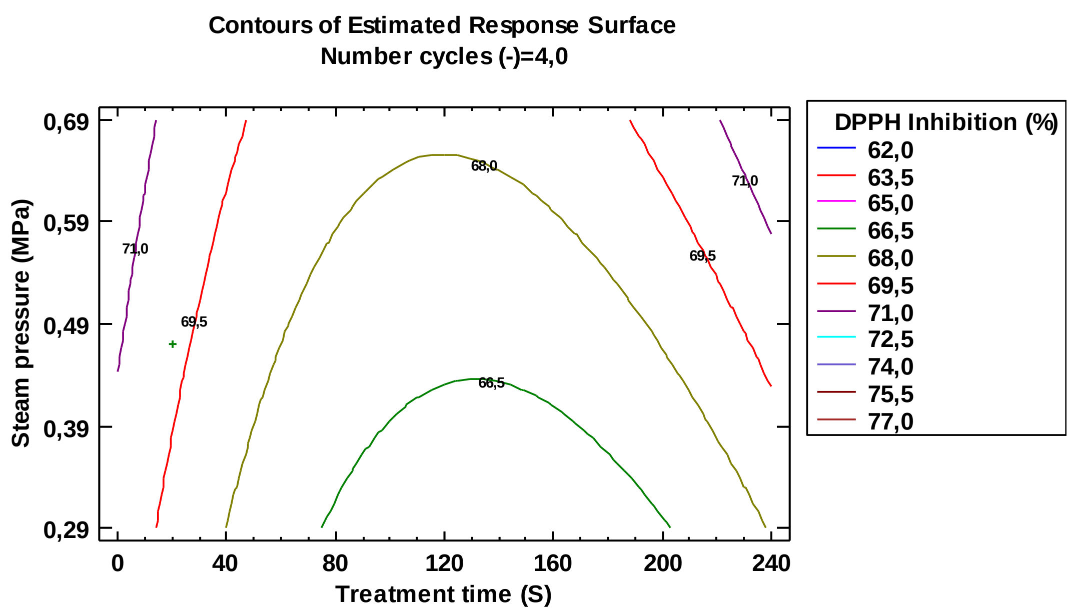

Figure 7. Effect Swell-Drying with DIC parameters (Treatment time t(s), steam Pressure P(Mpa) and Number of Cycles) on the % of the DPPH inhibition: (l) Pareto Chart; (m) Response surface

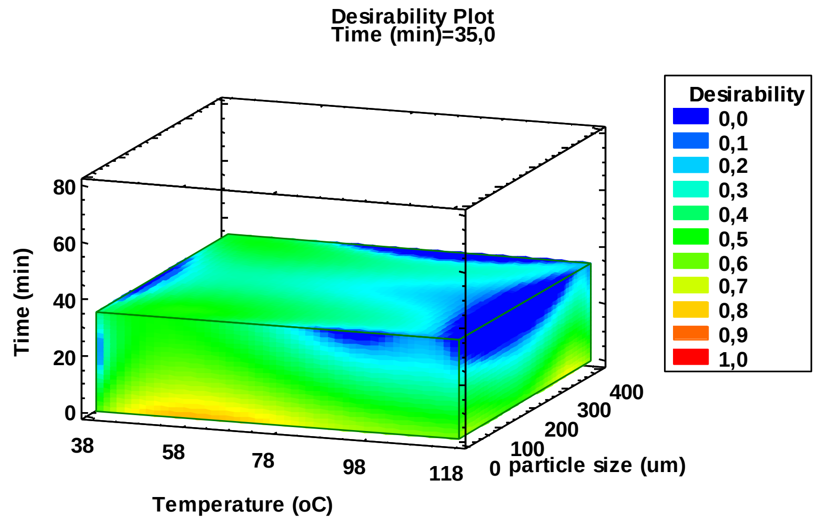

Figure 8. Response surface of the effect of open-air extraction parameters (temperature (oC), particle size (µm) and extraction time (min)) on desirability

3.3.2. Case of Swell- drying by DIC

The optimized DIC operating parameters with maximum desirability were found to be as follows: treatment time, 24.46 s; steam pressure, 0.59MPa; number of cycles, 6.38.

Fig.9 allowed obtaining the following response with the highest optimized desirability (d=1):

TFC=4.07 (mg QE/g d.b),
TCC= 1.37 (mg /g d.b)
DPPH inhibition=75.97 %

Hence, the predicted values are perfect (d=1).

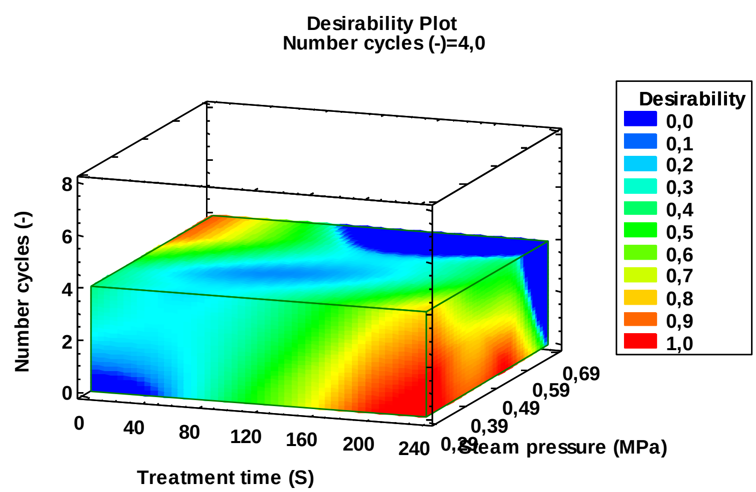

Figure 9. Effect of DIC-assisted Swell-Drying parameters (Treatment time t (s), steam Pressure P (Mpa) and Number of Cycles Nc)) on the Desirability

3.4. Discussions

The Response optimizer Function was used to optimize the operating conditions of two drying processes (open air and DIC assisted Swell Drying) in order obtain a maximum of nutraceutical components (flavonoids and carotenoids) from banana peels.

In this study, various quantitative findings on the biochemical properties were investigated. This concerns minerals, fatty acids, mucilage, flavonoids, and carotenoids.

The optimized extraction parameters for open-air dried banana peel were found at 60.47°C, extraction time (10min) and particle size (348.648µm). Additionally, the thermal treatment time (24.46s), saturated steam pressure (0.59MPa) and cycles Number 6.38 were the optimized operating DIC texturing parameters that were found. Under the selected optimum conditions, the suitability of the models to predict the responses of the Total Flavonoids Content and Total Carotenoids Content and % of DPPH inhibition was evaluated.

The richness of banana peels in nutraceuticals compounds (flavonoids and carotenoids) was linked to the drying processes and the operating conditions. The highest optimized concentration of Total Flavonoids Content (5.13 mg QE/g d.b) was observed from open-air dried banana peels and correlated positively with the particle size.

However, the TFC released from DIC Swell-dried banana peels was correlated positively with the heat treatment time with DIC at the optimum value (4.07 mg QE/g d.b).

In plant tissues, phenolic compounds appear as glucosides and have a lot of hydroxyl groups. This produces a large variety of these molecules with various properties, including solubility (Muzolf-Panek, and Gliszczynska-Swiglo, 2022).

Using water as an extraction solvent, in order to hydrate the particle, which intensifies mass transfer by diffusion (Ghitesci et *al*. 2015).

Our findings are comparable to those found by Someya et *al*. (2002), who showed that banana peels had a high level of total phenolic content (907mg/100g). On the other hand, banana peels heat-dried by microwave irradiation have a higher phenolic component level than freeze-dried banana peels (Vu et *al*. 2018).

Conversely, increasing temperature resulted in a loss of sensitive compounds and decreased the antioxidant activity. According to Passo Tsamo et *al*. (2015), boiling banana peels decreased the amount of flavonoids while increased the ferulic acid.

According to earlier studies, the use of other extraction procedures was responsible for the loss of some phenolic compounds (Gonzalez-Montelongo, 2010; Toh et *al*. 2016; Hernandez-Carranza et *al*. 2016).

The variation of phenolic compounds depends on the variety, cultivation condition and the maturity of fruit.

Additionally, it can be said that the heat treatment with DIC is an effective process for releasing bound phenolic compounds from their phenolic acids. This has attracted a lot of interest due to their antioxidant qualities.

When using DIC-texturing, biological composition is preserved thanks to the expanded granule powder with a high level of interaction (porosity and capillarity) (Benahmed Djilali et *al*., 2016; Benseddik et *al*., 2022).

The level of carotenoids was maximised at 1.72 mg /g d.b by using Swell-drying with DIC.

Our findings are comparable to those of Nguyen et *al*. (2014), who showed that carrots subjected to Swell-Drying assisted by DIC, which maximised porosity for the steam pressure (P=0.5MPa) and thermal holding time (~ 36 s). Furthermore, the optimal effectiveness of an extract cannot result from one active compound but rather form the combined synergistic action of various constituents.

The effects of temperature, extraction time, and methanol concentration on the TFC from *Nigella sativa* seeds were examined in the study by Muzolf-Pan and Gliszczynska-Swiglo (2022). TFC increased with an increase in temperature and extraction time up to T =

67oC, t = 208 min, and methanol concentration = 50%, allowing the maximum predicted value of TFC =7.68 mg QE/g.

4. Conclusions

Some operational parameters of the two drying processes (open air and Swell-Drying with DIC were optimized to maximise the availability of Total Flavonoids and carotenoids using single- and multi-response desirability functions.

Texturing banana peel by DIC promotes high levels of carotenoids and maximised the antioxidant activity

Banana peel water extract could be a good source of bioactive substances, which could be further used as a natural antioxidant in various industrial settings.

However, for the sake of this study it would be interesting to apply the optimum operational parameters resulting from the open air to the second drying process.

Future study will focus on identifying the phenolic components of the obtained powders, optimizing additional parameters, and using those components to elaborate medicinal forms.

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6. Abbreviations

db Dry basis (g)
DIC Instant Controlled Pressure-Drop
DPPH 2,2-diphenyl-1-picrylhydrazyl
SD Swell-Drying
SD Swell-Drying
TFC Total Flavonoids Content
TCC Carotenoids Content