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Recovery of valuable components from carrot peel as vegetable waste using microwave-assisted extraction

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ABSTRACT

Food waste is a growing problem. In many cases, the wasted part of the food could still be consumed. In this research, the extraction of the peeled skin of carrots was investigated in order to find an easier and more economical extraction process of fewer preparation steps. For the retrieval of carotenoids and polyphenols from carrot peel microwave-assisted extraction was used. Three factors were changed: Microwave power (100–450–800 W), treatment time (4–8–12 min), and ethanol concentration (10–35–60 V/V %). For the statistical analysis CCD (central composite design) method was used. Total polyphenol content (TPC) was measured with Folin-Ciocalteu method, antioxidant capacity (AC) with FRAP method and carotenoid ratios with colorimetry. Different settings for different components proved to be effective, but the proposed setting for the overall optimization was also economically efficient: $t = 12$ min; $P = 624$ W; $c = 10$ V/V %; so the yield would be: TPC = 152 mg L^{-1}; AC = 459 mg L^{-1}; $L^* = 74.9$; $a^* = 8.4$; $b^* = 47.7$.

KEYWORDS

green extraction technology, microwave, plant by-products, biologically active compounds, carrot peel, ethanol

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INTRODUCTION

Food waste is a major problem today. One of the biggest challenges for the food industry is to develop sustainable ways to reduce and recycle food waste (Melikoglu et al., 2013). Many by-products of food production are usually treated as waste but still contain valuable components. In this case, general recoveries (e.g. composting, use as fuel) can still be wasteful compared to extracting the materials already produced. For environmental reasons, it is important to be able to use them with as little energy as possible.

The processing of fruits and vegetables generates a large amount of food waste, as a large amount of flesh is removed during the peeling process, which in many cases could still be consumed. In this research, we investigated the extraction of the peeled skin of carrots.

The extract contains high levels of bioactive compounds that could be used to produce functional products in the future. Bioactive compounds can be classified into three main groups: terpenes and terpenoids (25,000 types), alkaloids (12,000 types) and phenolic compounds (10,000 types) (Antolak and Kregiel, 2017). Most of them are used as additives in food due to their organoleptic and nutritional properties, but they also add nutritional value to food products.

The inclusion of foods rich in phytochemicals in the daily diet has been associated with a reduced risk of birth defects, cancer, cardiovascular diseases, and neurodegenerative disorders (Blancquaert et al., 2010; Liu, 2013). Carrot, as a valuable source of various phytochemicals – such as carotenoids, phenolic compounds, ascorbic acid, and polyacetylenes – offers significant potential in this regard (Ahmad et al., 2019). Carrot contains high amounts of carotenoids – which give their color – as well as antioxidants and polyphenols, for this reason, it can be used as an added value in functional drinks (Hariadi et al., 2023).

Umair et al. (2021) studied the carotenoid content of whole carrots, after grinding and freeze drying, the extraction was achieved by ethanol and was helped with ultrasound. They also made the extraction with methanol, acetone, acetonitrile, and n-hexane, but out of these five solvents, which also can be used in the food industry, ethanol produced the maximum yield of carotenoids.

Kaur et al. (2022) investigated the carotenoid content and antioxidant capacity of by-products using a hexane–ethanol mixture as a solvent. They also freeze-dried and ground the sample as a preparation. They found that the optimum extraction set-up for the FRAP test was 5 min, the solvent ratio was 1:40, and the temperature was around 50 °C, because at a higher temperature the molecules would probably be damaged. The results of the ABTS test (abbreviation for 2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid)) optimized the time at 10 min, the other two parameters (solvent ratio and temperature) were approximately the same.

Another study (Park et al., 2023) investigated the optimal extraction conditions for dried purple beet preparation in terms of total phenol and total flavonoid content, as well as radical scavenging activity. The predicted optimal conditions were 41.9 °C, 46.1 min, and 26.0% ethanol.

Microwave assisted extraction (MAE) is more effective than the conventional methods. The first microwave extraction was used to heat biological and soil samples to extract organic compounds by Ganzler et al. (1986).

The interaction and friction among molecules at the molecular level result in the conversion of electromagnetic wave energy into heat, eventually raising the temperature of the matrix. This

thermal effect promotes the rupture of cell structures, thereby enhancing the release and extraction of target compounds (Aspé and Fernández, 2011).

There is a lot of research on this topic, but in most cases they are based on completely dried and pulverized raw material. This process is expensive and energetically unfavorable. The aim of this research is to find an economically suitable extraction process for the extraction of carotenoids and polyphenols, which can be later applied to further (e.g.) food production or pharmaceutical use.

MATERIALS AND METHODS

Preparation of carrot peel

Carrots (*Daucus carota*, napa cultivar, from Róna Ker-Tész Kft.) were peeled as thinly as possible (approx. 10% of the carrots' weight was the peel) and grated the skin with Knife Mill GM200 Grindomix Retsch (Berlin, Germany) to ~1 mm. It was then homogenized, measured for dry matter content and frozen in small portions (approx. 45 g/bag). The measurement was performed after thawing under normal room conditions.

Solvent

As the primary object of study was extraction of polyphenols and carotenoids, but with a view of minimalizing of chemical usage, ethanol was used for the measurements.

To maximize recovery and minimize costs, 10, 35 and 60% ethanol was used as solvent. The volume was determined so that the dry matter: liquid mass ratio was 1:40 (according to Kaur et al., 2022), by including the moisture content of the sample in the mass of the liquid (Mao et al., 2021).

Details of microwave treatment

As regards the microwave measurements, it was essential to avoid overheating the sample, so the required sample volume was calculated for 300 mL of solvent; see the Table 1 for the dosage.

The treatment was carried out in a microwave oven (Specs Electrolux EMM, 2005, PRC) for a duration of 4, 8 and 12 min at power levels of 100, 450 and 800 W, respectively. Breaks were taken when the samples were rapidly cooled in ice water to ensure that the temperature did not exceed 55 °C. The temperature was varying between 38 and 50 °C during the whole treatment, which was measured by thermometer during the cooling section.

Table 1. Sample weights according to moisture and alcohol content

	Sample mass (g)	Moisture content (g)	Dry matter (g)	Solvent mass (g)
Measuring dy matter content	100.0	89.9	10.1	313.0
To 3 dL of 10 V/V % ethanol	91.9	82.7	9.3	287.7
To 3 dL of 35 V/V % ethanol	89.9	80.9	9.1	281.4
To 3 dL of 60 V/V % ethanol	85.7	77.1	8.6	268.3

The rest–cooling procedure was conducted in accordance with the following protocol based on preliminary trial measurements:

- samples of 100 W, 6 min treatment followed by a 2 min cooling cycle
- samples of 450 W, 1 min treatment – 1 min cooling cycle
- samples of 800 W, 0.5 min treatment – 1 min cooling cycle

The total extraction time, including the rest–cooling period following each treatment was 36 min long and the process was stopped by filtration.

Details of centrifugation process

Following the extraction treatments, the samples were placed in a centrifuge (Z206 A Hermle, Germany) and rotated at 6,000 rpm for a 20-min long period. This procedure was undertaken to ensure that any small particles contained within the samples did not have a measurable effect on further measurements.

Total phenolic content – TPC test

The total polyphenol content of the samples was measured using Folin-Ciocalteu method described in Singleton and Rossi (1965). The calibration line was created using gallic acid. Measurements were performed at 760 nm, measured absorbances fell on the calibration line.

The polyphenol content was calculated with the following equation (1):

$$TPC = \frac{A_1 \cdot V_{total_1} \cdot DF}{S_1 \cdot a_1} \left(mg\ GAE\ L^{-1}\right) \tag{1}$$

where: A_1 is the measured absorbance (–); V_{total1} is the total amount of the sample and the reagents (µL); DF is the dilution factor (–); S_1 is the amount of the sample (µL); a_1 is the slope of the calibration curve; and the GAE is the gallic acid equivalent value, what is standard for the calibration (Zin et al., 2021). Each sample was measured three times.

Antioxidant capacity – ferric reducing ability of plasma assay – FRAP test

The antioxidant capacity (AC) was tested using the FRAP method, as described by Benzie and Strain (1996), with some modifications.

1,500 µL of FRAP reagent was added to a 50 µL sample and the absorbance was measured at 593 nm after 5 min. Calibration was performed using ascorbic acid; therefore, the concentration can be expressed as an ascorbic acid equivalent value (Gonelimali et al., 2023).

The antioxidant capacity was calculated with the following equation (2):

$$AC = \frac{A_2 \cdot V_{total_2} \cdot DF}{S_2 \cdot a_2} \left(mg\ AAE\ L^{-1}\right) \tag{2}$$

whereby: A_2 – measured absorbance (–); V_{total2} – total amount of the sample and the reagents (µL); DF – dilution factor (–); S_2 – amount of the sample (µL); a_2 – slope of the calibration curve; and AAE – ascorbic acid equivalent value is standard for the calibration. Each sample was measured three times.

Absorbances were measured using a Hitachi U-2900 spectrophotometer (Hitachi High Technologies Europe GmbH, Krefeld, Germany).

Colorimetry measurement

The carotenoid content can be estimated based on color measurements. The color measurement was performed by using a ColorLite sph850 spectrophotometer (ColorLite GmbH, Katlenburg-Lindau, Germany). The machine performs three measurements automatically during operation and then calculates the average value. According to Hariadi et al. (2023), the L^* value decreases and the a^* and b^* values increase when the concentration of the carrot in the extract increases. This is proportional to the carotenoid concentration.

In this study, through colorimetry we aimed to maximize the yield of carotenoids by optimizing extraction without precisely determining the value of carotenoids.

Statistical evaluations

The statistical calculations were conducted in Design-Expert Trial Version (Stat-Ease Inc., USA). The experiment was carried out using the CCD (central composite design) sampling.

Central Composite Design (CCD) is a widely used Response Surface Methodology (RSM) that combines a two-level factorial (or fractional factorial) design with additional axial ("star") points and replicated center points to fit a quadratic model efficiently. The factorial points define the corners of the experimental space, axial points (at $\pm\alpha$) extend beyond to capture curvature, and center points help estimate experimental error. This structure allows accurate modeling of second-order relationships without conducting a full three-level factorial experiment (Bayuo et al., 2020).

In the present system, which has three independent variables (time, microwave power, and ethanol concentration), three types of experimental points are included by CCD:

1. Factorial points are combinations of high and low levels for each variable, which are coded as $+1$ and -1 respectively.
2. Axial (star) points are defined as points that explore the effect of extreme values set at a distance ($\pm\alpha$) from the center to estimate curvature.
3. The center points are determined by the repeated experiments at the midpoint of all variables, which are utilized for the purpose of detecting experimental error (Myers et al., 2016).

Table 2 presents the experimental sampling design, including both coded and real values. Following the measurement process, the "run"-s provided the sample numbers, thus the sample numbers described below are based on Table 2.

RESULTS

TPC and AC – analytical measurements results

Table 3 shows the results obtained for the Folin–Ciocalteau (TPC) and FRAP (AC) methods for samples treated in different ways have been calculated as the mean and standard deviation of three measurements.

Colorimetry results

The results of the color measurement are presented in Table 4. The different columns are color-coded to indicate the carotenoid content of the samples. Color scales visually highlight the

Table 2. CCD table for the sampling

Run	Time (min)	MW power (W)	Ethanol content (V/V %)	Time (min)	MW power (W)	Ethanol content (V/V %)
	Coded parameters			Real values		
1	1	−1	−1	12	100	10
2	−1	1	1	4	800	60
3	−1	0	0	4	450	35
4	0	0	−1	8	450	10
5	0	0	0	8	450	35
6	1	1	−1	12	800	10
7	0	0	0	8	450	35
8	0	0	0	8	450	35
9	−1	−1	1	4	100	60
10	1	0	0	12	450	35
11	0	−1	0	8	100	35
12	−1	1	−1	4	800	10
13	0	0	0	8	450	35
14	0	0	0	8	450	35
15	−1	−1	−1	4	100	10
16	0	0	1	8	450	60
17	1	1	1	12	800	60
18	0	1	0	8	800	35
19	0	0	0	8	450	35
20	1	−1	1	12	100	60

distribution and variation of data to aid understanding. With two-color scales (using a transition between two colors), a comparison was made across a range of cells. A given hue represents a higher or lower value. In Table 3 a green–red color scale is showing, so that cells with higher values are given a greener color and cells with lower values a redder color (Internet 1). The values are formatted per column and are proportional to the carotenoid content, based on the article by Hariadi et al. (2023). Since a row represents the three color factors of a pattern, we need to observe row by row. It can be seen that the three factors move together here. However, it should be noted that these color values are not necessarily proportional to the exact carotenoid concentration, because the color is also affected by the medium.

The coloring clearly shows that each row has a similar color, suggesting a correlation between the three parameters. This was tested using the statistical method of the correlation analysis. The resulting correlation coefficients are shown in Table 5. These results indicate that the correlation coefficient (r) is higher than |0.94| in all cases, suggesting a strong correlation between the color parameters.

The correlations in the change in color confirm the assumption of carotenoid content, so we further treated the color intensity as proportional to carotenoid leaching.

Examination of the optimization process

Firstly, the linearity of the resulting model was tested. The cross effects were examined as well, but since these were not significant (P-value >0.05), they were removed for a better fit. A linear

Table 3. Analytical results of TPC and AC

Sample	TPC (mg GAE L^{-1})	AC (mg AAE L^{-1})
1	141.7 ± 4.4	363.1 ± 23.9
2	126.8 ± 1.8	437.1 ± 27.4
3	134.4 ± 5.0	387.6 ± 40.2
4	150.1 ± 4.2	354.2 ± 24.8
5	134.4 ± 1.6	357.4 ± 20.8
6	173.4 ± 2.3	509.0 ± 42.6
7	145.6 ± 2.0	499.4 ± 26.6
8	136.9 ± 6.7	402.9 ± 18.7
9	77.4 ± 1.5	216.50 ± 9.4
10	104.0 ± 2.3	404.9 ± 29.5
11	110.1 ± 1.8	301.6 ± 16.2
12	157.0 ± 3.3	408.9 ± 38.1
13	129.1 ± 4.3	299.1 ± 18.3
14	86.1 ± 0.4	437.9 ± 21.3
15	57.0 ± 0.7	217.1 ± 46.1
16	82.9 ± 4.2	431.4 ± 46.9
17	86.2 ± 2.1	429.4 ± 20.5
18	94.9 ± 2.4	384.4 ± 14.4
19	96.5 ± 5.8	357.8 ± 16.1
20	91.3 ± 3.2	421.8 ± 26.0

Table 4. Color measurement results, colored by the carotenoid content compared to each other

sample	L*	a*	b*
1	79.63	4.45	41.37
2	88.35	–0.01	26.69
3	82.4	3.57	40.22
4	76.16	8.32	49.48
5	83.22	3.26	39.41
6	70.95	12.14	51.82
7	77.4	6.82	44.16
8	76.75	7.12	44.93
9	95.46	–1.35	15.94
10	89.06	0.6	26.4
11	76.69	6.48	44.06
12	74.63	8.81	48.94
13	78.43	6.29	45.72
14	84.98	2.49	28.76
15	82.72	4.14	28.31
16	95.3	–0.88	15.54
17	91.81	–0.31	19.62
18	86.41	1.92	28.13
19	88.39	1.2	27.13
20	95.28	–0.98	15.43

Table 5. Correlation between the color parameters representing the different correlation coefficients (r)

	Correlation coefficient (r)
Correlation between parameter L^* and a^*	−0.973
Correlation between parameter L^* and b^*	−0.975
Correlation between parameter a^* and b^*	0.942

model was fitted to all the tested factors, which showed significant fit. The lack of fit was not significant, which confirms the fit.

TPC evaluation

To fit the model to the experimental data obtained for the independent variables, the Design Expert Trial Version used ANOVA analysis as shown in Tables 6–9. A 95% confidence interval was used, which means that the randomness (P-value) of the observed effect must be less than 0.05 for the model fit to be significant (Kennedy-Shaffer, 2019).

As shown in Table 6, the model-validation statistic known as the lack of fit (LOF) test is non-significant (P-value >0.05). This demonstrates that the model fit is appropriate for the measured data points.

Table 6. ANOVA table of TPC

Source	Sum of squares	df	Mean square	F-value	P-value	
Model	9179.21	3	3059.74	9.47	0.0017	Significant
A-Time	10.21	1	10.21	0.0316	0.8619	
B-MW power	19.36	1	19.36	0.0599	0.8108	
C-Ethanol conc.	6749.65	1	6749.65	20.89	0.0006	
Residual	3877.05	12	323.09			
Lack of fit	1657.24	8	207.16	0.3733	0.8902	Not significant
Pure error	2219.81	4	554.95			
Cor total	13056.3	15				

Table 7. ANOVA table of AC

Source	Sum of squares	df	Mean square	F-value	P-value	
Model	71909.7	3	23969.9	12.87	0.0003	Significant
A-Time	31919.96	1	31919.96	17.14	0.0012	
B-MW power	49262.6	1	49262.60	26.45	0.0002	
C-Ethanol conc.	3106.48	1	3106.48	1.67	0.2191	
Residual	24216.33	13	1862.79			
Lack of fit	13209.76	9	1467.75	0.5334	0.8009	Not significant
Pure error	11006.57	4	2751.64			
Cor total	96126.02	16				

Table 8. ANOVA table of L*

Source	Sum of squares	df	Mean square	*F*-value	*P*-value	
Model	706.29	3	235.43	11.29	0.0003	Significant
A-Time	1	1	1	0.0482	0.8291	
B-MW power	31.08	1	31.08	1.49	0.2399	
C-Ethanol conc.	674.21	1	674.21	32.32	<0.0001	
Residual	333.8	16	20.86			
Lack of fit	222.46	11	20.22	0.9083	0.5869	Not significant
Pure error	111.33	5	22.27			
Cor total	1040.09	19				

Table 9. ANOVA table of a*

Source	Sum of squares	df	Mean square	*F*-value	*P*-value	
Model	180.99	3	60.33	10.35	0.0005	Significant
A-Time	0.0548	1	0.0548	0.0094	0.924	
B-MW power	9.62	1	9.62	1.65	0.2171	
C-Ethanol conc.	171.31	1	171.31	29.39	<0.0001	
Residual	93.25	16	5.83			
Lack of fit	61.34	11	5.58	0.8736	0.6063	Not significant
Pure error	31.91	5	6.38			
Cor total	274.24	19				

In order to evaluate the parameters, it is recommended that the *F*-value should be observed. The magnitude of the *F*-value is proportional to the observed effect of the given factor within the model. As demonstrated in Table 6, the TPC measurement data indicates that the ethanol concentration had the most significant effect on the result, while the other two parameters (Microwave power and treatment time) did not have a significant effect. This means that reducing alcohol content can increase yields much more than changing the other two parameters.

The R^2 (determination coefficient) is a statistical measure that represents the proportion of the data that is explained by the model. The closer the number to 1 is, the better the model is considered to be. In this case, 0.703 is the value that is used to indicate a satisfactory fit.

The adjusted R^2 value is a measure of complexity of the model, i.e. the number of variables. The program provides a warning if the model is overfitted. The Predicted R^2 value is an indicator of the model's ability to "predict" data, which has been not measured. In cases where the difference between the Adjusted R^2 and Predicted R^2 values is significant, it can be concluded that overfitting is present and the model is not generalizing effectively.

In our measurement relation to the TPC analysis the Adjusted R^2 was found to be 0.629 and the Predicted R^2 was 0.512.

The program suggested a maximum 0.2 for the acceptability of the difference. In our case this difference is 0.117, which is appropriate (Internet 2).

Figure 1 shows the Response Surface Methodology diagram of the TPC model at 10 V/V % ethanol concentration, because this setting gives the highest yield for the model. In this diagram, the higher the yield, the redder the color of the point, which ranges from blue to red on the scale. It can be seen that the surface is almost completely flat, indicating that the impact of other factors on the yield is negligible. This finding is in accordance with the F values obtained in the ANOVA table (see Table 5). The following equation (3) can be used to calculate the yield:

$$TPC\ \left(mg\ GAE\ L^{-1}\right) = 166.3 - 0.314 \cdot\ t + 0.00545\ \cdot P - 1.425\ \cdot c \tag{3}$$

where '*t*' is time (4–12 min); '*P*' is microwave power (100–800 W); '*c*' is ethanol concentration (10–60 V/V %)

Design-Expert Trial Version provides several solutions for optimization. From these, the setting with the highest yield and the setting with the best energy demand/yield ratio are described below.

The optimal setting to maximize the TPC yield was found as: $t = 4$ min; $P = 800$ W; $c = 10$ V/V % with 155.5 mg L^{-1} yield. Recommended setting for energy saving and economic reasons: $t = 4$ min; $P = 228$ W; $c = 10$ V/V % then the yield is: 152.4 mg L^{-1}.

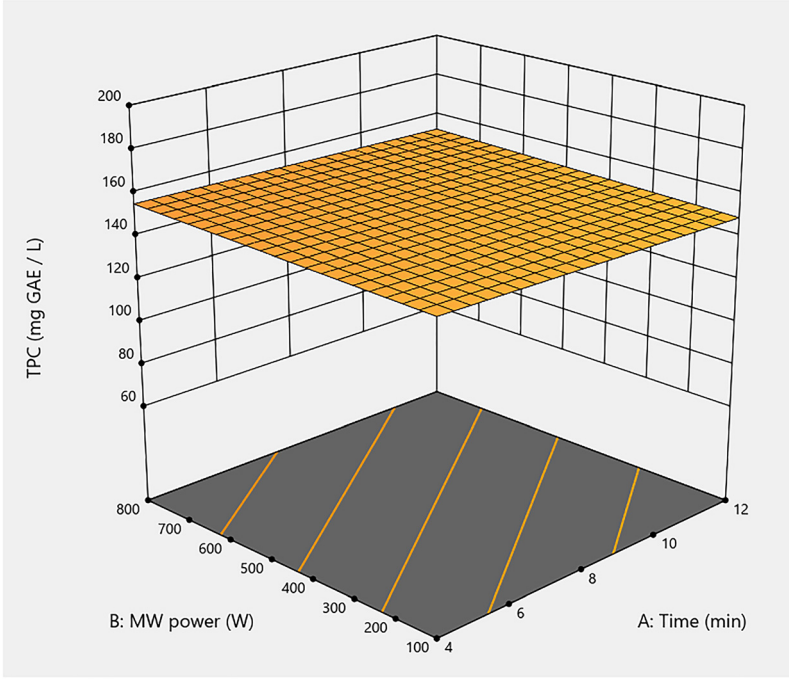

Fig. 1. Effect of microwave power (MW power, W) and time (Time, min) on polyphenol content (TPC, mg GAE L^{-1}) at 10 V/V % ethanol concentration

Antioxidant capacity evaluation

As regards antioxidant capacity, the data form ANOVA analysis is presented in Table 7. The model was found to be significant for the antioxidant capacity measure (*P*-value of 0.0003) and the lack of fit was found not to be significant, which means the relationship is linear. Looking at the *F*-values, it can be seen that this measurement is the most affected by microwave power, followed by treatment time. Alcohol concentration had no significant effect on this measurement.

For the AC the determination coefficient (R^2) was 0.7481; the Adjusted R^2 was 0.6899 and Predicted R^2 was 0.5895. The difference between the two last coefficients was less than 0.2. All of these significant indicators demonstrate the efficacy of the model employed.

As illustrated in Fig. 2, the Response Surface Methodology diagrams of the AC model are presented. In these diagrams, the color of the point corresponds to the yield, with higher values represented by redder color (from blue to red scale). Diagram a) illustrates a concentration of 10 V/V % ethanol, while diagram b) shows a concentration of 60 V/V %. Two diagrams are comparable due to the similarity in their axes and resolution. It can be observed that, in contrast to results of TPC measurement, the AC yield increases with higher ethanol content. However, this increase is not so significant, with a maximum of around 490 mg L^{-1} at 10 V/V % and around 530 mg L^{-1} at 60 V/V %, representing a negligible difference. The tilted surface confirms that for this measurement, microwave power and treatment time had a significant effect on the yield.

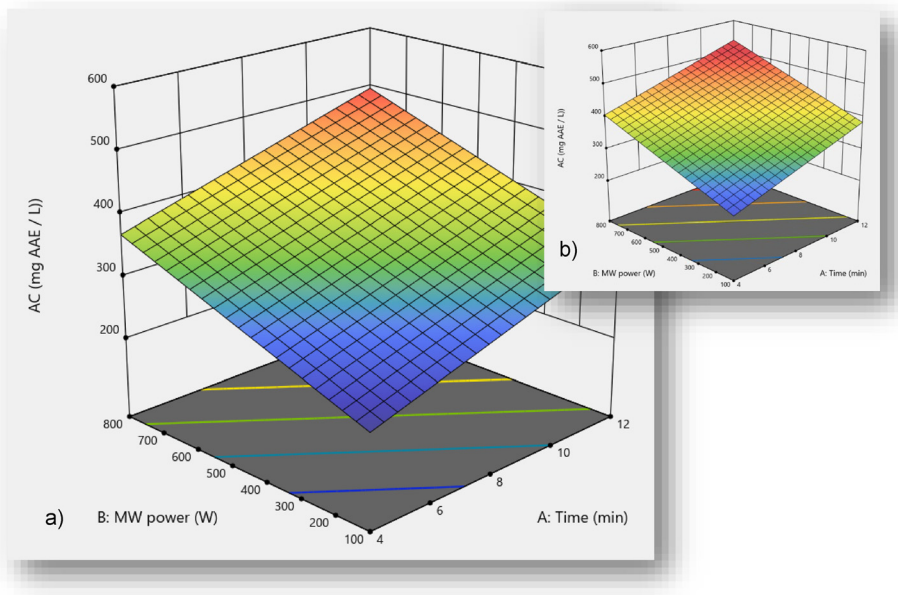

Fig. 2. Effect of microwave power (MW power, W) and time (Time, min) on antioxidant capacity (AC, mg AAE L^{-1}) at a) 10 V/V % ethanol concentration; b) 60 V/V % ethanol concentration

The following equation (4) can be used to calculate the yield of AC:

$$AC\ \left(mg\ AAE\ L^{-1}\right) = 124.55 + 16.05\ \cdot t + 0.216\ \cdot P + 0.758\ \cdot c \tag{4}$$

where '*t*' is time (4–12 min); '*P*' is microwave power (100–800 W); '*c*' is ethanol in the solvent (10–60 V/V %)

Based on the Eq. (4), the maximum yield from the AC was found to be at setting: $t = 11.3$ min; $P = 750$ W; $c = 58$ V/V % with 511 mg L^{-1} yield. It is important to note that ethanol is a relatively expensive solvent when used in large quantities in industry. Therefore, the following setting is suggested: $t = 12$ min; $P = 798$ W, $c = 26.5$ V/V %; providing AC = 509 mg L^{-1}.

Colorimetry

The first parameter of the color measurement (brightness or L^*) is inversely proportional to the carotenoid content, as previously described: an increase in carotenoids results in a darker solution. Table 8 presents the ANOVA table of the fitted model to this component. The *P*-values indicate that the model is significant, the lack of fit is not significant, and the F-values demonstrate that the ethanol concentration is the primary factor influencing the yield, while microwave power and time have no significant effect.

For the L^*: the R^2 was found to be 0.6791; with an Adjusted R^2 value of 0.6189 and a Predicted R^2 value of 0.5373. The R^2 of this model is not high, but it is within the acceptable range. The difference between Adjusted R^2 and Predicted R^2 is here also less than 0.2 in this case.

As illustrated in Fig. 3, the Response Surface Methodology diagram of the L^* model at 10 V/V % ethanol concentration is presented. In the diagram, the color intensity demonstrates the yield from red to blue on the scale. This is the only one of the measured parameters where the objective is to determine the minimum value, so the diagram shows that the darker the blue area, the more appropriate it is. This area is also very flat, which is consistent with the *F*-values found in the ANOVA table (Table 8).

The following equation (5) can be used to calculate the L^* parameter:

$$L^* = 73.84 + 0.079\ \cdot t - 0.0050437\ \cdot P + 0.328\ \cdot c \tag{5}$$

where *t* is the time (4–12 min), *P* is the microwave power (100–800 W), *c* is the concentration of ethanol in the solvent (10–60 V/V %).

The ANOVA table of the model fitted to a^* color parameter is shown in Table 9. As it can be seen from the table the model is significant (*P*-value <0.05) and the lack of fit is not significant ($P > 0.05$). The data show that the a^* parameter was affected by the concentration of ethanol.

For the a^* parameter the R^2 value was found to be 0.66; the Adjusted R^2 was 0.596 and the Predicted R^2 value was 0.476. This suggests that the fit of our model is acceptable.

Figure 4 presents the RSM diagram of the a^* color parameter. In this diagram, the color of the point corresponds to the yield, with higher yields indicated by redder points (from blue to red scale). The diagram is consistent with the ANOVA table, as it varies significantly with alcohol content and increases towards higher levels of microwave power.

The following equation (6) can be used to calculate the yield:

$$a^* = 8.089 + 0.0185\ \cdot t + 0.0028\ \cdot P - 0.1656\ \cdot c \tag{6}$$

where '*t*' is time (4–12 min); '*P*' is microwave power (100–800 W); '*c*' is ethanol in the solvent (10–60 V/V %).

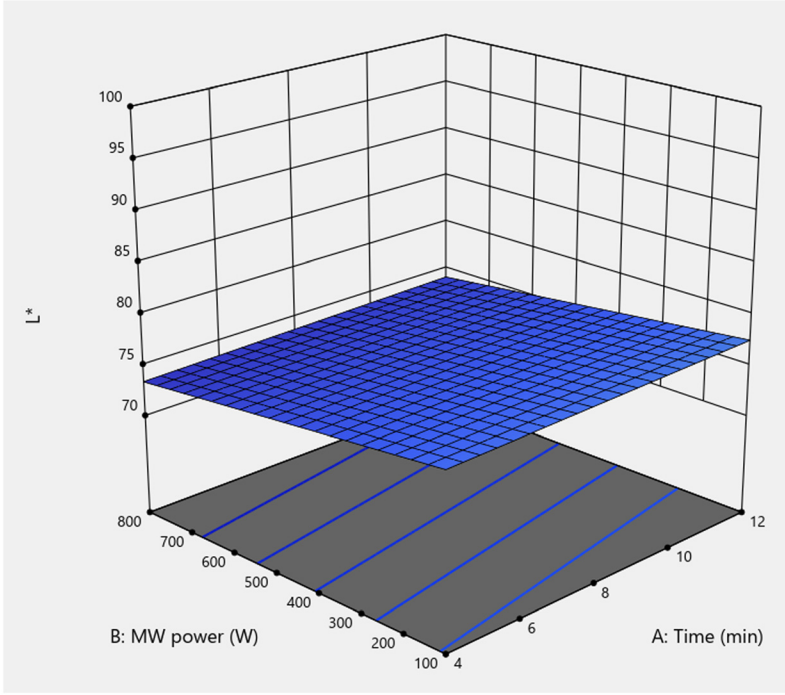

Fig. 3. Effect of microwave power (MW power, W) and time (Time, min) on L* (L*, rel. unit) component at 10 V/V % ethanol concentration

The ANOVA table for the b* color component is presented in Table 10. The *P*-value indicates that the model is significant and the lack of fit is not significant. The ethanol concentration was also the most significant parameter for this component.

In Fig. 5, the RSM diagram of the model fitted to samples extracted with a 10 V/V % ethanol concentration of component b* is demonstrated. In this diagram, the color of the point is indicative of yield, with higher yields corresponding to redder points (from blue to red scale). It can be seen from the plot that the treatment time had a negative effect on the extraction process. Therefore, it can be concluded that the shorter treatment time for this component would be optimal. The effect of the ethanol content of the plot is in accordance with the results presented in the ANOVA table.

For the b* parameter: R^2 value was found to be 0.735; the Adjusted R^2 was 0.682 and the Predicted R^2 was 0.6103.

The following equation (7) can be used to calculate the yield:

$$b^* = 61.83 - 0.75 \cdot t + 0.001564 \cdot P - 0.6052 \cdot c \tag{7}$$

where '*t*' is time (4–12 min); '*P*' is microwave power (100–800 W); '*c*' is ethanol in the solvent (10–60 V/V %).

As all three parameters of the colorimetry are associated with carotenoids, the objective was to optimize these together by finding the minimum of L* and the maximum of a* and b*.

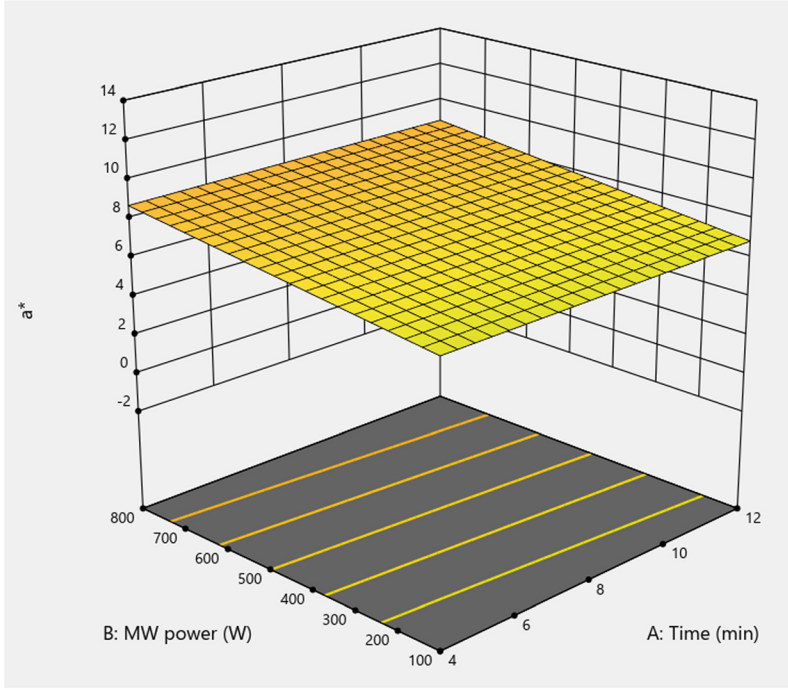

Fig. 4. Effect of microwave power (MW power, W) and time (Time, min) on a* (a*, rel. unit) component at 10 V/V % ethanol concentration

Table 10. ANOVA table of b*

Source	Sum of squares	df	Mean square	*F*-value	*P*-value	
Model	2057.33	3	685.78	13.86	0.0001	Significant
A-Time	78.39	1	78.39	1.58	0.2274	
B-MW power	2.6	1	2.6	0.0525	0.8219	
C-Ethanol conc.	1984.35	1	1984.35	40.1	<0.0001	
Residual	742.29	15	49.49			
Lack of fit	391.94	10	39.19	0.5594	0.7969	Not significant
Pure error	350.35	5	70.07			
Cor total	2799.62	18				

According to these conditions, the optimal setting in this case is as follows: $t = 4$ min; $P = 800$ W; $c = 10$ V/V %. The expected outcomes are as follows: the L* was found to be 73.41, the a* value was 8.75, and b* parameter was 54.02.

Optimizing the results in combination

It is important to note that despite the overlap between polyphenols and antioxidants, very different results were obtained for the TPC and AC assays. As demonstrated in Fig. 6, the relationship between these two parameters is not strong, $R = 0.457$.

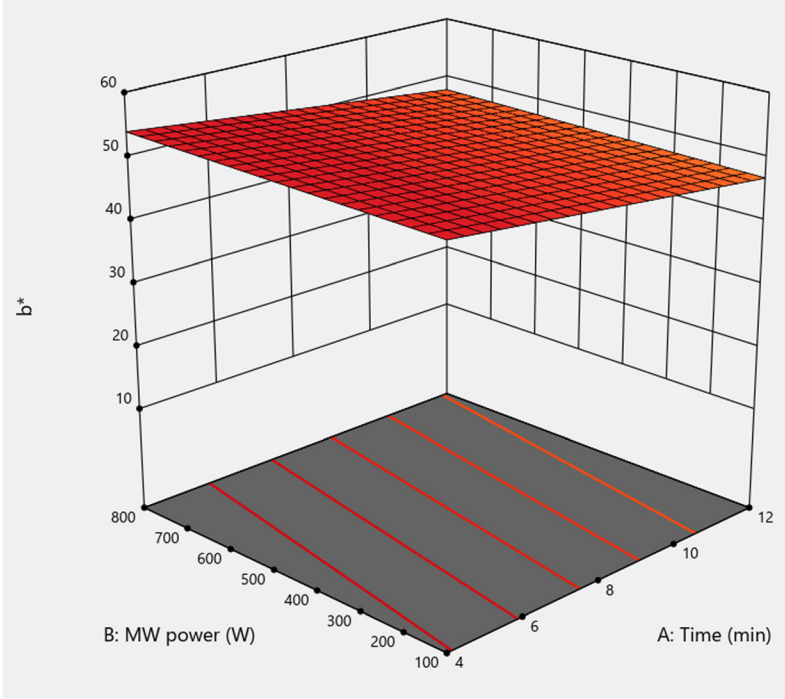

Fig. 5. Effect of microwave power (MW power, W) and time (Time, min) on b* (b*, rel. unit) component at 10 V/V % ethanol concentration

Since carotenoids are not considered polyphenols but have antioxidant capacity, this may cause a discrepancy between the two analytical measurements (Naranjo-Durán et al., 2023).

The solvent concentration has a negative effect on the model, i.e. the yield, for several measurements (TPC, a*, b*, L*). From this analysis, it can be concluded that while ethanol is a good solvent it can enhance the yield of some molecules, but can also degrade the structure of many bioactive components. These bioactive components are frequently sensitive and relatively unstable molecules, thus reducing the yield in the extract. Boussetta et al. (2012) also found that polyphenols are less extracted with pure ethanol than with an ethanol–water mixture. Consequently, although the AC value increased with increasing the alcohol content, the other values decreased to a level where the optimization resulted in an alcohol content around the minimum for almost all solutions.

The method was optimized to maximize TPC, AC, a* and b* values, and minimize L*. The optimal option, which maximizes the yield from each component is as follows: $t = 12$ min; $P = 800$ W; $c = 10$ V/V %. The resulting yield would be as follow: TPC = 153 mg L^{-1}; AC = 497 mg L^{-1}; L* = 74.0; a* = 8.9; b* = 48.

From an energetical point of view, a method to reduce microwave power consumption was also investigated, the results of which are presented as follow: $t = 12$ min; $P = 526$ W; $c = 10$ V/V %; yield: The TPC was found to be 152 mg L^{-1}; the AC was 438 mg L^{-1} and the L* was 75.4; the a* was 8.13 and the b* was 47.6.

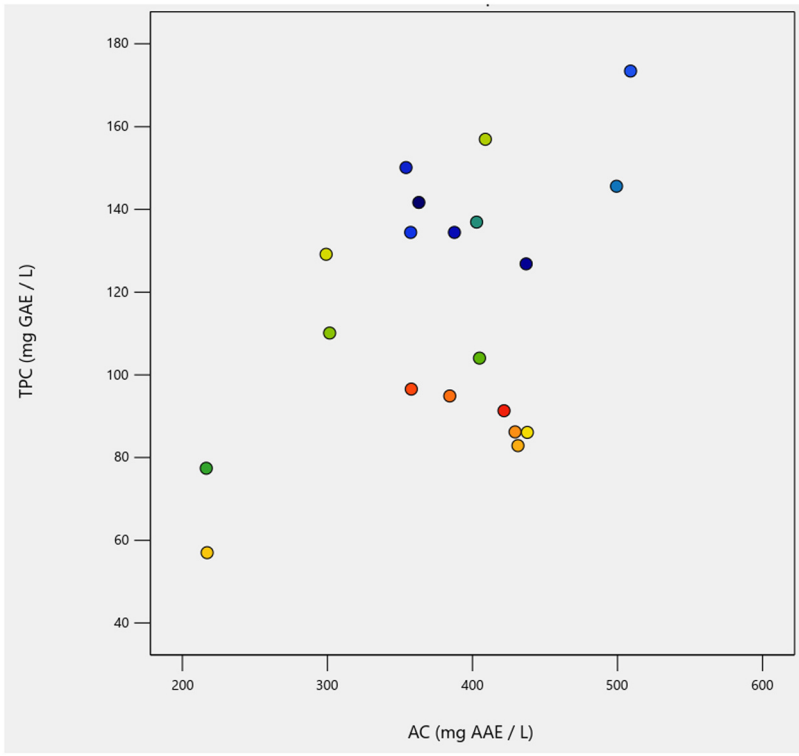

Fig. 6. Correlation between AC and TPC concentrations

It is important to note that this adjustment will result in a 7.65 % decrease in the expected results for AC and a 5.6 % decrease for a^*. The reduction in the other values is negligible (L^* reduced by 1.22 %, TPC reduced by 0.65 % and b^* reduced by 0.62 %). This trade-off can be made in exchange for a 22 % reduction in total power consumed.

CONCLUSIONS

The problem of food waste is a significant global challenge these days. The processing of fruits and vegetables is responsible for generating significant quantities of food waste, which is due to the removal of a layer of flesh during the peeling process. This flesh, in many cases, could still be of use. In this research, the focus was on the extraction of the peeled skin of carrots.

The primary objective of this study was the extraction of polyphenols and carotenoids. However, it was also important to minimize the use of chemicals. The extraction process was performed using ethanol and microwave treatment was applied to assist with the extraction process. The CCD statistical method was used with three variables at low and high levels and at the center point: treatment time (4–8–12 min), microwave power (100–450–800 W) and ethanol concentration (10–35–60 V/V %).

The total polyphenol content (TPC) was determined using the Folin–Ciocalteu method, while the antioxidant capacity (AC) was measured using the FRAP method. The carotenoids were determined using colorimetry. Additionally, it should be noted that this method does not determine the exact value of carotenoids, only the ratios.

The application of ANOVA analysis with 95% confidence intervals showed that all models were significant for the parameters that were tested. Different settings for different components proved to be effective, but the proposed setting for the overall optimization was also economically efficient: $t = 12$ min; $P = 624$ W; $c = 10\%$. The resulting yields were as follows: TPC = 152 mg L^{-1}; AC = 459 mg L^{-1}; $L^* = 74.9$; $a^* = 8.4$; $b^* = 47.7$.

In future experiments, the results of this study will be utilized to either reduce the concentration of ethanol or to investigate the possible use of other solvents, even by reducing the solvent ratio. This extraction process has been demonstrated to be a valuable tool for obtaining substances that can potentially be used as functional food ingredients in the future.

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REFERENCES

Ahmad, T., Cawood, M., Iqbal, Q., Ariño, A., Batool, A., Tariq, R.M.S., Azam, M., and Akhtar, S. (2019). Phytochemicals in Daucus carota and their health benefits—review article. *Foods*, 8: 424, https://doi.org/10.3390/foods8090424

Antolak, H. and Kregiel, D. (2017). Food preservatives from plants. *Food additives*, InTech, https://doi.org/10.5772/intechopen.70090

Aspé, E. and Fernández, K. (2011). The effect of different extraction techniques on extraction yield, total phenolic, and anti-radical capacity of extracts from Pinus radiata Bark. *Industrial Crops and Products*, 34(2011): 838–844, https://doi.org/10.1016/J.INDCROP.2011.02.002

Bayuo, J., Abukari, M.A., and Pelig-Ba, K.B. (2020). Optimization using central composite design (CCD) of response surface methodology (RSM) for biosorption of hexavalent chromium from aqueous media. *Applied Water Science*, 10: 135, https://doi.org/10.1007/s13201-020-01213-3

Benzie, I.F.F. and Strain, J.J. (1996). The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay. *Analytical Biochemistry*, 239(1): 70–76, https://doi.org/10.1006/ABIO.1996.0292

Blancquaert, D., Storozhenko, S., Loizeau, K., De Steur, H., De Brouwer, V., Viaene, J., Ravanel, S., Rébeillé, F., Lambert, W., and Van Der Straeten, D. (2010). Folates and folic acid: from fundamental research toward sustainable health. *Critical Reviews in Plant Science*, 29: 14–35, https://doi.org/10.1080/07352680903436283

Boussetta, N., Vorobiev, E., Le, L.H., Cordin-Falcimaigne, A., and Lanoisellé, J.-L. (2012). Application of electrical treatments in alcoholic solvent for polyphenols extraction from grape seeds. *LWT - Food Science and Technology*, 46(1): 127–134, https://doi.org/10.1016/j.lwt.2011.10.016

Ganzler, K., Salgó, A., and Valkó, K. (1986). Microwave extraction: a novel sample preparation method for chromatography. *Journal of Chromatography A*, 371: 299–306.

Gonelimali, F., Szabó-Nótin, B., and Máté, M. (2023). Purification of the apple pomace polyphenol extract using adsorbent resin. *Progress in Agricultural Engineering Sciences*, 19(S1), https://doi.org/10.1556/446.2023.00087

Hariadi, H., Riana, A., Hidayat Rahmawati, L., Quddus, A.A., Danggi, E., and Judiono (2023). Physico-chemical properties of carrot (Daucus carota L.) milk produce from rotary extraction. *Food Science and Technology (Brazil)*.

Internet 1, Available at: https://support.microsoft.com/hu-hu/office/adatok-kiemel%C3%A9se-felt%C3%A9teles-form%C3%A1z%C3%A1ssal-az-excelben-fed60dfa-1d3f-4e13-9ecb-f1951ff89d7f.

Internet 2, Available at: https://www.statease.com/docs/v25.0/right-click-help/anova/anova-adj-rsquared/.

Kaur, P., Subramanian, J., and Singh, A. (2022). Green extraction of bioactive components from carrot industry waste and evaluation of spent residue as an energy source. *Scientific Reports*, 12: 16607, https://doi.org/10.1038/s41598-022-20971-5

Kennedy-Shaffer, L. (2019). Before $p < 0.05$ to beyond $p < 0.05$: using history to contextualize p-values and significance testing. *The American Statistician*, 73(S1): 82–90, Statistical Inference in the 21st Century, https://doi.org/10.1080/00031305.2018.1537891

Liu, R.H. (2013). Dietary bioactive compounds and their health implications. *Journal of Food Science*, 78(Suppl. 1): A18–A25, https://doi.org/10.1111/1750-3841.12101

Mao, Y., Robinson, J., and Binner, E. (2021). Understanding heat and mass transfer processes during microwave-assisted and conventional solvent extraction. *Chemical Engineering Science*, 233(6 April 2021): 116418, https://doi.org/10.1016/j.ces.2020.116418

Melikoglu, M., Sze Ki Lin, C., and Webb, C. (2013). Analysing global food waste problem: pinpointing the facts and estimating the energy content. *Central European Journal of Engineering*, 3(2): 157–164, https://doi.org/10.2478/s13531-012-0058-5

Myers, R.H., Montgomery, D.C., and Anderson-Cook, C.M. (2016). *Response surface methodology: process and product optimization using designed experiments*, 4th ed. Wiley.

Naranjo-Durán, A.M., Quintero-Quiroz, J., Ciro-Gómez, G.L., Barona-Acevedo, M.-J., and Contreras-Calderón, J.de C. (2023). Characterization of the antioxidant activity, carotenoid profile by HPLC-MS of exotic Colombian fruits (goldenberry and purple passion fruit) and optimization of antioxidant activity of this fruit blend. *Heliyon*, 9(7): e17819, https://doi.org/10.1016/j.heliyon.2023.e17819

Park, H.Y., Hong, J.W., Kim, J.H., Kim, Y.H., and Kim, J.W. (2023). Optimization of ultrasound-assisted extraction conditions for extraction of bioactive compounds from purple carrot (*Daucus carota L.*) using response surface methodology. *Food Science and Technology*, 43, https://doi.org/10.1590/fst.000523

Singleton, V.L. and Rossi, J.A. (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture*, 16: 144–158, https://doi.org/10.5344/ajev.1965.16.3.144

Umair, M., Jabbar, S., Nasiru, M.M., Lu, Z., Zhang, J., Abid, M., Murtaza, M.A., Kieliszek, M., and Zhao, L. (2021). Ultrasound-assisted extraction of carotenoids from carrot pomace and their optimization through response surface methodology. *Molecules*, 26: 6763, https://doi.org/10.3390/molecules26226763

Zin, M.M., Borda, F., Márki, E., and Bánvölgyi, Sz (2021). Betalains, total polyphenols, and antioxidant contents in red beetroot peel (Cylindra type). *Progress in Agricultural Engineering Sciences*, 16(S2), https://doi.org/10.1556/446.2020.20004