Effect of hot air drying temperatures on drying characteristics and physicochemical properties of beetroot (Beta vulgaris) slices

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Abstract: The objective of this study was to investigate the influence of hot air drying temperatures ranging from 50 to 100 °C on the drying characteristics and physicochemical properties of beetroot slices. The results showed that by increasing temperatures from 50 to 100 °C, the drying time could be from 12.5 to 4.5 h, which could significantly increase the drying rate. The beetroot slices dried at 60 °C showed the smallest total color difference compared with fresh beetroot slices. The betalain content (betacyanin and betaxanthin) of beetroot slices decreased with the increase of drying temperatures, and betacyanin was more temperature sensitive than betaxanthin. The total phenol content and antioxidant capacity had the same trend with drying temperatures, and both reached to the maximum at 100 °C.

1. Introduction

Beetroots (Beta vulgaris) have attracted significantly attention as a functional food that promotes health. This scientific interest has arisen because of its various nutrients. Beetroot is rich in valuable active compounds, such as betalains, glycine betaine, polyphenols, betacyanins, nitrates, flavonoids, saponins, vitamins, carotenoids, minerals, folates, and ascorbic acids.[1-2]

Betalains in beetroots are composed of red-purple betacyanins (such as betanin and isobetanin) and yellow-orange betaxanthins (such as vulgaxanthin and miraxanthin), which have beneficial effects on human health, including stimulating the hematopoietic system and immune system, antitumor, antiinflammatory, and hepatoprotective properties.[3] It is usually used to enhance the color of jam, tomato paste, jellies, desserts, candies, ice cream, sauces and breakfast cereals. [4] Nowadays, because of the health benefits of natural colorants, many people prefer natural colorants to synthetic ones. Therefore, it is recommended that beetroot powder can be used to take the place of synthetic colorants in food products.[5] Fresh beetroots have high moisture content and cannot be stored for a long time. Drying is one of most useful preservation methods to ensure microbial safety of products.

Hot air drying is one of the most widely used drying methods. It has many advantages, such as high drying efficiency, easy operation, low cost, and low environmental requirements. There are not much research on the effect of different hot air drying temperatures on drying characteristics and physicochemical properties of beetroot slices. Therefore, the main objective of this study was to investigate the influence of hot air drying temperatures on drying characteristics and physicochemical
properties in hot air drying of beetroot slices. For this purpose, the drying rate curve, color, content of betalains and total phenols, and antioxidant capacity of beetroot slices dried at different drying temperatures were evaluated.

2. Materials and Methods

2.1. Sample Preparation
The fresh beetroots (Beta vulgaris) were purchased from the local vegetable market in the city of Xuzhou in Jiangsu Province, China and stored at 4 ℃ until use. Beetroots were washed with cold tap water and peeled by stainless steel knives. The peeled beetroots were sliced into 5 mm slices and the slices were spread evenly in a tray (dimension, 600×500 mm). The average weight of the fresh beetroot slices was 800.0 ± 2.0 g. The hot air tray dryer (DHG-9245A, Shanghai Yiheng Scientific Instrument Co., Ltd, Shanghai, China) was preheated for 0.5 h to reach the set temperature. The loss of moisture was quickly determined by a laboratory electronic balance (JJ1000, G&G Measurement plant, Changshou, China) every half an hour. Moisture content of beetroot slices was estimated by a moisture analyzer (MA150, Sartorius Group, Germany) and was expressed on dry basis (g water/g dry solid). The initial moisture content of beetroot slices was 10.7 ± 0.2 g/g and samples were dried till the moisture content reduced to about 0.03 g/g. Drying experiments were carried out at various hot air drying temperatures (50–100 ℃).

2.2. Drying Characteristics
The moisture content was expressed as dry basis moisture content (gram water per gram dry solid).

\[
M'_t = \frac{m_t - m}{m}
\]

Where, \(M'_t\) is the dry basis moisture content of the sample at a given time, g·g\(^{-1}\); \(m_t\) is the weight of the sample at a given time, g; \(m\) is the absolute dry weight of the sample, g.

Drying rate refers to the change in the moisture content of the material per unit time under certain drying conditions. It is an important parameter for the study of drying characteristics and reflects the degree of dehydration of the material during the drying process. The drying rate was calculated with equation (2).

\[
DR = \frac{M_t - M_{t+\Delta t}}{\Delta t}
\]

Where, \(DR\) is the drying rate, g·g\(^{-1}\)·h\(^{-1}\); \(M_{t+\Delta t}\) and \(M_t\) are the dry basis moisture content of the sample at \(t+\Delta t\) and \(t\), respectively, g·g\(^{-1}\); \(\Delta t\) is the time difference between two consecutive measurements, h.

2.3. Color Measurement
Color of beetroot slices was measured on a Hunter Lab scale (\(L, a, b\)) using the colorimeter (CR-400, Konica Minolta, Japan). Value of “\(L\)” indicates degree of brightness, (+) value of “\(a\)” is redness and (-) is greenness whereas (+) \(b\) indicates yellowness and (-) \(b\) is blueness.[6]

One of the most important qualitative parameters of a sample is the total color change (\(\Delta E\)) of the dried sample relative to the fresh one. \(\Delta E\) was calculated with equation (3).

\[
\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2}
\]

Where, \(L, a, b\) are the values of dried beetroot slices, \(L_0, a_0, b_0\) are the values of fresh beetroot slices.

2.4. Extraction
Dried beetroot slices obtained from triplicate were mixed and then ground into powders to obtain samples with representative chemical components for particular drying conditions. 1.0 g of beetroot
power sample was placed in a centrifuge tube, and 20 mL distilled water was added, then mixed by a vortex mixer (VORTEX-5 Kylin-Bell Instrument Manufacturing Co., Ltd, Jiangsu, China). The homogeneous mixture was centrifuged at 5500 rpm for 15 min using a centrifuge (H1850, Xiangyi Centrifuge Instrument Co., Ltd, Hunan, China). The supernatant was collected and the insoluble part was extracted with 10 mL distilled water two more times. The supernatants were combined and brought up to a volume of 50 mL with distilled water. The supernatants were stored in the dark at 4 °C until further analysis.

2.5. Betalain Analyses
Betalains of beetroots were calculated according to betanin and vulgaxanthin-I, respectively. The supernatants were diluted with 0.05 M phosphate buffer (pH 6.5) so that the absorbance of the samples at 538 nm were between 0.4 and 0.5 AU. The absorbance of the samples was measured at 476 nm, 538 nm, and 600 nm, and the corrected absorbance of betanin and vulgaxanthin-I were calculated according to von Elbe.\(^7\)

\[
\begin{align*}
x &= 1.095 \times (a - c) \\
z &= a - x \\
y &= b - z - \frac{x}{3.1}
\end{align*}
\]

Where, \(a\) is absorbance of the sample at 538 nm, \(b\) is absorbance of the sample at 476 nm, and \(c\) is absorbance of the sample at 600 nm. \(\chi\) is absorbance of betanin minus colored impurities, \(z\) is absorbance of impurities, \(y\) is absorbance of vulgaxanthin minus contribution of betanin and colored impurities.

2.6. Determination of total phenolic content
The total phenolic content (TPC) of beetroot slices was determined by the Folin-Ciocalteu method as described by Emilio et al.\(^8\) Diluted sample extracts (0.5 mL) were mixed with 2.5 mL of 10% Folin-Ciocalteu’s reagent (v/v), and then 2 mL of 7.5% sodium carbonate (w/v) was added. The mixture was incubated for 15 min at 50 °C, and the absorbance was recorded at 760 nm using a visible spectrophotometer (722N, Precision Scientific Instruments Co., Ltd, Shanghai, China). Using gallic acid as the standard, the total phenolic content of beetroot slices was calculated according to the calibration curve. Total phenolic content was expressed as mg of gallic acid equivalent (GAE) per g of dry weight (dw).

2.7. Evaluation of Antioxidant capacity by DPPH, ABTS and FRAP
Antioxidant capacity of beetroot slices was evaluated by three methods: free radical-scavenging activity by the DPPH method, total antioxidant activity by the ABTS method and ferric-reducing ability by the FRAP method. The selection of different methods could better understand the wide variety and range of action of antioxidant compounds in beetroots.\(^9\)

The DPPH assay was conducted according to the method of Brand-Williams et al.\(^10\) Diluted sample extracts (2 mL) were mixed with 4 mL of 0.1 mM DPPH solution for 30 s and reacted in the dark at room temperature for 30 min. The absorbance of the mixture at 517 nm was read. A calibration curve with Trolox at concentrations of 0–80 μmol/L was used. The results were expressed as milligram of Trolox (TE) equivalent per gram of dry weight ( mg TE/g dw).

The ABTS assay followed the method of Re\(^11\) with some modification. Equal quantities of 2.45 mM K_{2}S_{2}O_{8} solution and 7 mM ABTS were mixed to obtain ABTS\(^+\) solution. The ABTS\(^+\) solution was allowed to stand for 16 h at room temperature in the dark. Before measurement, the ABTS\(^+\) solution was diluted with 80 % ethanol to obtain an absorbance of 0.70 ± 0.02 at 734 nm. Diluted sample extracts (0.8 mL) were reacted with 7.2 mL diluted ABTS\(^+\) solution for 6 min at room temperature, then the absorbance of the mixture was measured at 734 nm. Trolox with concentration of 0–160 μmol/L was used as the standard curve. Results were expressed as mg TE/g dw.
The FRAP assay was determined according to Benzie et al.\textsuperscript{[12]} FRAP reagent was prepared by mixing 10 mM TPTZ solution in 40 mM HCl solution, 20 mM FeCl\textsubscript{3} solution and 0.3 M acetate buffer (pH 3.6) at the ratio of 1:1:10 (v/v/v). The FRAP reagent was incubated at 37 °C before use. The diluted sample extract (0.2 mL) was fully reacted with 6 mL of FRAP reagent. After incubating at 37 °C for 10 min, the absorbance at 593 nm was recorded. A calibration curve was obtained using different concentrations (0–600 μmol/L) of Trolox. All of these solutions were prepared on the day of analysis. The results were expressed as mg TE/g dw.

2.8. Statistical analysis

All the experiments were conducted at least in triplicate and results were expressed as means ± standard deviation (SD). The results were analyzed by analysis of variance (ANOVA), and the least significant difference (LSD) test (P < 0.05) was performed to determine the significant difference between the groups using SPSS Statistics Version 20 (IBM Corporation, Chicago, IL, USA). Origin 9.0 (Origin Lab, MA, USA) was used to draw figures.

3. Results and Discussion

3.1. drying characteristics

The changes of moisture content with drying time under different hot air drying temperatures are shown in Figure 1.

![Fig.1 Changes of moisture content with drying time under different hot air drying temperatures](image)

It can be seen from Figure 1 that the moisture content decreased with increasing drying time. The higher of drying temperature of the sample, the shorter of drying time for drying the sample to a certain moisture content. In fact, the drying air temperature has an obvious effect on the moisture content, and the high temperature will lead to more loss of moisture content, thus shortening the drying time. This may be due to the increased heat transfer between the sample and the air temperature, resulting in the rapid removal of moisture from the sample.\textsuperscript{[13]} Moisture content decreased from 10.7 to 0.03 g·g\textsuperscript{-1} at all the hot air drying temperatures where the drying time decreased from 12.5 to 4.5 h. The drying time at 50 °C was 12.5 h, while the drying time at 100 °C was reduced to 4.5 h. The drying time was shortened by 64% when the hot air drying temperature was increased from 50 to 100 °C.

The drying rate curves of beetroot slices are shown in Figure 2.
Fig. 2  Drying rate curves of beetroot slices at different hot air drying temperatures

It was observed from Figure 2 that different hot air drying temperatures had a great influence on the drying rate of beetroot slices. It was noticed that the drying rate increased with the increase of drying temperatures, and higher values of the drying rate were recorded at 100 °C. The drying rates were higher at the beginning of drying and then decreased. The drying rate was mainly in the falling rate period, which indicated that the moisture removal of beetroot slices in hot air drying was mainly controlled by diffusion.

3.2. Effect of hot air drying temperatures on color

The color parameters of beetroot slices are shown in Table 1. It can be observed that the variables L, a and b presented significant differences (p<0.05) among the different hot air drying temperatures. Meanwhile, L (lightness) values and b (yellowness) values were increased with the increase of hot air drying temperatures. Compared with the fresh beetroot slices, there was no significant difference (p ≥ 0.05) in the L value of the beetroot slices dried at 50 and 60 °C. Among the dried beetroot slices samples, the beetroot slices dried at 90°C exhibited the highest L value (49.81), while the beetroot slices dried at 50 °C showed the lowest L value (36.51).

Regarding a (redness), values ranged from 19.86 to 25.39, where the lowest a value was at 100 °C and the highest a value at 60 °C, while a values of the dried beetroot slices at 60 and 80 °C were slightly higher than the fresh beetroot slices, but the difference was not statistically significant (p ≥ 0.05), opposite of this, a values of the dried beetroot slices at 50, 70, 90 and 100 °C were significantly lower than the fresh beetroot slices.

The variable b ranged from 1.74 to 12.17. The increase in the value of b can be interpreted by the increase in yellowness of the beetroot slices after drying. The b values of the dried beetroot slices increased with the increase of drying temperatures. Compared with that of fresh beetroot slices, there was significant difference (p<0.05) in the b values under different hot air drying temperatures.

Table 1  Effect of different hot air drying temperatures on color parameters of beetroot slices

| Drying temperature (°C) | L       | a       | b       | ΔE      |
|------------------------|---------|---------|---------|---------|
| 50                     | 36.51 ± 1.18<sup>d</sup> | 23.29 ± 0.52<sup>c</sup> | 1.74 ± 0.27<sup>c</sup> | 1.89 ± 0.09<sup>c</sup> |
| 60                     | 37.23 ± 1.36<sup>d</sup> | 25.39 ± 0.98<sup>b</sup> | 2.78 ± 0.42<sup>d</sup> | 1.49 ± 0.05<sup>f</sup> |
| 70                     | 42.09 ± 0.97<sup>c</sup> | 22.78 ± 0.06<sup>c</sup> | 2.30 ± 0.08<sup>e</sup> | 5.58 ± 0.07<sup>d</sup> |
| 80                     | 46.29 ± 0.70<sup>b</sup> | 25.09 ± 0.85<sup>b</sup> | 6.81 ± 0.66<sup>c</sup> | 10.13 ± 0.08<sup>c</sup> |
| 90                     | 49.81 ± 1.02<sup>a</sup> | 22.74 ± 0.11<sup>c</sup> | 10.48 ± 0.24<sup>b</sup> | 14.87 ± 0.10<sup>a</sup> |
| 100                    | 46.63 ± 1.47<sup>b</sup> | 19.86 ± 0.70<sup>d</sup> | 12.17 ± 0.30<sup>a</sup> | 13.84 ± 0.16<sup>b</sup> |
| Fresh beetroot slices  | 36.79 ± 0.49<sup>d</sup> | 24.12 ± 0.30<sup>ab</sup> | 3.42 ± 0.59<sup>d</sup> | -       |
Notes: Values are means ± SD of triplicate samples. Means with different superscript letter in a column are significantly different according to LSD test (p < 0.05).

The statistical analysis of ΔE of the dried beetroot slices indicated that ΔE showed significant differences (p < 0.05) under different hot air drying temperatures. Beetroot slices dried at 60°C had the lowest ΔE, while beetroot slices dried at 100°C had the highest ΔE, where higher hot air drying temperature resulted in a larger ΔE value. As lower ΔE value is advantageous, the color of beetroot slices dried at 60 °C is the closest to the color of fresh beetroot slices.

3.3. Effect of hot air drying temperatures on betalain content

The main colorants in beetroot are betanin (betanin 5-O-glucoside), isobetanin (isobetanidin 5-O-glucoside), vulgaxanthin-I and -II and indicaxanthin.[14] It has been found that betacyanins in beetroots is composed of 75-95% betanin, while betaxanthin is composed of approximately 95% vulgaxanthin.[15-16] The betalain content of beetroot slices dried at different hot air drying temperatures were measured by betacyanin (reported as betanin) and betaxanthin (reported as vulgaxanthin) contents and are reported in Table 2.

| Table 2  Effect of different hot air drying temperatures on betalain content of beetroot slices |
|---------------------------------------------------------------|
| Drying temperature (℃) | mg betanin/g dry beetroot slices | mg vulgaxanthin/g dry beetroot slices |
|-------------------------|-------------------------------|-------------------------------------|
| 50                      | 284.50 ± 1.47a               | 193.01 ± 0.56a                      |
| 60                      | 210.69 ± 1.77b               | 174.67 ± 0.71b                      |
| 70                      | 170.11 ± 1.76c               | 137.30 ± 1.06d                      |
| 80                      | 136.59 ± 1.95d               | 135.46 ± 0.83e                      |
| 90                      | 95.13 ± 1.28e                | 127.85 ± 0.62f                      |
| 100                     | 76.63 ± 0.98f                | 146.70 ± 0.53c                      |

Notes: Values are means ± SD of triplicate samples. Means with different superscript letter in a column are significantly different according to LSD test (p < 0.05).

Betacyanins are heat labile compounds, there was significant difference in betanin content among beetroot slices dried at different drying temperatures. It was been found by Herbach[17] that betalain in beetroots can undergo various forms of degradation during heat treatment, including isomerization, decarboxylation, and cleavage by heat and acids.

Betacynin content of beetroot slices decreased significantly with the increase of drying temperature, ranged from 76.63 to 284.50 mg betanin/g dry beetroot slices. Betacyanin content was the highest (284.50 mg betanin/g dry beetroot slices) for beetroot slices at 50 °C, and the lowest for beetroot slices with 76.63 mg betanin/g dry beetroot slices at 100 °C. The betacyanin content was reduced by 73.07% when the drying temperature was increased from 50 to 100 °C.

Betaxanthin content of beetroot slices was also significant difference among samples dried at different temperatures. Betaxanthin content of beetroot slices decreased significantly with the increase of drying temperature in the range of 50 to 90 °C, ranging from 127.85 to 193.01 mg vulgaxanthin/g dry beetroot slices. The betaxanthin content was reduced by 33.76% when the drying temperature was increased from 40 to 90 °C. The betaxanthin content (146.70 mg vulgaxanthin/g dry beetroot slices) at 100 °C was similar to vacuum belt drying (147.3 mg vulgaxanthin/g dry beet, powder dried at 95 °C with 0.3 g MD/g DS) conduct by William.[18] which was slightly greater than the samples dried at 70, 80 and 90 °C, the possible reason was that when the drying temperature rose, betacyanin was converted into betaxanthin.[6] These findings confirm that betalains are sensitive at high temperatures and betacyanin is more temperature sensitive than betaxanthin.

3.4. Effect of hot air drying temperatures on total phenolic content and antioxidant capacity

The influence of hot air drying temperatures on the total phenolic content and antioxidant capacity of beetroot slices are shown in Table 3. The correlation between total phenolic content and antioxidant
capacity for the dried beetroot slices can be observed. It can be seen that with the increase of hot air drying temperature, the total phenol content and antioxidant capacity increased. The results showed that as the hot air drying temperature increased within 50 to 100 °C, the total phenolic content and antioxidant capacity both decreased first and then increased.

Total phenolic content was the lowest (8.17 mg GAE/g dw) at 70 °C, while total phenolic content reached the highest (13.81 mg GAE/g dw) at 100 °C. Meanwhile, the DPPH radical scavenging capacity was the lowest (7.26 mg TE/g dw) at 70 °C, the highest (10.88 mg TE/g dw) at 100 °C. The ABTS values and the FRAP values of beetroot slices were in exactly the same trend, that was the lowest activity at 60 °C and the highest activity at 100 °C. In short, beetroot slices dried at 100 °C had the highest total phenol content and antioxidant capacity.

### Table 3  Effect of different drying temperatures on total phenolic content and antioxidant capacity of beetroot slices

| Drying temperature (°C) | Total phenolic content (mg GAE/g dw) | DPPH (mg TE/g dw) | ABTS (mg TE/g dw) | FRAP (mg TE/g dw) |
|-------------------------|-------------------------------------|-------------------|-------------------|-------------------|
| 50                      | 10.52 ± 0.39<sup>c</sup>             | 8.45 ± 0.30<sup>c</sup> | 9.88 ± 0.28<sup>d</sup> | 11.61 ± 0.16<sup>c</sup> |
| 60                      | 9.35 ± 0.07<sup>d</sup>              | 7.84 ± 0.20<sup>d</sup> | 9.10 ± 0.11<sup>c</sup> | 9.78 ± 0.24<sup>d</sup> |
| 70                      | 8.17 ± 0.20<sup>e</sup>              | 7.26 ± 0.27<sup>f</sup> | 9.62 ± 0.24<sup>de</sup> | 10.15 ± 0.27<sup>e</sup> |
| 80                      | 10.74 ± 0.06<sup>c</sup>             | 8.30 ± 0.17<sup>cd</sup> | 12.01 ± 0.34<sup>c</sup> | 12.29 ± 0.39<sup>c</sup> |
| 90                      | 11.87 ± 0.14<sup>b</sup>             | 9.69 ± 0.32<sup>b</sup> | 17.39 ± 0.48<sup>b</sup> | 17.50 ± 0.47<sup>b</sup> |
| 100                     | 13.81 ± 0.13<sup>a</sup>             | 10.88 ± 0.41<sup>a</sup> | 20.45 ± 0.39<sup>a</sup> | 19.95 ± 0.42<sup>a</sup> |

Notes: Values are means ± SD of triplicate samples. Means with different superscript letter in a column are significantly different according to LSD test (p < 0.05).

### 4. Conclusions

Hot air drying temperature has a vital influence on the drying time. The moisture content of beetroot slices decreased exponentially with the drying time. The higher hot air drying temperature reduced the drying time. The drying rate was mainly in the falling rate period and was affected by hot air drying temperature. The color of the beetroot slices dried at 60 °C was the closest to the color of the fresh beetroot slices. Betalain content, total phenolic content and antioxidant capacity of beetroot slices depends on drying temperature. Betalains were sensitive at high hot air drying temperatures. The content of betacyanin and betaxanthin of beetroot slices decreased significantly with the increase of drying temperature from 50 to 90 °C, and betacyanin was more temperature sensitive than betaxanthin. The positive correlation between total phenolic content and antioxidant capacity of the dried beetroot slices at the same drying temperatures. The total phenol content and antioxidant capacity of beetroot slices dried at 100 °C were the highest.

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### References

[1] Lech, K., Figiel, A., Wojdyło, A., Korzeniowska, M., Serowik, M., Szarycz, M. (2015) Drying kinetics and bioactivity of beetroot slices pretreated in concentrated chokeberry juice and dried with vacuum microwaves. Drying Technol., 33(13): 1644–1653.

[2] Carolina, C.C., Cecilia, E.M.S., Jesús, R.M., José M.J.B., Roselis, C.G., Erasmo, H.L.(2020) Evaluation of the combined effect of osmotic and Refractance Window drying on the drying kinetics, physical, and phytochemical properties of beet. Drying Technol., 38(12):1663-1675.

[3] Kamiloglu, S., Grootaert C., Capanoglu E., Ozkan, C., Smaghe, G., Raes, K., Camp, J.V. (2017) Anti-inflammatory potential of black carrot (Daucus carota L) polyphenols in a co-culture
model of intestinal Caco-2 and endothelial EA.hy926 cells. Mol. Nutr. Food Res., 61(2): 1600455.

[4] Lim, T.K. (2016) Edible Medicinal and Non-Medicinal Plants: Modified Stems, Roots, Bulbs. Springer Netherlands, New York.

[5] Ng, M.L., Sulaiman, R. (2018) Development of beetroot (Beta vulgaris) powder using foam mat drying. LWT-Food Sci. Technol., 88: 80–86.

[6] Gokhale, S.V., Lele, S.S. (2014) Betalain content and antioxidant activity of Beta vulgaris: effect of hot air convective drying and storage. J. Food Process. Preserv., 38(1): 586–590.

[7] von Elbe, J.H. (2001) Betalains. Current Protocols in Food Analytical Chemistry., F3.1.1–F3.1.7.

[8] Emilio A.P., Laura A. de la R., Ryszard A., Fereidoon S. (2011) Antioxidant activity of fresh and processed jalapeño and serrano peppers. J. Agric. Food Chem., 59(1): 163–173.

[9] Vallespir, F., Carcel, J.A., Marra, F., Eim, V.S., Simal, S. (2018) Improvement of mass transfer by freezing pre-treatment and ultrasound application on the convective drying of beetroot (Beta vulgaris L.). Food Bioprocess Technol., 11(1): 72–83.

[10] Brand-Williams, W., Cuvelier, M.E., Berset, C. (1995) Use of a free radical method to evaluate antioxidant activity. LWT-Food Sci. Technol., 28: 25–30.

[11] Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M., Rice, E.C. (1999) Antioxidant activity applying an improved ABTS radical cation decolorization assay. Free Radic. Biol. Med., 26(9–10): 1231–1237.

[12] Benzie, I.F.F., Strain, J.J. (1996) The ferric reducing ability of plasma (FRAP) as a measure of “antioxidant power”: the FRAP assay. Anal. Biochem., 239(1): 70–76.

[13] Alara, O.R., Abdurahman, N.H., Olalere, O.A. (2019) Mathematical modelling and morphological properties of thin layer oven drying of Vernonia amygdalina leaves. J. Saudi Soc. Agric. Sci., 18(3): 309–315.

[14] Sekiguchi, H., Ozeki, Y., Sasaki, N. (2013) Biosynthesis and regulation of betalains in red beet. In: Neelwarne, B. (Ed.), Red Beet Biotechnology. Food and Pharmaceutical Aplications. Springer, Boston. pp. 45–54.

[15] Piatelli, M. (1981) The betalains: structure, biosynthesis, and chemical taxonomy. In: Stumpf, P.K., Conn, E.E. (Eds.), The biochemistry of plants: a comprehensive treatise. Academic Press, New York. pp. 557–575.

[16] Francis, F.J. (1999) Anthocyanins and betalains. In: Francis, F.J. (Ed.), Colorants. Eagen Press, St. Paul. pp. 280–309.

[17] Herbach, K.M., Stinzing, F.C., Carle, R. (2004) Impact of thermal treatment on color and pigment pattern of red beet (Beta vulgaris L.) preparations. J. Food Sci., 69(6), C491–C498.

[18] Kerr, W.L., Varner, A. (2019) Vacuum belt dehydration of chopped beetroot (Beta vulgaris) and optimization of powder production based on physical and chemical properties. Food Bioprocess Technol., 12(12): 2036–2049.