Journal of Chemistry and Technologies, 2021, *29*(4), 589-598

Journal of Chemistry and Technologies

pISSN 2663-2934 (Print), ISSN 2663-2942 (Online).

journal homepage: http://chemistry.dnu.dp.ua

UDC 664.834.1

EFFECT OF HEAT PUMP TEMPERATURE ON THE PHYSICAL PROPERTIES, BIOACTIVE COMPOUNDS AND ANTIOXIDANT CAPACITY OF BEETROOTS

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Received 22 September 2021; accepted 12 November 2021; available online 22 January 2022

Abstract

Beetroot is a widely consumed vegetable in the world. However, it is easily dehydrated and perishable, causing great waste and financial losses. Heat pump drying is an efficient and low-cost method, widely used in temperature sensitive vegetables and fruits processing to produce new products and extend the shelf life of food. The purpose of this study was to investigate the influence of heat pump drying temperatures ranging from 45 to 65°C on the physical properties, bioactive compounds and antioxidant capacity of dried beetroots. The results showed that increasing heat pump drying temperature from 45 to 65°C could significantly decrease drying time and rehydration ratio of dried beetroots ($p < 0.05$). The beetroots dried at 50°C showed the smallest total color difference (ΔE) in comparison to freeze-dried beetroots, and there was no significant effect on the ΔE of beetroots dried at different drying temperatures ($p > 0.05$). The content of bioactive compounds in dried beetroots, including betacyanin, betaxanthin, ascorbic acid, total phenolic and total flavonoid, all increased with increasing of drying temperatures from 45 to 65°C and showed the highest values at 65°C. Beside this, the 2,2′-azino-bis-(3-ethylbenzthiazoline-6-sulfonic acid) (ABTS) radical scavenging ability and ferric reducing antioxidant power (FRAP) values of dried beetroots had the same tendencies with drying temperature, significantly increased with drying temperature and both reached the maximum values at 65°C. However, the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging ability decreased significantly with the increase of drying temperature ($p < 0.05$). As to bioactive compounds and antioxidant capacity of dried beetroots, it is considered that 65°C is the optimal temperature for heat pump drying of beetroots.

Keywords: *beetroot; heat pump drying; betalain; rehydration ratio; total flavonoid; antioxidant capacity*

ВПЛИВ ТЕМПЕРАТУРИ ТЕПЛОВОГО НАСОСУ НА ФІЗИЧНІ ВЛАСТИВОСТІ, БІОАКТИВНІ СПОЛУКИ І АНТИОКСИДАНТНУ ЗДАТНІСТЬ БУРЯКІВ

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Анотація

Буряк – широко споживаний овоч у світі. Однак він легко зневоднюється і швидко псується, що призводить до великих втрат та фінансових витрат. Сушіння тепловим насосом є ефективним і недорогим методом, що широко використовується при переробці чутливих до температури овочів та фруктів для виробництва нових продуктів та продовження терміну придатності продуктів харчування. Метою даного дослідження було вивчення впливу температури сушіння тепловим насосом у діапазоні від 45 до 65°C на фізичні властивості, біологічно активні сполуки та антиоксидантну здатність сушених буряків. Результати показали, що підвищення температури сушіння тепловим насосом з 45 до 65°C може значно скоротити час сушіння та коефіцієнт регідратації висушеного буряка ($p < 0,05$). Буряк, висушений при 50°C, показав найменшу загальну різницю в кольорі (ΔE) порівняно з ліофілізованим буряком, і не було значного впливу на ΔE буряків, висушених при різних температурах сушіння ($p > 0,05$). Вміст біоактивних сполук у висушеному буряку, у тому числі бетаціаніну, бетаксантину, аскорбінової кислоти, суми фенолів та суми флавоноїдів, збільшувалося з підвищенням температури сушіння від 45 до 65°C і досягало найбільших значень при 65°C. Крім того, здатність висушеного буряка поглинати радикали 2,2'-азино-біс-(3-етилбензтіазолін-6-сульфонової кислоти) (ABTS) та антиоксидантна здатність відновлення заліза (FRAP) мали ті ж тенденції залежно від температури сушіння, що значно збільшується з температурою сушіння і обидва досягають максимальних значень при 65°C. Однак здатність 2,2-дифеніл-1-пікрилгідразил (DPPH) поглинати радикали значно знижувалася з підвищенням температури сушіння ($p < 0,05$). Що стосується біологічно активних сполук та антиоксидантної здатності сушених буряків, то вважається, що 65°C є оптимальною температурою для сушіння буряків тепловим насосом.

Ключові слова: *буряк; сушіння тепловим насосом; беталаїн; коефіцієнт регідратації; загальний флавоноїд; антиоксидантна здатність.*

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doi: 10.15421/jchemtech.v29i4.240470

Journal of Chemistry and Technologies, 2021, *29*(4), 589-598

ВЛИЯНИЕ ТЕМПЕРАТУРЫ ТЕПЛОВОГО НАСОСА НА ФИЗИЧЕСКИЕ СВОЙСТВА, БИОАКТИВНЫЕ СОЕДИНЕНИЯ И АНТИОКСИДАНТНУЮ СПОСОБНОСТЬ СВЕКЛЫ

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Аннотация

Свекла – широко потребляемый овощ в мире. Однако он легко обезвоживается и скоропортится, что приводит к большим потерям и финансовым потерям. Сушка тепловым насосом является эффективным и недорогим методом, широко используемым при переработке чувствительных к температуре овощей и фруктов для производства новых продуктов и продления срока годности продуктов питания. Целью данного исследования было изучение влияния температуры сушки тепловым насосом в диапазоне от 45 до 65°C на физические свойства, биологически активные соединения и антиоксидантную способность сушеной свеклы. Результаты показали, что повышение температуры сушки тепловым насосом с 45 до 65°C может значительно сократить время сушки и коэффициент регидратации высушенной свеклы ($p < 0,05$). Свекла, высушенная при 50°C, показала наименьшую общую разницу в цвете (ΔE) по сравнению с лиофилизированной свеклой, и не было значительного влияния на ΔE свеклы, высушенной при разных температурах сушки ($p > 0,05$). Содержание биоактивных соединений в высушенной свекле, в том числе бетацианина, бетаксантина, аскорбиновой кислоты, суммы фенолов и суммы флавоноидов, увеличивалось с повышением температуры сушки от 45 до 65°C и достигало наибольших значений при 65°C. Кроме того, способность высушенной свеклы поглощать радикалы 2,2'-азино-бис-(3-этилбензтиазолин-6-сульфоновой кислоты) (ABTS) и антиоксидантная способность восстановления железа (FRAP) имели те же тенденции в зависимости от температуры сушки, что значительно увеличивается с температурой сушки, и оба достигают максимальных значений при 65°C. Однако способность 2,2-дифенил-1-пикрилгидразил (DPPH) поглощать радикалы значительно снижалась с повышением температуры сушки ($p < 0,05$). Что касается биологически активных соединений и антиоксидантной способности сушеной свеклы, то считается, что 65°C является оптимальной температурой для сушки свеклы тепловым насосом.

Ключевые слова: *свекла; сушка тепловым насосом; беталаин; коэффициент регидратации; общий флавоноид; антиоксидантная способность.*

Introduction

Beetroot (*Beta vulgaris* L.) has attracted a significant amount of scientific interests due to its abundant bioactive compounds, such as betalains, nitrates, phenolics, flavonoids, carotenoids, vitamins, minerals, and ascorbic acids, which are beneficial for human health [1]. It has been reported that bioactive compounds (betalains, phenolics, ascorbic acids, flavonoids) in beetroots display antioxidative, anticancer, anti-inflammation, antidiabetic, blood pressure and lipid lowering, antiviral, anti-obesity and immunomodulatory activities [2]. Nowadays, beetroot is cultivated in many countries in the world, and it is often consumed in our daily life. Beetroot can be consumed not only in the form of fresh vegetable, but also can be processed to acquire frozen or desiccated products [3]. In the past few years, especially in the United States and European countries, the consumption of beetroot in the pretreatment market has increased significantly due to its good taste and high nutritional value. Beetroots are widely used as food colorant or addition in food products, such as yogurts, ice cream and other products, which can improve the redness in soups, jams, desserts, sauces, tomato pastes, jellies, sweets and breakfast cereals [4]. Beetroot is also an important precursor of bioactive components, especially betalains [5].

It is known that drying is an effective method for preserving the quality of vegetables and fruits and it works by applying heat to remove moisture [6], which plays a vital role in prolonging shelf life of fresh perishable foods, reducing packaging costs as well as the weight of transportation [7]. Heat pump drying (HPD) can improve the energy efficiency and independently control the drying temperature and air humidity, which is especially suitable for the heat-sensitive vegetables and fruits as drying can occur at a low temperature. In recent years, some scholars have studied the heat pump drying of apple, ginger, tomato, cocoa, grape and other fruits and vegetables [8-12]. According to various studies, color and flavor quality of agricultural products dried by HPD system were better than those dried by the conventional hot air dryer.

During heat pump drying process the bioactive compounds and antioxidant capacity of beetroot might be lost. The heat pump drying temperature is one of the principal parameters of the process since it influences the physicochemical properties and antioxidant activity of dried products. Therefore, it is important to study different heat pump drying temperatures to determine the best drying condition for dried beetroots, to optimize the drying process and properties. There are few researches studying the effect of different heat

pump drying temperatures on the physical properties, bioactive compounds and antioxidant capacity of dried beetroots. Therefore, the object of this study was to investigate the influence of various heat pump drying temperatures ranging from 45 to 65°C on the quality attributes of beetroots. Color, rehydration ratio, contents of betalain, total phenolic, total flavonoid and ascorbic acid, and antioxidant capacity of dried beetroots were determined.

Materials and Methods

Materials. Fresh beetroots (*Beta vulgaris* L.) were got from a market in the city of Xuzhou in Jiangsu Province, China. They were washed and rinsed by running water to remove impurities. The washed beetroots were peeled and cut transversely with a vegetable slicer, chopped into slices with 5 mm in thickness.

Heat pump drying process. Beetroot slices were arranged in a thin layer in a polyethylene tray (610 mm × 430 mm × 50 mm) with a load density of 2.0 kg/m^2. The tray was placed to a heat pump dryer (L3.5AB, Guangdong IKE Industrial Co. Ltd, China). The average initial moisture content of fresh beetroots was 90.1 % (wet basis). The drying process was carried out at the heat pump temperature of 45, 50, 55, 60, and 65°C, respectively. The drying process stopped when the final moisture content of dried beetroots fell below 7.0 % (wet basis).

Color measurement. Color of dried beetroots was measured on a Hunter Lab scale (*L*, *a*, *b*) using a colorimeter (CR-400, Konica Minolta, Japan). *L* value represents the brightness, *a* value refers to the area ranging from green (-*a*) to red (+*a*). The *b* parameter refers to the area ranging from blue (-*b*) to yellow (+*b*). Chroma (*C*) represents color saturation. Values of hue angle (*H*°) range from 0° (red), 90° (yellow), 180° (green) to 270° (blue). Total color change (Δ*E*) indicates the magnitude of color changing. *C*, *H*° and Δ*E* had been calculated by equations (1)-(3) as it was described by García-Toledo et al [13].

$$C = \sqrt{a^2 + b^2} \quad (1)$$

$$H^\circ = \tan^{-1}\left(\frac{b}{a}\right) \quad (2)$$

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2} \quad (3)$$

where: *L*, *a*, *b* are the values of dried beetroots obtained at different heat pump drying temperatures; L_0, a_0, b_0 are the values of freeze-dried beetroots.

Rehydration ratio. Five grams of dried beetroots had been placed into a beaker with 100 ml of distilled water; then this was kept at the temperature of 40°C for 2 h [14]. The rehydrated beetroots were taken out; the surface water was absorbed with absorbent papers, and then weighed. Rehydration ratio was calculated according to equation (4).

$$RR = \frac{m_2}{m_1}, \quad (4)$$

where: *RR* is the rehydration ratio; m_1 is the mass of dried beetroots, g; m_2 is the mass of beetroots after rehydration, g.

Extraction technique. Dried beetroots obtained in triplicate had been mixed, grounded into powder and passed through a 60-mesh sieve to get the samples with representative chemical components for particular drying temperatures. 1.0 g of beetroot powder was placed in a 50-mL centrifuge tube, and 50 % ethanol (v/v) was added; then this was mixed for 2 min with a vortex mixer (VORTEX-5 Kylin-Bell Instrument Manufacturing Co., Ltd, Jiangsu, China). After centrifugation using a centrifuge (H1850, Xiangyi Centrifuge Instrument Co., Ltd, Hunan, China) at 5500 rpm for 10 min, the supernatant was collected and the sample residue was extracted twice with 20 ml of 50 % ethanol (v/v). The combined extracts were adjusted to 100 ml with 50 % ethanol (v/v). The extracts were stored at 4°C until further analysis.

Betalains analyses. Betalains are natural water-soluble pigments containing nitrogen, which are subdivided into betacyanins (red-violet pigments) and betaxanthins (yellow-orange pigments) [15]. The betalain content of dried beetroots was determined according to the method of Stintzing et al [16]. The extracts were diluted with 0.05 mol/l phosphate buffer solution (pH 6.5) to obtain absorption values of 0.8≤ A_{538} ≤1.0 at 538 nm using a visible spectrophotometer (722N, Precision Scientific Instruments Co., Ltd, Shanghai, China). The betalain content (BC) was calculated as it was described according to equation (5).

$$BC(mg/L) = \frac{(A_{538}/A_{480} - A_{600}) \times DF \times MW \times 1000}{\varepsilon \times l} \quad (5)$$

where: A_{480}, A_{538} and A_{600} are the absorption values of diluted extracts at 480 nm, 538 nm and 600 nm, correspondingly. *DF* is the dilution factor, and l is the path length (1 cm) of the cuvette. For quantification of betacyanins and betaxanthins, the molecular weights (*MW*) and molar extinction coefficients (ε) of betanin (*MW* = 550 g/mol; ε = 60000 L/(mol cm) in H_2O; λ = 538 nm) and indicaxanthin (*MW* = 308 g/mol; ε = 48000 L/(mol cm) in H_2O; λ = 480 nm) were applied. The betalain content was expressed as milligram betanin equivalent per milliliter (mg BE/L) for betacyanins and milligram indicaxantin equivalent per milliliter (mg IE/L) for betaxanthins.

Determination of ascorbic acid content. Ascorbic acid content of dried beetroots was determined by spectrophotometry in Fe(II)-Phenanthroline-BPR system described by Huang et al [17]. Data were calculated on dry weight and expressed as milligram per gram (mg/g dw).

Determination of total phenolic content. The total phenolic content (TPC) of dried beetroots was determined by the Folin-Ciocalteu method as it was described by Alvarez-Parrilla et al [18]. Diluted sample extract (0.5 ml) was 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 at 50°C for 15 min, and the absorbance was recorded at 760 nm. Using gallic acid as the standard, the total phenolic content of dried beetroots was calculated according to the calibration curve with gallic acid at concentrations of 0–0.1 mg/ml. Total phenolic content was expressed as milligram gallic acid equivalent per gram of dry weight (mg GAE/g dw).

Determination of total flavonoid content. The total flavonoid content of dried beetroots was determined using a modified colorimetric method described by Jia et al [19]. Diluted sample extract (0.5 ml) was mixed with 30 ml of 5 % $NaNO_2$ solution (w/v); then it was allowed staying for 5 min. Thereafter, 30 ml of 10 % $AlCl_3$ solution (w/v) was added and mixed for 6 min. Then, 0.4 ml of 1.0 M NaOH and 40 ml of distilled water was added. The mixture was allowed staying at room temperature for 15 min. The absorbance was measured at 502 nm. Total flavonoid content was expressed as milligram catechin equivalent per gram of dry weight (mg CE/g dw) based on a calibration curve using catechin as a standard at concentrations of 0–0.1 mg/ml.

Evaluation of antioxidant capacity. Antioxidant capacity of dried beetroots was evaluated by three methods: free radical-scavenging activity by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) method, total antioxidant activity by the 2,2′-azino-bis-(3-ethylbenzthiazoline-6-sulfonic acid) (ABTS) method and ferric-reducing ability by the ferric reducing antioxidant power (FRAP) method. The selection of different methods allowed better understanding the wide variety and range of action of antioxidant compounds in beetroots [20].

The DPPH assay was conducted according to the method of Brand-Williams et al [21]. Diluted sample extract (2 ml) was mixed with 4 ml of 0.1 mM DPPH solution for 30 s and reacted for 30 min at room temperature in the dark. The absorbance of the mixture at 517 nm was reached. A calibration curve with Trolox at concentrations of 0–80 μmol/l was used. Results were expressed as milligram trolox equivalent per gram of dry weight (mg TE/g dw).

The ABTS assay followed the method reported by Re et al. [22] with some modifications. Equal quantities of 2.45 mM $K_2S_2O_8$ solution and 7 mM ABTS were mixed to obtain $ABTS^{\bullet+}$ solution. The $ABTS^{\bullet+}$ solution was allowed staying for 16 h at room temperature in the dark. Before measurement, the $ABTS^{\bullet+}$ solution was diluted with 80 % ethanol to obtain an absorbance of 0.70 ± 0.02 at 734 nm. Diluted sample extract (0.8 ml) reacted with 7.2 ml diluted $ABTS^{\bullet+}$ solution for 6 min at room temperature, then the absorbance of the mixture was measured at 734 nm. Trolox with concentration of 0–120 μmol/l was used as the standard curve. Results were expressed as milligram trolox equivalent per gram of dry weight (mg TE/g dw).

The FRAP assay was determined according to Benzie et al [23]. FRAP reagent was prepared by mixing 10 mM TPTZ solution in 40 mM HCl solution, 20 mM $FeCl_3$ 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 using it. The diluted sample extract (0.2 ml) completely reacted with 6 ml of FRAP reagent. After incubating at 37°C for 10 min, the absorbance was recorded at 593 nm. A calibration curve was obtained using different concentrations (0–600 μmol/l) of Trolox. All these solutions had been prepared on the day of analysis. Results were expressed as milligram trolox equivalent per gram of dry weight (mg TE/g dw).

Statistical analysis. All experiments were carried out at least three times and results were expressed as means ± standard deviation (SD). The results were analyzed by analysis of variance (ANOVA), and Tukey's multiple range test ($p <$

0.05) was made to determine significant differences among the groups using SPSS Statistics Version 20 (IBM Corporation, Chicago, IL, USA). Origin 9.0 (Origin Lab, MA, USA) was used to draw the figures.

Results and Discussion

Drying time. The beetroot slices were dried from an initial moisture content of 90.1% (wet basis) until obtain this less than 7.0% (wet basis) using different heat pump drying temperatures. The drying time of beetroots at different drying temperatures are presented in the Fig. 1. As it was expected, the drying time was inversely related to the drying temperatures. The drying time decreased significantly with the increase of drying temperature at the designed levels ($p < 0.05$). As it is presented in the Fig. 1, the drying time of beetroots at different heat pump drying temperatures ranged from 340.0 till 620.0 min. The beetroots dried at 65°C showed the shortest drying time of 340.0 min, while the beetroots obtained at 45°C required the longest drying time (620.0 min). The drying time of beetroots dried at 65°C accounted only 54.8% of that of beetroots dried at 45°C. In other words, as the drying temperature increased from 45 to 65°C, the drying time of beetroots decreased by 82.4%. These results conform to those of Salima et al [24].

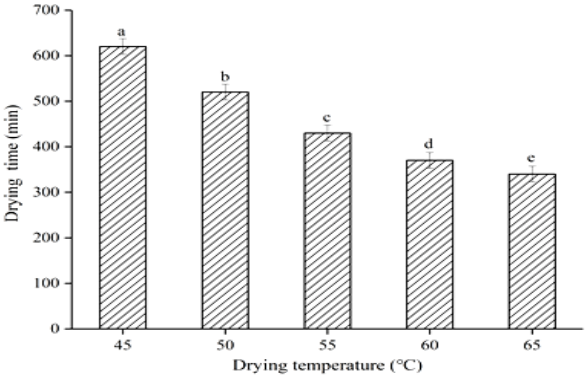

Fig. 1. Drying time of beetroots at different drying temperatures. Means with different letters are significantly different ($p < 0.05$)

Color changes of beetroots. Color is one of important quality factors that affect consumers' acceptability for dried products. The results of color parameters of dried beetroots at different drying temperatures are presented in the Table 1. Freeze drying (FD) is the best known method to retain the color of the sample well. So it was used for comparison.

The L value of beetroots dried at 50°C was the highest of 39.20, indicating the brightest character. The lowest L value was revealed in the dried beetroots produced using the drying temperature of 45 °C, a similar conclusion had been reported by Macedo et al [25]. The effect of drying temperature on L value of dried beetroots was not significant in comparison to freeze-dried samples. FD beetroots showed the largest a value, representing the greatest redness. Value of a was found decreasing during the drying temperature ranged from 45 to 60°C, and then it increased at 65°C. There was decreasing in yellowness (b) with increasing in drying temperatures. The individual analysis of L, a and b parameters is not comprehensive enough to explain the color changes of samples after drying at different temperatures. The chroma (C) value is a good illustration of the amount of color, distinguishing vivid and dull color reported by Abers and Wrolstad [26]. It was observed that increasing drying temperature (from 45 to 60°C) decreased the C values. The lower C value of dried beetroots at 60 °C indicated less saturation and a duller appearance in comparison to beetroots dried at other drying temperatures. FD beetroots presented the highest C value of 28.87. The a, b and C values of dried beetroots at all drying temperatures were lower than these of freeze-dried samples, and the differences were significant ($p < 0.05$). The H^0 values of dried beetroots showed a slight decrease as the drying temperature increased, and they are lower than these of freeze-dried samples. The $H°$ value of dried beetroots at 65 °C was the lowest ($H° = 1.52$). Regarding total color change (ΔE) with respect to the FD, values ranged from 4.05 to 6.47, where the lowest ΔE value was at 50°C and the highest ΔE value was at 60°C, but the differences were not significant ($p > 0.05$).

Table 1

Effect of different drying temperatures on color parameters of beetroots

Drying temperature, °C	L	a	b	C	$H°$	ΔE
45	36.27 ± 0.27^{c}	25.43 ± 0.22^{b}	1.91 ± 0.14^{b}	25.51 ± 0.22^{b}	4.30 ± 0.32^{b}	4.22 ± 0.30^{a}
50	39.20 ± 0.95^{a}	25.04 ± 1.18^{bc}	1.55 ± 0.23^{bc}	25.09 ± 1.19^{bc}	3.54 ± 0.41^{bc}	4.05 ± 1.24^{a}
55	37.44 ± 0.60^{abc}	23.11 ± 0.24^{c}	1.47 ± 0.09^{bc}	23.16 ± 0.23^{c}	3.64 ± 0.27^{bc}	5.95 ± 0.32^{a}
60	36.39 ± 1.56^{bc}	23.03 ± 0.34^{c}	1.44 ± 0.13^{bc}	23.08 ± 0.35^{c}	3.58 ± 0.22^{bc}	6.47 ± 0.19^{a}
65	39.10 ± 0.62^{ab}	24.99 ± 1.29^{bc}	1.22 ± 0.23^{c}	25.02 ± 1.30^{bc}	2.79 ± 0.39^{c}	4.17 ± 1.27^{a}
FD	38.71 ± 0.90^{abc}	28.73 ± 0.16^{a}	2.86 ± 0.07^{a}	28.87 ± 0.16^{a}	5.68 ± 0.11^{a}	0.00 ± 0.00

Notes: Values are means ± SD of triplicate samples. Means with different superscript letters in a column are significantly different according to Tukey's test ($p < 0.05$).

During drying the Maillard reaction occurs to form dark pigments, which change the color of the sample. The reaction is affected by drying temperature, where higher temperatures have tendency to produce more dark pigments [20]. However, the drying time when the sample is exposed to this condition is also an important factor; the shorter is the exposure time, the lower is the production of dark pigments, with a compensatory effect [27]. The a, *b*, *C* and *H*° parameters were similarly influenced by the drying temperature presenting the highest values in the dried beetroots submitted to the drying temperature of 45 °C.

Rehydration ratio of the dried beetroots. Rehydration is the main quality parameter, which reflects the ability of the material to maintain its original shape during the drying process, and displays the degree of damage of the cellular material. It depends on the materials' characteristics, drying and rehydration conditions, the degree of cellular material's damage during the drying process, and the type of pretreatment employed. The drying process usually causes irreversible structural changes and restricts the material from returning to its original shape [28; 29]. The rehydration ratio of dried beetroots under different drying temperatures are presented in the Fig. 2. As it can be seen from the Fig. 2 the rehydration ratio decreased significantly ($p < 0.05$) with the increase of drying temperature. Similar tendencies have been reported by Gokhale and Lele [30]. Rehydration ratio ranged from 5.17 to 4.50 while drying temperature increasing from 45 to 60°C, respectively. This may be that as the drying temperature increases, the moisture on the surface of the sample evaporates rapidly forming a hard film on the surface, and the high temperature destroys the structure of the tissue resulting in the decrease in rehydration ratio [31]. As we know, the lower is the rehydration ratio the more severe is the damage to the cell structure of the sample.

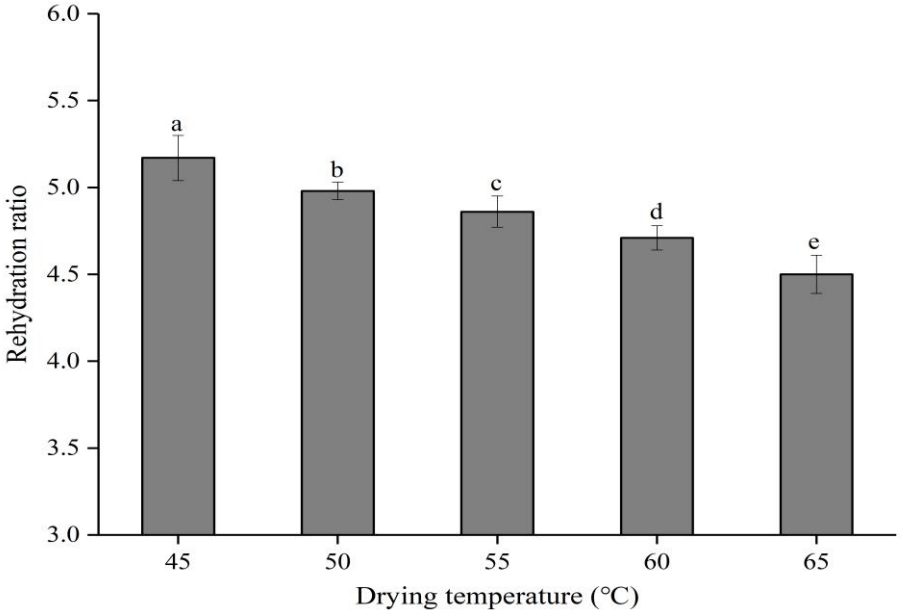

Fig.2. Effect of different drying temperatures on rehydration ratio of dried beetroots. Means with different letters are significantly different ($p < 0.05$)

Bioactive compounds of dried beetroots. Betalains are water-soluble, nitrogen-containing natural pigments, which can be divided into two groups: red-violet betacyanins and yellow-orange betaxanthins [32]. The betalain content of dried beetroots was measured by betacyanin (reported as betanin) and betaxanthin (reported as indicaxanthin) content, and results are presented in the Table 2. Significant differences ($p < 0.05$) were observed in betalain content of beetroots dried at different temperatures. The betacyanin content of dried beetroots increased significantly with the increase of drying temperature ranged from 19.60 to 35.85 mg BE/L. Betacyanin content was the highest (35.85 mg BE/L) for beetroots dried at 65°C, and the lowest (19.60 mg BE/L) for beetroots dried at 45°C. The content of betacyanin and betaxanthin showed the same tendency with the increase of drying temperature. The betaxanthin content of dried beetroots ranged from 11.69 to 20.94 mg/l. The

betaxanthin content was also the highest (20.94 mg IE/L) for beetroots dried at 65°C.

It has been reported that betanin in beetroots can undergo many forms of degradation during thermal processing, including isomerization, decarboxylation and cleavage with heats and acids [33]. Gokhale and Lele [29] reported that betalain content and antioxidant activity of the whole beetroots powder depends on drying temperature, and betacyanin decreased whereas betaxanthin increased with increase in drying temperature from 50 to 120°C. Content of betacyanin and betaxanthin was significantly different among the beetroots dried at different temperatures, and it increased with the increase of drying temperature, which indicated that the drying temperature reached in the dehydration process was not enough to degrade the pigment; on the contrary, the increase of drying temperature caused the increase of pigment.

Table 2

Effect of different drying temperatures on betalain content and ascorbic acid content of dried beetroots

Drying temperature, °C	Betacyanins, mg BE /L	Betaxanthins, mg IE/L	Ascorbic acid, mg/g dw
45	19.60 ± 0.16^{e}	11.69 ± 0.12^{e}	2.31 ± 0.02^{e}
50	24.42 ± 0.21^{d}	15.66 ± 0.15^{d}	2.72 ± 0.01^{d}
55	28.14 ± 0.26^{c}	16.70 ± 0.14^{c}	3.02 ± 0.03^{c}
60	31.73 ± 0.27^{b}	19.27 ± 0.17^{b}	3.13 ± 0.06^{b}
65	35.85 ± 0.80^{a}	20.94 ± 0.44^{a}	3.66 ± 0.01^{a}

Notes: Values are means ± SD of triplicate samples. Means with different superscript letters in a column are significantly different according to Tukey's test ($p < 0.05$).

Ascorbic acid as an important antioxidant plays a various role in the human diet. Ascorbic acid is well known to be very susceptible to oxidation under certain conditions, such as heat, presence of oxygen, heavy metal ions and alkaline pH. The effect of drying temperature on ascorbic acid content had been investigated, and the results are presented in the Table 2. As it is shown in the Table 2, the ascorbic acid content determined in the dried beetroots were revealed in the range from 2.31 to 3.66 mg/g dw, which was a significant ($p < 0.05$) increase with increasing drying temperatures, being the highest value of 3.66 mg/g dw at 65°C.

The influence of drying temperatures on the content of total phenolic and total flavonoid in dried beetroots is presented in the Fig. 3. As it is observed in the Fig. 3, the total phenolic content in dried beetroots at five heat pump drying temperatures increased from 8.39 to 11.07 mg GAE/g dw. The total phenolic content in dried beetroots was positively related to the heat pump drying temperatures. The beetroots dried at 65°C showed the highest total phenolic content (11.07 mg GAE/g dw) in comparison to the beetroots dried at other temperatures. It is well known that thermal treatment is the most critical factor that can affect the amount of phenolic compounds. The results obtained for total phenolics in this study indicated that increasing drying temperature significantly increased the total phenolics of beetroots in agreement with Gokhale and Lele [34], who reported that total phenolic content of beetroots increased with increase in drying temperatures (50–120°C). It has been reported by Kubra and Rao [35] that heat energy can cause the breakdown of the cellular constituents leading to a higher release of polyphenols from the matrices, which may be the reason for the high content of total phenolic obtained at 65°C in the current study.

It can also be seen that an increase in drying temperature leads to an increase in total flavonoid content. The total flavonoid content displayed the similar tendency as the total phenolic one. As it is presented in the Fig. 3, the highest content of the total flavonoid (9.50 mg CE/g dw) of dried beetroots was obtained at 65°C. The total flavonoid content decreased to 9.14 mg CE/g dw for the beetroots dried at 60°C, and the total flavonoid loss was further obtained by decreasing the drying temperature, so the total flavonoid content was reached 6.96 mg CE/g at 45 °C. High drying temperatures contribute to the destruction of cellular constituents, which release the flavonoids and make them available during extraction. On the other hand, a short exposure time during the drying process makes it advantageous in terms of flavonoid preservation [24].

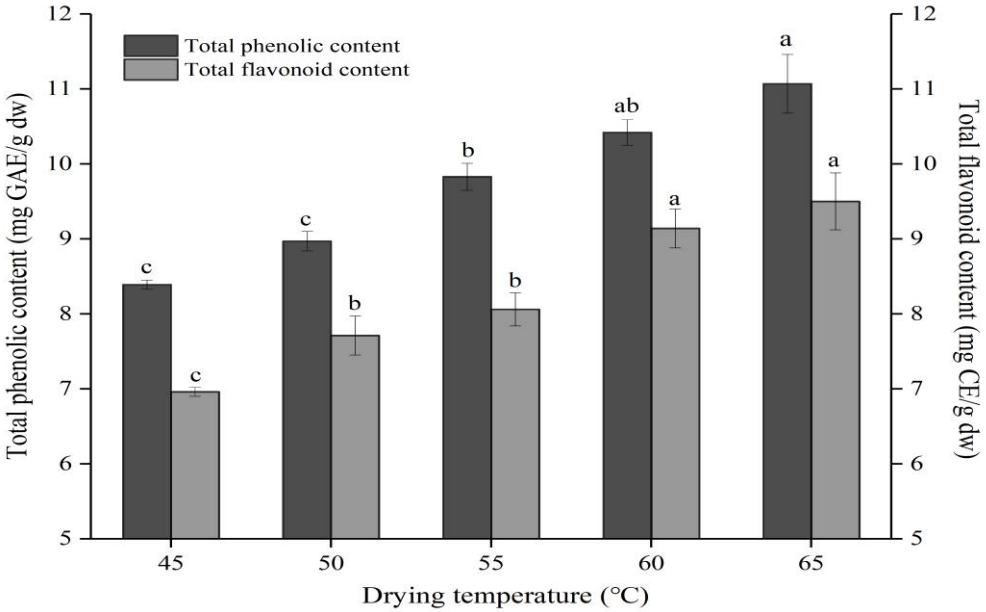

Fig. 3. Effect of different drying temperatures on total phenolic content and total flavonoid content of dried beetroots. Means with different letters are significantly different (p < 0.05)

Antioxidant capacity of dried beetroots. Beetroots contain a wide variety of phytochemicals that work as antioxidants. The present study evaluated the antioxidant capacity of beetroots by DPPH, ABTS and FRAP assays as this influenced by heat pump drying at different temperatures. The results of antioxidant capacity at different drying temperatures are presented in the Table 3.

Table 3

Effect of different drying temperatures on antioxidant capacity of dried beetroots

Drying temperature, °C	DPPH, mg TE/g dw	ABTS, mg TE/g dw	FRAP, mg TE/g dw
45	1.56 ± 0.03[a]	20.49 ± 0.16[b]	12.74 ± 0.45[d]
50	1.25 ± 0.01[b]	20.74 ± 0.13[b]	14.21 ± 0.35[c]
55	1.11 ± 0.01[c]	20.89 ± 0.56[b]	15.62 ± 0.66[b]
60	0.84 ± 0.01[d]	23.17 ± 0.45[a]	16.46 ± 0.08[b]
65	0.40 ± 0.02[e]	24.10 ± 0.16[a]	17.81 ± 0.04[a]

Notes: Means with different superscript letters in a column are statistically different according to Tukey's test (p < 0.05).

It has been reported that the antioxidant capacity depends on the presence of betalains and polyphenols, which increased after thermal treatment [32]. As it is shown in the Table 3, a significant (p < 0.05) decrease of DPPH radical scavenging ability in dried beetroots by increasing the drying temperatures were observed, where the lowest DPPH radical scavenging ability in dried beetroots was 0.40 mg TE/g dw at 65°C. It was obvious that ABTS radical scavenging ability increased with the increase of drying temperature. ABTS radical scavenging ability was the lowest (20.49 mg TE/g dw) at 45°C, while reached to the highest value of 24.10 mg TE/g dw at 65°C. The similar tendency has been reported by Gokhale and Lele [30]. As it can be seen in the Table 3, the FRAP value was the lowest (12.74 mg TE/g dw) at 45°C, while reached to the highest value (17.81 mg TE/g dw) at 65°C. The ABTS radical scavenging ability and FRAP values of beetroots had the same tendency with drying temperatures, and both them reached to the maximum at 65°C. Further increasing the drying temperature can lead to a greater increase in ABTS radical scavenging ability and FRAP value.

Conclusions

Heat pump drying temperature has a great influence on the physical properties, bioactive compounds and antioxidant capacity of dried beetroots. For the color parameters, b values and $h°$ decreased with the increase of drying temperature, while values of a and C decreased firstly and then increased at 65°C, and on the contrary, ΔE increased firstly and then decreased at 65°C. The content of betalain (betacyanin and betaxanthin), ascorbic acid, total phenolic and total flavonoid of beetroots increased with the increase of drying temperatures, while the rehydration ratio decreased. For antioxidant capacity, ABTS radical scavenging ability and

FRAP values increased with the increase of drying temperature, while DPPH radical scavenging ability decreased with the increase of drying temperature. It is considered that 65°C is the best drying temperature for heat pump drying of beetroots. Heat pump drying is a simple, efficient and low-cost process, which can even be used by small producers, contributing to increase family income and reduced waste, while offering a new beetroot-derived product. Therefore, determining the ideal temperature is an important step in the drying process, which can guide the producers and researchers to choose in the future.

Acknowledgments

This work was financially supported by Guangxi First-class Discipline Food Science and Engineering Cultivation Project (GXYLXKP1816) and Guangxi Natural Science Foundation (2020GXNSFAA259012). The authors would like to thank to Guangxi Key Laboratory of Health Care Food Science and Technology for providing laboratory facilities and technical support in this work.

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