Intensifying drying process with creation of functional plant compositions

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Abstract

Introduction. The process of drying agricultural raw products is associated with loss of bioactive substances by the products exposed to heat, light, oxygen, or pH medium. It is reasonable to enhance the table beet processing technology in order to achieve maximum betanin conservation at lower energy consumption.

Materials and methods. Table beets, rhubarbs, lemons, and tomatoes were dried at temperature of 50 to 100 ºC, air speed of 1.5 to 3.5 m/s, heat carrier water content of 7 to 15 g/kg, and layer thickness of 2 to 20 mm. The betanin content was determined via absorption spectra, using the optical density value at 540 nm wavelength. A differential microcalorimeter was used for measuring evaporation heat consumption.

Results and discussion. The effect of raw product pre-drying preparation was studied. With no preliminary preparation, the loss of betanin after drying reaches 66 %. The preliminary preparation technology we have developed includes boiling whole root crops with optimal selection of acid medium and allows us to reduce the betanin loss down to 6 %. Regretfully, the process requires large energy consumption. Low energy consumption pre-drying preparation method was developed for antioxidant raw products with thermal processing replaced by blending. The betanin loss, in this case, does not exceed 5 %. Optimal drying temperature of betanin-containing raw stock, after its preliminary processing, is 60 °C. It allows to keep up to 95 % of betanin. Specific heat consumption for water evaporation out of the developed table beet based antioxidant plant compositions, with addition of rhubarb and lemon, is less by 4 to 5 % as compared to the initial components.

Conclusions. Dependence of betanin loss in plant raw stock on the material temperature and composition components, in the course of their pre-drying preparation, was found. It was also found that water evaporation heat, for some antioxidant plant compositions developed, is less as compared to the initial raw stock components. It is reasonable to use the results for development of industrial thermal processing technologies used for functional food powder production.

Introduction

Production of food keeping its nutrients requires additional processing operations not used, so far, in modern technologies. One of the drawbacks of current table beet treatment methods is considerable loss (20 to 80 %) of biologically active substances.

Betalains contained in table beet are water soluble pigments classified earlier as anthocyans. They are found in cell vacuoles. However, betalains differ, structurally and chemically, from anthocyans and were never found in the same plant with the latter [1]. For example, betalains contain nitrogen in their structures that can never be found in anthocyans. Currently, it is known that betalains are indole compounds synthesized from tyrosine. Chemically, they differ from anthocyans as well as from flavonoids [2]. All betalains are glycosides containing sugar and pigments. Their synthesis is stimulated by light [3].

Two type of betalains exist: betacyanins that include pigments from red to violet and betaxanthins that may be yellow or orange. The betalain studied in most details is betanin otherwise called beetroot red. Betanin is glycoside hydrolysed to glucose and bethanidine. Bethanidine is glycosidic food pigment extracted from table beets [4].

Thus, table beet is an important raw stock for production various vegetable tinned food including those aimed for dietary and medioprophylactic use. But the main problem of its treatment is still retaining its natural color, even after thermal processing. Retaining table beet natural color (betanin) is the main purpose when creating beet-based antioxidant products.

To make table beet pigments more stable and to retain its color, it is recommended to add ascorbic, sorbic, citric, acetic, and lactic acids till reaching pH level of 3 to 5. Otherwise, apple or black chokeberry juices may be added, or else sauerkraut, or mashed ashberry. Besides, caramel syrup, sodium phosphate, or sodium chloride may be used as stabilizing additives. Vine seed extract, tea, oak acorn broth, cherry or Cornelian cherry extract show considerable stabilizing effect, too [5].

The stabilizing methods proposed enhance betanin stability, but they could not take their due place in the food and food-canning industries. That is why the search for new, efficient pigment preservation methods for table beets under processing is still going on.

Since table beets, while being stored, may lose up to 70 % of pigments, while after drying with high temperature heat carrier the loss may reach 85 %, we have developed a method of whole root crop hygrothermal processing in acid medium aimed to stabilize betanin by creation of optimized pH medium. The method allows retaining almost 96 % of betanin over a rather long period of storage [Yu.F. Snezhkin, Zh.O Petrova. Patent of Ukraine No. 92843. Method of Receiving Powdery Pigment from Table Beet]. However, such hygrothermal processing is power-consuming and takes much time, so a new method was developed based on creation of optimal pH medium. It has been proposed to create, prior to drying, functional compositions of the raw stock based on table beets with addition of lemons, rhubarbs, or tomatoes. [Yu.F. Snezhkin, Zh.O. Petrova, V.M. Pazyuk, K.M. Getmanyuk, O.P. Samoylenko. Patent of Ukraine No. 102358. Method of Receiving Beet-Lemon Antioxidant Pigment].

The aim of the study set forth in the proposed paper is development of table beet processing technology using the proposed method of creating plant raw stock functional compositions right prior to drying in order to reach maximum preservation of betanin and essential reduce of power consumption.

Materials and methods

To perform the study, parenchymal table beet, rhubarb, lemon, and tomato tissues were used along with their functional mixtures. Since betanin stabilizes in media with pH in the range of 3.2 to 4.0, table beet/rhubarb, table beet/lemon, and table beet/tomato compositions were taken in such proportions as to get required pH.

For drying the raw stock, an experimental drying stand was used having wide ranges of working parameters, such as 50 to 100 ºC for temperature, 1.5 to 3.5 m/s for air speed, 7 to 15 g/kg of dry air for heat carrier water content, 2 to 20 mm for layer thickness. The stand is equipped with a system of automatic collection and processing of information, like mass and temperature changes, based on a software application we have developed [6].

Within the development of the proposed preliminary processing method, the effect of preliminary plant raw stock processing on conserving betanin in the finished product and dehydration heat consumption was studied.

The betanin content was determined via absorption spectra, using the optical density value at 540 nm wavelength on the SF-26 spectrometer [7].

For determination of specific heat consumptions for water evaporation out of the functional plant raw stock in the drying process, the DMKI-01 differential microcalorimeter was used developed in the Institute of Technical Thermal Physics, National Academy of Sciences of Ukraine [Yu.F. Snezhkin, L.V. Dekusha, N.S. Dubovikova, T.G. Grishchenko, L.Y. Vorobyov, L.A. Boryak. Patent of Ukraine No. 84075. Calorimetric Device for Determination of Specific Heat of Water and Organic Liquid Evaporation out of Materials]. The device functioning is based on the Synchronous Thermoanalysis Method, that is simultaneous use of thermogravimetry and differential calorimetry. In the course of isotermic drying inside the calorimeter heat unit, the amount of heat used for water evaporation out of the material and the respective loss of mass by the sample are measured simultaneously. Current evaporation heat values for water evaporation out of a sample are determined after termination of the experiment using the formula:

$$r_i = \frac{\int_{\tau_i}^{\tau_{i+1}} Q(\tau)d\tau}{m(\tau_i) - m(\tau_{i+1})} \quad (1)$$

$\boldsymbol{r_i}$ are specific evaporation heat values for the drying period since $\boldsymbol{\tau_i}$ till $\boldsymbol{\tau_{i+1}}$, *kJ/kg*;
$\boldsymbol{\tau_i}$ and $\boldsymbol{\tau_{i+1}}$ are current times of the drying process, *s*;
$Q(\tau)$ is the heat flow inside the working chamber of the DMKI-01 heat unit as function of time, *J/s*;
$m(\tau_i)$ and $m(\tau_{i+1})$ are masses of the sample at $\boldsymbol{\tau_i}$ and $\boldsymbol{\tau_{i+1}}$ time moments, *kg*.

Results and discussion

For identifying the betanin stabilization effect reached, the betanin loss was studied in the course of table beet drying, at $\boldsymbol{t}$ = 60 ºC, with no preliminary preparation, with preliminary hygrothermal processing of whole root crops in acidulous medium, and with table beet composition with rhubarbs, tomatoes, and lemons in respective proportions required for creation of optimal pH medium (Fig.1). As can be seen on the figure, the betanin loss in the course of table beet drying with no preliminary processing is 66 %. Boiling whole root crops in acidulous medium with pH of 3.2 to 4 reduces the loss down to

6 %. Preliminary creation of the proposed table beet-based functional compositions minimizes the betanin loss in the course of drying down to 5 %.

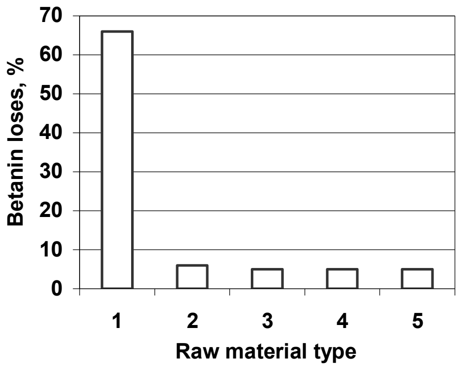


Fig. 1. Loss of betanin depending on raw stock and preliminary processing types:
1 – table beet with no hygrothermal processing;
2 – table beet after hygrothermal processing;
3 – table beet-rhubarb (blending);
4 – table beet-lemon (blending);
5 – table beet-tomato (blending).

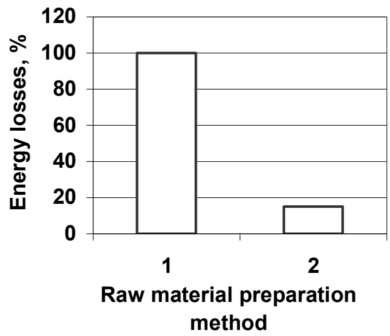


Fig. 2. Energy consumption for raw stock preparation prior to drying:
1 – hygrothermal raw stock processing;
2 – enhanced raw stock processing.

The process of the preliminary table beet hygrothermal processing (boiling whole root crops for 40 min.) requires a certain amount of energy. Taking this amount for 100 % (Fig. 2), we will have about 15 % of energy consumed for raw stock preparation via creation of respective pH medium by mixing minced table beets with minced tomatoes, lemons, or rhubarbs. Thus, the developed method of raw stock preparation for drying made it possible not only to minimize betanin loss in the course of drying down to 5 %, but also to reduce, by 85 %, the energy consumption for preliminary processing.

The study of dependence of betanin conservation in finished products of convective drying on heat carrier temperature has shown (Fig. 3) that maximum (94.0 to 96.5 %) conservation of betanin in table beet-based mixtures, as well as in table beets having passed hygrothermal processing in medium with pH of 3.2 to 4, takes place at heat carrier temperature of about 60 ºC. At temperatures of 40 to 50 ºC, the level of betanin conservation is in the range of 55 to 58 %. This is explained by the facts that table beets contain betalain oxidase enzyme, while the temperature of t = 40ºC and medium with pH = 2 to 3 are optimal conditions for detecting enzymatic activity of this enzyme. That is the cause of higher enzyme activity, essential betanin destruction and oxidation in minced table beets at temperatures of 40 to 50 ºC. At higher temperatures of 60 to 100 ºC, the percentage of retained betanin is gradually reduced returning to 50 % at the heat carrier temperature of 100 ºC. The level of betanin conservation in unprocessed table beets fluctuates around 30 % at the heat carrier temperature of 40 to 80 ºC, while in case of raising the temperature to 90 to 100 ºC, the percentage of betanin conservation drops down to 24 to 16 %.

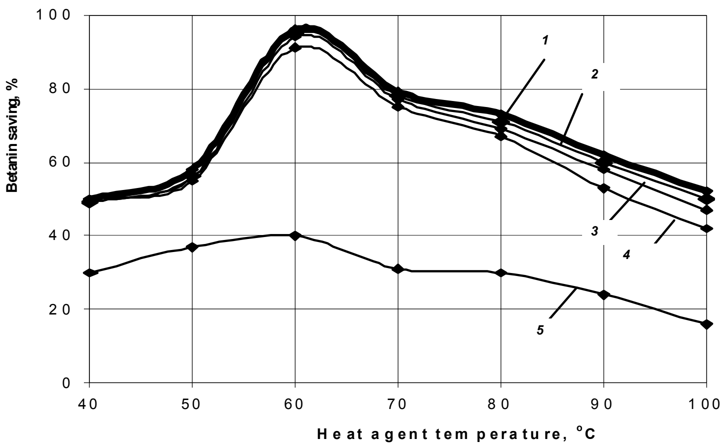


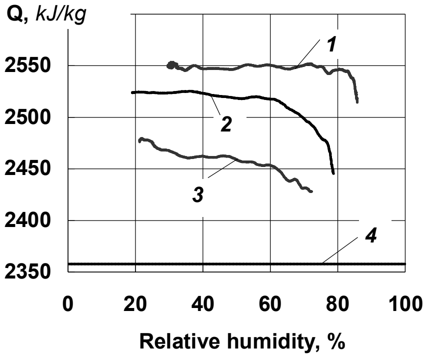
Fig. 3. Dependence of betanin conservation on drying temperature in various types of raw stock and with various preliminary processing.

1 – hygrothermal table beet; 2 –table beet-rhubarb (2:1); 3 – table beet- lemon (3:1); 4 – table beet-tomato (3:1); 5 – unprocessed table beet.

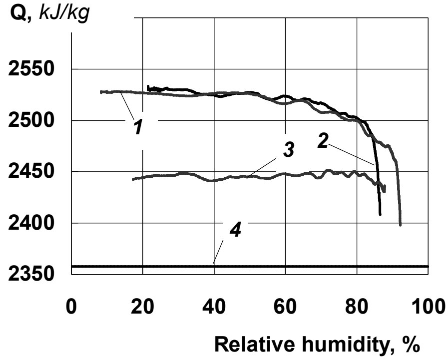
Thus, drying the mentioned table beet-based functional compositions, as well as table beets after hygrothermal processing, makes it possible to reach considerable rise of betanin conservation as compared to drying fresh table beets. Analysis of the betanin conservation results allows to come to the conclusion that the best betanin conservation is reached with convective drying at the heat carrier temperature of 60 ºC. I.e., drying compositions at 60 ºC is optimal according to qualitative indicators.

When calculating energy consumption for the drying process, it is necessary to know not only the process duration but also specific heat consumption for water evaporation. The practice of drying large number of complex plant materials shows an essential difference of actual heat consumption values required for water evaporation out of such materials as compared with the case of clean water evaporation [8]. Since energy consumption growth when drying plant materials is associated with difficult penetration of cell membranes by water and complicated remove of water interacting with soluble molecules of cellular fluid and material frame molecules, it would be important to study the effect of creating functional compositions of plant raw stock on the specific heat of its evaporation.

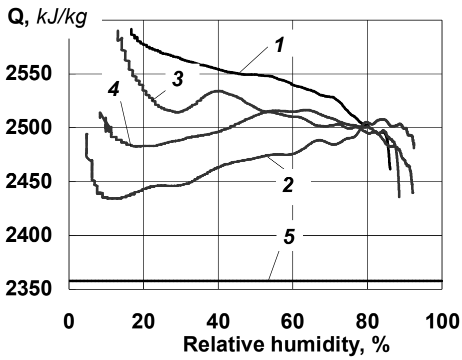
The drying process was taking place inside the DMKI-01 heat unit, at the temperature of 60 ºC which was optimal according to qualitative indicators. The results are shown on Fig. 4. The air (heat carrier) velocity and humidity values are shown in figure subscriptions.



t = 60 ºC, v = 0.4 cm/s, d = 6.5 g/kg
1 – table beet; 2 – lemon; 3 – table beet-lemon (3:1); 4 – water
A



t = 60 ºC, v = 0.8 cm/s, d = 10 g/kg
1 – table beet; 2– rhubarb; 3 – table beet-rhubarb (2:1); 4 – water
B



t = 60 ºC, v = 0.8 cm/s, d = 5 g/kg
1 – table beet; 2 –tomato; 3 – table beet – tomato (3:1); 4 – table beet – tomato (1:3); 5 – water.
C

Fig. 4. Comparison of water evaporation heat values for table beet-based antioxidant raw stock with lemons (A), rhubarbs (B), and tomatoes (C).

Fig. 4 A shows that the heat of water evaporation out of table beet/lemon mixture exceeds by 4 to 5 % the clear water evaporation heat and is less, by the same value, as compared to the heat of water evaporation out of unmixed table beet and lemon. The same picture is observed for heat of water evaporation out of the table beet and rhubarb mixture (Fig. 4 B). We suppose that mixing pieces of minced table beet with tissues of rhubarbs and lemons, like the previous table beet hygrothermal processing, causes some changes in chemical content of the composition and destruction of cell membranes by organic acids. The changes, in this case, cause reduce of plant tissue water capture properties and reduce heat consumption for water evaporation out of these tissues by 4 to 5 %. That is, the effect of mixing different plant tissues was not just averaging heat consumption and water evaporation out of individual components, as might be expected. Instead, a synergy effect was observed.

Fig. 4 C shows water evaporation heat values for tomatoes, table beets, and table beet/tomato compositions in comparison with one another and the clear water evaporation heat. As can be seen, the values of specific evaporation heat consumption for the table beet/tomato mixture (3:1 and 1:3) are between respective values for table beet and tomato individual tissues. That is, in this case, the mixture dehydration resulted in sum of the component dehydrations, according to the additive rule, instead of general reduce of evaporation heat consumption as in the cases of the table beet/rhubarb and table beet/lemon compositions. However, we managed to reach the effect of maximum retaining of both table beet and tomato colors in the final product. Moreover, their colors even became somewhat enhanced, more bright. We may suppose that the changes having occurred in the raw product after creation of the table beet/tomato composition were sufficient for conservation of table beet betanin and tomato licopin in the drying process but evidently are not sufficient for reducing water capturing.

Conclusions

Preliminary preparation of betamin-containing plant raw stock via creation of functional compositions with selected component proportions makes it possible not only to stabilize the native raw material components but also to reduce the drying period duration thanks to exclusion of rather long-time preliminary hygrothermal processing in acidulous medium.

The optimal drying temperature equal to 60 ºC was found experimentally for preliminarily processed betanin-containing raw stock (table beets) allowing to retain up to 95 % of betanin.

It was found that values of specific heat consumption required for evaporation of water out of the antioxidant plant compositions developed based on table beets with addition of rhubarbs and lemons are less by 4 to 5 % as compared to the initial components. The additive rule is not met for the specific heat of waster evaporation out of a mixture of various substances thanks to changes in the initial component plant tissues and creation, on the preliminary processing step, of an exactly new material to be dried.

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