Effects of drying methods on quality parameters of potato and red beetroot purée with *Lactobacillus delbrueckii*

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Summary

The aim of this study was to investigate the influence of conventional and foam-mat drying methods on the quality parameters of a non-dairy solid product based on potato (*Solanum tuberosum* L.) and red beetroot (*Beta vulgaris* L.). The vegetable purée was used as a fermentation substrate for the potentially probiotic *Lactobacillus delbrueckii* subsp. *bulgaricus* Lb12 strain. The purée samples were evaluated for rheological, microstructural, microbiological and phytochemical properties. Rheological low amplitude oscillatory measurements revealed low resistance to the applied strain (between 0.1 % and 1 %). The instrumental texture measurements revealed that the samples obtained by foam-mat drying were the most similar to the fresh purée (from 0.6 ± 0.04 N to 1.6 ± 0.14 N). Confocal laser microscopy revealed vegetal tissues fragments with a rich content of bioactive compounds and lactic acid bacteria aggregated in biofilms. The counts of Lb12 were above 10^7 CFU·g^{-1} after 28 days of storage. The content of betaxanthins, β-carotene and lycopene of the samples varied from 1 100 ± 12 mg·kg^{-1} to 2 160 ± 9 mg·kg^{-1}, from 69 470 ± 250 mg·kg^{-1} to 5 940 ± 160 mg·kg^{-1} and from 46 520 ± 14 mg·kg^{-1} to 3 550 ± 270 mg·kg^{-1}, respectively.

Keywords

Lactobacillus delbrueckii; potatoes; probiotic; purée; red beetroot

Vegetables are an important source of indispensable dietary nutrients such as vitamins, minerals and fibres. Because fresh vegetables have a moisture content above 80 %, they are classified as highly perishable horticultural commodities [1]. Drying fresh vegetables is a processing method whereby water elimination prevents the proliferation of pathogenic microorganisms [2], thus preserving the composition, sensorial properties and nutritional value of the starting material [3]. Drying is a unit operation used to eliminate water from a product and, consequently, to diminish its water activity [4]. Convective drying is the process of removing water with air through concomitant heat, mass and momentum transfer. The heat flux produces an increase in the product temperature and water evaporation. The moisture is transferred from the product surface to the air by convection as water vapour, and from the interior of the product by diffusion, convection or capillarity [5]. The drying rate and the dried product properties depend on the external conditions of the process, like air temperature, humidity, velocity and the air flux direction. Additionally, the drying rate depends on internal conditions such as the product geometry, thickness, type and structure [4]. In the field of drying technology, foam-mat drying is a new method used in the case of liquids and semi-liquid/solid foods with a high content of water. It is an adequate drying technique

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for vegetables that are very sensitive to heat and for those that are viscous, sticky and difficult to be dried. By this method, a number of food products was shown to be dried without major quality changes [6]. This drying method involves incorporation of a foaming agent (proteins, gums or various emulsifiers) into liquid or semi-liquid/solid foods, with subsequent whipping to form a stiff foam [7]. Compared to other drying methods, foam-mat drying is rapid, the colour and flavour of the products are enhanced since the heat-damage is minimal. The process can take place at lower temperatures and during shorter drying times due to the fact that water is distributed in thin layers. The finite product is a free flowing powder of a high quality, which can be easily reconstituted in cold water. This process was successfully used to dry juices, fruits, beverages, milk and jams. Several studies were carried out to examine the effects of foam-mat drying on yacon juice, mango pulp and fruits like papaya, sour cherry, tomato, guava and banana [6].

Potatoes (*Solanum tuberosum* L.) belong to the Solanaceae family, being one of the most widely consumed vegetables. Potatoes are considered to be a nourishing food that is rich in calories and biologically active compounds like β-carotene, polyphenols, tocopherols and dietary fibres, which contribute to the health of consumers. Potatoes are a cheap source of energy, provide a good quality protein and polysaccharide starch [8]. By the several authors oppinion, potatoes could be considered a potential functional food, which is similar to legumes being an important source of antioxidants, phenolyphenols [9].

Red beetroot (*Beta vulgaris* L.) belongs to the Chenopodiaceae family and is a vegetable root rich in carotenoids, flavonoids and water-soluble pigments, betalains like betacyanins (red-violet colour), and betaxanthins (yellow-orange colour), all of which are believed to provide numerous nutritional and health benefits. Several researchers reported that red beetroot is an important source of bioactive compounds that may provide health benefits [10]. Numerous epidemiological studies demonstrated that consumption of potatoes and red beetroot has health-supporting properties such as antioxidant, hypocholesterolemic, anti-inflammatory, antiobesity, anticancer, cardiovascular disease lowering, anticarcinogenic and hepatoprotective activities as well as antidiabetic effects due to the content of these bioactive compounds [9, 11].

Based on the presented knowledge, using potatoes and red beetroot in the human diet, or as an ingredient to obtain various food products, imparts beneficial effects on human health and provides the opportunity for the development of new functional foods [12]. The novelty of the work is represented by the use of a vegetable matrix (potatoes and red beetroot purée) rich in bioactive compounds (betalains, betaxanthin, carotens) instead of fruits and the incorporation of the inoculum of *Lactobacillus delbrueckii* subsp. *bulgaricus* Lb12, which will lead to obtain a potentially functional product. The aim of the present work was to evaluate the influence of the conventional and foam-mat drying methods on the quality parameters, such as phytochemical parameters, viability of *Lb. delbrueckii* subsp. *bulgaricus* Lb12, texture, microstructure and colour parameters of vegetable purée based on potatoes and red beetroot with 5% egg white used as a foaming agent.

MATERIALS AND METHODS

Materials and chemicals

Fresh potatoes (tubers of *Solanum tuberosum* L.) of Cumidava variety, packed in 2.5 kg pouches (packer Agrico–M, Covasna, Romania) and red beetroot (taproots of *Beta vulgaris* L.) of Bordo variety were obtained from a local supermarket (Galati, Romania) to serve as a raw material for preparation of the vegetable purée. Chicken eggs were obtained from a local supermarket (Galati, Romania) and egg white was obtained from them to be used as a foaming agent. The chemicals used for chemical analyses, namely, 2,2'-azino-*bis*(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS), 6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid (Trolox), ethanol, ethyl acetate, methanol, β-carotene and lycopene were obtained from Sigma-Aldrich (St. Louis, Missouri, USA).

Inoculum preparation

A lyophilized culture of *Lactobacillus delbrueckii* subsp. *bulgaricus* Lb12 was provided by Chr. Hansen (Hoersholm, Denmark). It was propagated without shaking during 18 h at 37 °C in de Man, Rogosa and Sharpe (MRS) broth (Sigma-Aldrich) and reached the stationary phase with a density of 10^9 CFU·g^{-1}.

Preparation of vegetable purée

Fresh potatoes (~1 kg) and red beetroot (~1 kg) were washed, peeled, cut into small pieces (3–4 cm) and boiled in 4 l of tap water for 20 min. After boiling, the potatoes and red beetroot were mashed at 29.2 Hz for 5 min using a kitchen blender Braun MQ 9087 Gourmet (Braun,

Kronberg im Taunus, Germany). To obtain a non-dairy based probiotic product, the vegetable purée was inoculated with 10 % (v/v) of the cell suspension containing approximately 10^9 CFU·g^{-1} of Lb12. Three different vegetable purées were prepared, namely, fresh (control sample, labelled as PCS), non-foamed dried samples (PCSS) and foamed vegetable purée (PCSA) with 50 g·kg^{-1} egg white used as foaming agent. The obtained vegetable purées were dried using conventional convective drying (CD) or foam-mat drying (FMD).

Conventional convective drying

The vegetable purée was dried in a computer-controlled pilot tray dryer (UOP8MKII Tray Dryer, Fabr. No. 036010-004, model 2014; Armfield, Ringwood, United Kingdom). The purée (approximately 450 g) was spread on the tray surface (28.5 cm × 25 cm, layer thickness 1.5 mm). The drying experiment was performed at constant air velocity of 1.09 m·s^{-1}, relative humidity of 10.6 % and drying temperature of 50 °C, while the ambient air temperature was 20 °C. The drying of the purées was carried out for 70 min. All drying experiments were performed in triplicate.

Foam-mat drying

The vegetable purée (approximately 450 g) was mixed with 50 g·kg^{-1} egg white using a kitchen blender Braun MQ 9087 Gourmet. The foamed vegetable purée was spread (layer thickness 1.5 mm) in food grade stainless steel trays and then dried in UOP8MKII Tray Dryer. The foam-mat drying process was performed at 50 °C, air velocity of 1.09 m·s^{-1}, and relative humidity of 10.6 %, while the ambient air temperature was 20 °C. The drying time was 55 min. All drying experiments were performed in triplicate.

Mathematical modelling of drying kinetics

The simplest model for describing thin layer drying characteristics in food products is in the form of the exponential model by Henderson and Pabis (Eq. 1):

$$MR = \frac{M - M_e}{M_i - M_e} = a \cdot exp^{-kt} \quad (1)$$

where MR is the moisture ratio, M is the moisture content at any time t (in percent dry basis), M_e is the equilibrium moisture content (emc) in the conditions of the drying air (in percent dry basis), M_i is the initial moisture content of the sample (in percent dry basis), t is the drying time (in minutes), and a and k are drying coefficients [13, 14].

Henderson and Pabis model is a simple model. The model has been widely applied in describing the drying behaviour of various food products. The mathematical model was fitted to the experimental data sets using non-linear regression using XLSTAT Software (free trial version; Addinsoft, New York, New York, USA). The results were evaluated using statistical indicators coefficient of determination (R^2), sum of squared estimate of errors (SSE), mean squared error (MSE), root mean square error ($RMSE$) and correlation tests. Regression analysis is a statistical tool for the investigation of the relationships between variables, in the current study between moisture ratio (Y) and time (X) [14].

Phyto-chemical properties of the purée

The phyto-chemical profile of the fresh, non-foamed and foamed vegetable purée consisted in the determination of the antioxidant activity and the total content of carotenoids, β-carotene, lycopene, betacyanins and betaxanthins.

Ultrasound-assisted extraction of carotenoids

Ultrasound-assisted extraction was performed using an ultrasonic bath system (MRC Scientific Instruments, Harlow, United Kingdom). An amount of 1 g of the freeze-dried powder (purée) was mixed with 10 ml of ethyl acetate and then introduced in an ultrasonic bath equipped with a digital control system of sonication time, temperature and frequency. The extraction was performed at a constant frequency of 40 kHz, with a constant power of 100 W for 30 min. Cold water was added to maintain a constant temperature (T = 40 ± 3 °C) in the ultrasonic bath. Afterwards, the supernatant was separated by centrifugation at 9000 ×g for 10 min.

Content of total carotenoids, β-carotene and lycopene

The extracts obtained were diluted in the extraction solvent (ethyl acetate) in order to measure the absorbance at different wavelengths, i.e. λ = 470 nm for total carotenoids, λ = 450 nm for β-carotene and λ = 503 nm for lycopene. The content of carotenoids (CC) was calculated according to Britton [15] and Escoto et al. [16]:

$$CC = \frac{A \cdot V \cdot 10^6}{\varepsilon \cdot m \cdot 100} \cdot f_d \quad (2)$$

where A is absorbance, V is the final volume of the analysed extract (in millilitres), ε is the extinction coefficient (ε = 2590 for total carotenoids, ε = 2500 for β-carotene, ε = 3450 for lycopene), m is the weight of the sample (in grams), and f_d is the dilution factor. Content is expressed in milligrams per kilogram.

Content of betalains

The betalains content was determined spectrophotometrically at λ = 536 nm (betacyanins) and λ = 477 nm (betaxanthins) with a UV–Vis spectrometer Libra S22 (BioChrom, Holliston, Massachusetts, USA), according to the method of Castellanos et al. [17]. The betalain content (*BC*) was calculated according to Eq. 3:

$$BC = A \cdot DF \cdot MW \cdot \frac{V_d}{\varepsilon} \cdot L \cdot W_d \quad (3)$$

where A is absorbance, DF is the dilution factor, V_d is the solution volume (in millilitres), W_d is the dried sample weight (in grams), and L is path-length (1 cm) of the cuvette. The molecular weight (*MW*) and molar extinction coefficients (ε) for the quantification of betacyanins (*MW* = 550 g·mol^{-1}; ε = 60 000 l·mol^{-1}cm^{-1}) and betaxanthins (*MW* = 308 g·mol^{-1}; ε = 48 000 l·mol^{-1}cm^{-1}) were applied.

Antioxidant activity

The antioxidant activity of the extracts dissolved in ethyl acetate was measured by using the modified ABTS radical decolorization assay according to the method described by Miller et al. [18]. The fresh ABTS solution was diluted with ethanol (96%) to the absorbance of 0.700 ± 0.02 at 734 nm. Then, 10 μl of the extract was added to 1 ml of the ABTS radical solution and shaken for 10 s. One minute after the addition of the sample, the decolorization that was caused by the reduction of the cations by the antioxidants from the sample was measured spectrophotometrically at 734 nm (Libra S22). The experiments were performed in triplicate. A standard curve using Trolox was used to express the antioxidant activity as micromoles Trolox per litre of dry weight (*DW*) of the extract. The experiments were performed in triplicate.

Microbiological analysis

The viable cell counts of lactic acid bacteria over 28 days were measured using a cultural method on MRS agar [19]. The plates were incubated for 72 h at 40 ± 3 °C.

Rheological measurements

The rheological properties of potato-based purée was determined by means of a controlled stress rheometer AR2000ex (TA Instruments, New Castle, Delaware, USA) equipped with a Peltier plate for temperature control with a plate geometry of 40 mm in diameter, and a set gap of 2 mm. The system temperature was set to 20 °C. Low amplitude dynamic shearing tests, namely, strain sweep and frequency were applied, and the storage modulus (*G'*) as well as loss modulus (*G"*) were recorded. The strain sweep test was performed at an oscillatory frequency of 1 Hz, while increasing the strain from 0.01 % to 100 %. It was used to identify the linear viscoelastic region (LVR) for all investigated samples. The dynamic frequency sweeps were further performed in the 0.1–100 Hz domain, at a constant strain of 0.2 % (determined to be within the linear viscoelastic region). The experiments were performed in triplicate.

Texture analyses

The texture of both fresh and reconstituted purée samples was analysed using a Brookfield CT3 Texture Analyzer (AMETEK Brookfield, Middleboro, Massachusetts, USA).

The samples were poured into cylindrical plastic containers (diameter 45 mm and height 62 mm) and then subjected to a double penetration test with a 25.4 mm diameter acrylic cylinder. The deformation speed was set at 1 mm·s^{-1}, the target depth was 15 mm, the load cell was 9.8 N and the trigger load was 0.02 N. TexturePro CT V1.5 (AMETEK Brookfield) software was used to register and process the results. The texture parameters determined by the method described above were firmness, adhesiveness, cohesiveness and springiness. Six determinations for each sample were done and the results included in the study were obtained by calculating their mean values.

Colour analysis

The L^*, a^* and b^* colour parameters were determined before and after drying using a colorimeter Chroma Meter CR-410 (Konica Minolta, Osaka, Japan) fitted with a granular accessory, after standardization with a white calibration plate according to the equipment specifications. The total colour difference (Δ*E*) was used to describe the colour change during drying, calculated according to Eq. 4 [20]:

$$\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (4)$$

where L^* represents the lightness of colour that ranges from 0 (black) to 100 (white) on the CIELAB scale, a^* (range between $-a^*$ = greenness and $+a^*$ = redness), and b^* (scaled between $-b^*$ = blueness and $+b^*$ = yellowness). Subscript 0 refers to the colour of the fresh sample.

The chroma (C^*) and hue angle (h^*) values of the samples were calculated according to Eq. 5 and Eq. 6 [21]:

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (5)$$

$$h^* = tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (6)$$

The browning index (*BI*) was calculated according to MASKAN [22] using the following formula:

$$BI = 100 \times \left(\frac{X - 0.31}{0.17}\right) \quad (7)$$

where

$$X = \frac{(a^* + 1.75 \cdot L^*)}{(5.645 \cdot L^* + a^* - 3.012 \cdot b^*)} \quad (8)$$

All these parameters are dimensionless. The colour measurements were performed in triplicate.

Confocal laser scanning microscopy

The aim of the confocal laser scanning microscopy (CLSM) analyses was to highlight the size and morphology of the original mixture of potato with red beet purée (simple or with ovalbumin) and added lactic acid bacteria. A Zeiss LSM 710 confocal laser system (Carl Zeiss MicroImagining, Göttingen, Germany) was used for this study and the 3D images were captured and analysed by ZEN 2012 SP1 software (black edition; Carl Zeiss MicroImagining). The technical specifications of the used equipment were: diode laser (405 nm), Ar-laser (458 nm, 488 nm, 514 nm), diode pumped solid state laser (DPSS; 561 nm) and HeNe-laser (633 nm), AxioObserver Z1 inverted microscope, 63x apochromatic objective (numerical aperture 1.4) and filters FS49, FS38 and FS15. To capture autofluorescence of the native powders, emission was measured at wavelengths between 405 nm and 633 nm. In order to acquire the images, the microparticles were stained with 4',6-diamidino-2-phenylindole (DAPI, 1 $\mu g \cdot ml^{-1}$) and Red Congo (40 $\mu mol \cdot l^{-1}$) in a 1:1 ratio. The acquisition parameters of the images were: line scan mode, mean method, speed 6 and 12-bit depth. In order to increase the signal-to-noise ratio, a frame average of eight scans was used.

RESULTS AND DISCUSSION

Phytochemical analysis

The contents of phytochemicals in fresh and non-foamed or foamed vegetable purées are shown in Tab. 1. The content of bioactive compounds is a quality attribute that can be used to characterize the final nutritional quality of the vegetable purée. During drying at 50 °C, the values of all measured bioactive compounds of non-foamed or foamed vegetable purées decreased in comparison to the control sample. These results apparently reflected the fact that carotenoids are sensitive to heat, oxygen, light and activity of enzymes.

The total carotenoids in PCSA were found to be 9270 ± 130 $mg \cdot kg^{-1}$, which was significantly higher than in PCSS (6180 ± 150 $mg \cdot kg^{-1}$). The drying process led to a decrease in total carotenoids content of the non-foamed vegetable purée by approximately 12.2 % of the initial content. In the case of foamed vegetable purée, this decrease was by approximately 18.2 % of the initial content. When comparing our results with those of other authors, it should be taken into account that some factors can affect the composition of carotenoids in vegetable purée, such as the cultivar, stage of maturation, climate or season, and the analysis method. According to PRAKASH et al. [23], the high rate of β-carotene loss during conventional drying of vegetable purée was caused by a longer drying time and by exposure to light, which led to the light-induced oxidation of

Tab. 1. Phytochemical characteristics of fresh and nonfoamed or foamed vegetable purées.

Phytochemical characteristic	Type of vegetable purée		
	PCS (fresh)	PCSS (non-foamed dried)	PCSA (foamed dried)
Total carotenoids [$mg \cdot kg^{-1}$]	50840 ± 110	6180 ± 150	9270 ± 130
β-Carotene [$mg \cdot kg^{-1}$]	69470 ± 250	5940 ± 160	8910 ± 190
Lycopene [$mg \cdot kg^{-1}$]	46520 ± 140	3550 ± 270	5340 ± 250
Betaxanthins [$mg \cdot kg^{-1}$]	2160 ± 9	1100 ± 12	1700 ± 8
Betacyanins [$mg \cdot kg^{-1}$]	1460 ± 5	1700 ± 32	2600 ± 21
Antioxidant activity [$\mu mol \cdot l^{-1}$]	2.10 ± 0.04	1.50 ± 0.03	1.90 ± 0.03

All values are mean ± standard deviation.

β-carotene. In addition, reduction in β-carotene during drying could be assigned to oxidation of its highly unsaturated chemical structure [24].

The lycopene content determined in the PCSS sample was 3 550 ± 270 mg·kg^{-1}, which was lower than the lycopene content in the PCSA sample (5 340 ± 250 mg·kg^{-1}). A higher content of lycopene was determined in samples treated by the foam-mat drying process, which was apparently due to the lesser damage in the vegetal structure compared with the conventional drying method.

The influence of the drying methods on the betacyanin and betaxanthin contents as well as on the antioxidant activity are shown in Tab. 1. During the drying process, the betaxanthin content decreased accordingly, by 7.5 % in the case of the PCSS sample and by 11.6 % in the case of the PCSA sample as compared to the initial content, and the content of betacyanins by 7.9 % in the PCSS sample and 12 % in the PCSA sample. These results are similar to the findings of Jiratanan and Liu [25].

Degradation of betalains leads to other phenolic compounds, which stimulate the increase in the antioxidant activity. The cause of the increase could be the compounds released by the mechanical destruction of the cells. In our study, ABTS was used to determine the antioxidant activity of vegetable purée samples. The values of the antioxidant activity for all samples ranged from 2.1 ± 0.04 μmol·l^{-1} to 1.5 ± 0.03 μmol·l^{-1}. The order of antioxidant capacity of the vegetable purée samples was PCS > PCSA > PCSS. The high content of total carotenoids, β-carotene, lycopene and betalains in fresh (PCS) or reconstituted vegetable purée (PCSS or PCSA) showed that these bioactive compounds have a good antioxidant activity.

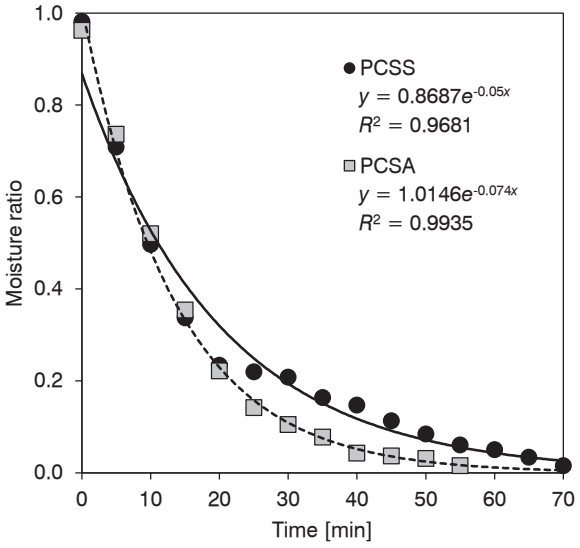

Fig. 1. Experimental and calculated drying curves.

PCSS – non-foamed dried vegetable purée, PCSA – foamed dried vegetable purée.

Microbiological analysis

Probiotics can be mixed or spread either in fresh or dry foods, and a current trend is to produce non-dairy products with additional contents of probiotic bacteria. Therefore, the production of food, especially fruit and vegetables, with added lactic acid bacteria, has become a subject of great interest of the food industry.

An important objective of this research work was to obtain a new dried product with a high rate of the survival of *Lb. delbrueckii* subsp. *bulgaricus* Lb12. The viability of Lb12 inoculated in the vegetable purée was investigated in its three forms, namely, fresh, non-foamed and foamed. Initially, the Lb12 population in fresh purée was 9.1 log CFU·g^{-1}, and it fluctuated between 8.5 CFU·g^{-1} and 7.9 log CFU·g^{-1} throughout the storage at refrigeration temperatures. A noticeable reduction in Lb12 viability was revealed after 28 days of storage for both foamed and non-foamed dried samples, as the counts decreased to 7.2 CFU·g^{-1} and 7.0 log CFU·g^{-1}, respectively. Comparable results were obtained by Rędo et al. [26] for apple samples inoculated by immersion with *Lb. plantarum*. The authors obtained a decrease of approximately 0.5 log CFU·g^{-1} after 20 days of storage.

For dried samples, the reduction in viability was more significant (by approximately 2 logs) after 14 days of storage, remaining almost constant for the other last five days of storage. The reduction may be a result of the drying procedure. Thus, cell death is probably caused by the water content decrease, leading to cell membrane disruption [26]. In a study conducted by Ribeiro et al. [27] on dried kiwi and strawberry inoculated with *Lb. plantarum*, a reduction of 0.5–1.5 log was obtained after 37 days of storage at 4 °C. Similar results were obtained by Betoret et al. [28] with apple cylinders impregnated with apple juice containing *Lb. rhamnosus* (10^{7}–10^{8} CFU·ml^{-1}), air-dried at 40 °C and stored at room temperature for two months. The results (dried samples PCSS and PCSA) revealed 10^{7} CFU·g^{-1} after the storage period of 28 days. Impregnation of vegetable matrices and viability of bacteria may be influenced by the drying procedure and the storage of these potentially functional foods. However, a vegetable may represent a good matrix in the development of functional food.

Tab. 2. Statistical values of drying model analysis for drying the purée samples under study.

Mathematical model	Type of vegetable purée	Model constants	R^2	*SSE*	*MSE*	*RMSE*
Henderson and Pabis model	PCSS (non-foamed dried)	a = 0.937, k = –0.059	0.968	0.181	0.002	0.043
	PCSA (foamed dried)	a = 1.005, k = –0.072	0.990	0.062	0.001	0.026

R^2 – coefficient of determination, *SSE* – sum of squared estimate of errors, *MSE* – mean squared error, *RMSE* – root mean square error.

Drying characteristics and model fitting

Drying kinetic curves were assessed to evaluate the effect of the air temperature on the moisture reduction and to estimate the drying time of the samples. From Fig. 1, the difference between the drying time of the dried samples can be observed. The drying time of the foamed dried vegetable purée was reduced by 21.4 % (55 min) compared to the non-foamed dried vegetable purée (70 min). From the drying curves shown in Fig. 1, it can be seen that the first stage of the drying process (up 20 min) was more intense in removing the moisture from the samples.

Results of the regression analysis performed for the experimental data are summarized in Tab. 2. For both foamed and non-foamed samples, the statistical parameter estimations showed that R^2 values ranged from 0.968 to 0.990, *SSE* values ranged from 0.062 to 0.181 and *RMSE* values ranged from 0.026 to 0.043. The high values of the R^2 coefficient (0.990) confirmed that the chosen model perfectly described the drying processes.

For a more detailed analysis of the mathematical model, the Pearson correlation test was performed. The value of Pearson correlation coefficient (r) was 0.929. A correlation coefficient (r) of 1 or very close to +1, means that for each positive increase of a variable, there is a positive increase of a fixed proportion in the other one. Thus, *MR* decreased in (almost) perfect correlation (r = 0.929) with the removal of water from the product, in a certain amount of time.

Another parameter in the statistical analysis is the coefficient of determination (Pearson) (r^2). The coefficient of determination (Pearson) represents the percent of the data that is the closest to the line of best fit. For example, if r = 0.929, then r^2 = 0.863, which means that 86.3 % of the total variation in Y can be explained by the linear relationship between time and *MR* (as described by the regression equation; Fig. 2). The remaining 13.7 % of total variation in Y remains unexplained.

Rheological properties

Data on the rheological behaviour of the purée samples in low amplitude oscillatory tests is shown in Fig. 3. It can be seen that reconstituted purée samples displayed better resistance to the applied strain (Fig. 3A) in comparison to the control sample-the fresh purée. The widest domain of strain within the linear viscoelastic region, where the applied strain does not affect the structure of the tested product, was observed for the PCSS purée sample, with a value of approximately 1 %, followed by the sample containing egg white (0.9 %). The fresh purée sample presented both low consistency and stiffness (lower G' and G" values) and low resistance to flow marked by the G'/G" intersection point, usually associated with the structure breakdown and beginning of flow. In this respect, the reconstituted purée sample containing egg white showed the highest resistance with an intersection point at 12 % strain, while the control sample (PCS) presented the G'/G" intersection point at 0.7 %. The effect of egg white addition in terms of the increase in resistance to flow could be explained by the elasticity increase due to polymer fraction increase in the matrix [29].

The rheological behaviour of the tested purées as a function of frequency sweep is shown in

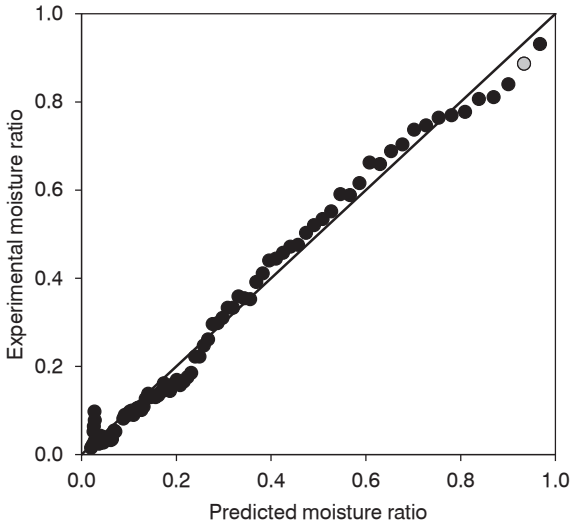

Fig. 2. Moisture ratio values of both samples predicted by the Henderson and Pabis model.

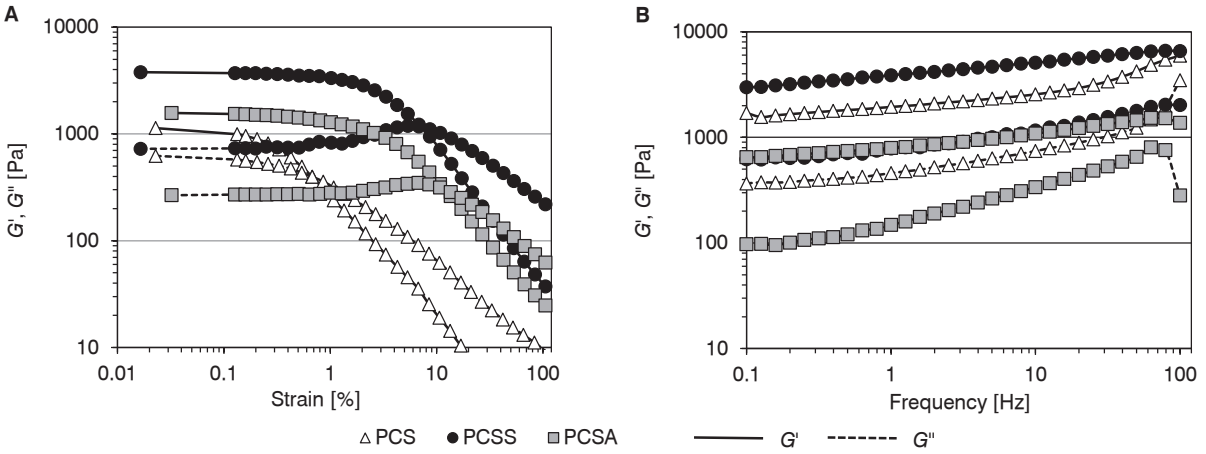

Fig. 3. Rheological behaviour of vegetable purée samples as a function of low amplitude oscillatory tests.

A – strain sweep, B – frequency sweep.
PCS – fresh vegetable purée; PCSS – non-foamed dried vegetable purée; PCSA – foamed dried vegetable purée.

Fig. 3B. The frequency sweep test provides information about the structural assembly of the viscoelastic material subjected to tests as a function of the time scale of the applied deformation. Thus, it is considered that a viscoelastic material will flow over long periods and bind over short periods when subjected to deformation. During the frequency sweep, the test purée samples behaved as soft solids with the elastic modulus *G'* exceeding the viscous modulus *G"* values, resembling a gel-like perfectly cross-linked behaviour, with no *G'*/*G"* intersection point.

Texture profile analysis

The results of the instrumental texture analysis are shown in Tab. 3. The firmness of the fresh purée sample registered the lowest value (0.6 N). The reconstituted samples showed higher values for firmness: 0.9 N for the sample obtained by foam-mat drying and 1.6 N for the sample obtained by convection drying. These results could be explained by the degree of water absorption during the rehydration process. Due to the damage to the vegetal tissue that occurred during drying, some of the solid particles lost their rehy-

Tab. 3. Effects of different drying treatments on instrumental texture and colour parameters of fresh and reconstituted vegetable purées.

	Type of vegetable purée		
	PCS (fresh)	PCSS (non-foamed dried)	PCSA (foamed dried)
Textural parameters			
Firmness [N]	0.6 ± 0.04	1.6 ± 0.14	0.9 ± 0.07
Adhesiveness [mJ]	1.8 ± 0.33	9.4 ± 0.64	6.5 ± 0.70
Cohesiveness	0.7 ± 0.03	0.7 ± 0.03	0.7 ± 0.01
Springiness [mm]	14.8 ± 0.13	11.8 ± 0.53	13.9 ± 0.43
Colour parameters			
*L** (clarity)	28.8 ± 0.09	27.6 ± 0.05	28.7 ± 0.08
*a** (red/green colour component)	22.0 ± 0.05	22.3 ± 0.06	22.6 ± 0.05
*b** (blue/yellow colour component)	7.6 ± 0.04	7.3 ± 0.05	7.1 ± 0.04
Δ*E* (total colour difference)	–	1.4 ± 0.06	0.8 ± 0.06
*C** (chroma)	23.3 ± 0.06	23.5 ± 0.07	23.8 ± 0.06
*h** (hue angle)	19.0 ± 0.04	18.2 ± 0.06	17.5 ± 0.04
BI (browning index)	81.1 ± 0.50	83.9 ± 0.50	80.3 ± 0.50

All values are mean ± standard deviation.

dration capacity. When the deformation was applied, these particles thronged at the bottom of the container, leading to an increase in resistance force. Adhesiveness, expressed as the energy required to detach the sample, was the highest (9.4 mJ) in the case of PCSS, while the lowest value (1.8 mJ) was registered for the fresh sample. This behaviour could be also correlated with the rehydration capacity. Cohesiveness, as well as springiness, had lower values in the case of the fresh purée, showing that the drying process had a negative influence on its structure. On the other hand, a comparison between samples revealed that the purée reconstituted from foam-mat dried powder was more similar to fresh samples. Therefore, it can be concluded that this drying process caused less damage to the vegetable structure in comparison to convection drying.

Colour

An important parameter for acceptability of a powdered product is its colour, because it is one of the main properties examined by the consumers and, therefore, reconstituted powder should have an almost identical colour to the fresh product [30]. The colour values of fresh and dried non-foamed or foamed vegetable purées are shown in Tab. 3.

The initial L^* value of fresh vegetable purée samples was 28.8 ± 0.09, which is the brightness indicator. In addition, the L^* value for dried samples was higher in the case of the foamed vegetable purée (PCSA), i.e. 28.7 ± 0.08. It seems that the results were influenced by the drying conditions. Similar results were obtained by ARSLAN and OZCAN [31] in the drying of red bell pepper.

With regard to the a^* coordinate (from green to red) for the PCS sample, this parameter had the value of 22.0 ± 0.05. The a^* values of dried non-foamed or foamed vegetable purée were higher when compared to those of the fresh sample, an indicator reflecting the darkening of the colour. A similar observation was made by GARCÍA-MARTINEZ et al. [32] regarding the drying process of apricots.

The drying process also affected the yellow-blue coordinate (b^*) with results corresponding to yellow for all the vegetable purée samples, as b^* ranged from 7.1 ± 0.04 to 7.6 ± 0.05. The yellow tone may be attributed to the presence of carotenoids in the vegetable purée.

The colour values of the non-foamed and foamed vegetable purées revealed that the total colour difference (ΔE) was higher in the case of the PCSS sample (1.4 ± 0.06) dried at 50 °C, due to the longer exposure to this temperature. The major causes of colour change were probably due to carotenoid degradation and non-enzymatic browning or the Maillard reaction.

The chroma of the vegetable purée samples ranged from 23.3 ± 0.06 (PCS) to 23.8 ± 0.06 (PCSA). Use of the foam-mat drying method resulted in a higher chroma value, which may be explained by the higher Maillard reaction.

The hue angle values of all the vegetable purée samples were between 19.0 ± 0.04 (PCS) and 17.5 ± 0.04 (PCSA), indicating the yellowish red colour of the fresh sample. A possible reason may be the fact that the fresh sample has a higher lycopene content in comparison to the other samples.

A significant factor in the drying processes, where enzymatic and non-enzymatic browning occurs, is the browning index (*BI*) which indicates the purity of the brown colour. The PCSS sample

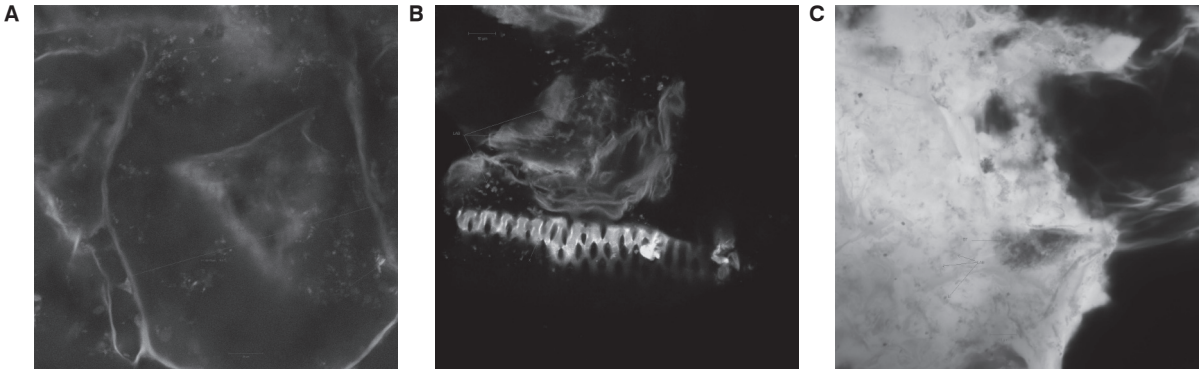

Fig. 4. Confocal laser scanning microscopy images of fresh and reconstituted vegetable purée with potatoes and red beetroot.

A – fresh vegetable purée, B – non-foamed dried vegetable purée, C – foamed dried vegetable purée.

showed the highest value (83.9 ± 0.5) for *BI* and the lowest value (80.3 ± 0.5) was registered for the sample obtained by foam-mat drying (PCSA).

Confocal laser scanning microscopy

Using confocal microscopy, we focused on the microstructure of the novel mixture of potato with red beet purée and added lactic acid bacteria, aiming at proving the functionality of the product. The fresh variant showed lactobacilli (in green) that agglutinated in the palisades, forming a biofilm on the surface of the vegetable (in yellow-green; Fig. 4A). Often, fragments of parenchymatic tissue, isodiametric cells (78.4–149.8 μm) with integral walls, could be observed. The dehydrated purée was a powder displayed as irregular, compact and hard flakes or scales with variable sides. These particles resulted from the aggregation of betalains from the beetroot and the starch from potatoes. The rehydrated variant (Fig. 4B and Fig. 4C) showed the presence of bioactive compounds from the red beet (in red) and the lactobacilli (in green) microencapsulated in the vegetal matrix (in yellow). The carbohydrate component of mashed potatoes is believed to be an important energy source for *Lb. delbrueckii* subsp. *bulgaricus* Lb12, which remained viable in a significant proportion according to the results of the quantitative microbiological analysis. It is known that during the thermal treatment, betanin can be degraded by isomerization, decarboxylation or cleavage, and the red colour is reduced step-by-step, allowing a brown colour to appear [33]. This original encapsulation formula can protect the antiradical properties of betalains. According to Vinson et al. [34], beetroot is classified among the top ten vegetables with a powerful antioxidant capacity, and some in vitro studies demonstrated that betalains are responsible for these properties [35]. In conclusion, it can be stated that carbohydrates from the vegetable matrix and ovalbumin act as an encapsulating material for *Lb. delbrueckii* subsp. *bulgaricus* Lb12 and for the red beetroot biocompounds with antioxidant properties.

CONCLUSIONS

The foam-mat drying method proved to be an efficient alternative for the processing of vegetable purée, since it allowed the development of a product with appropriate features for purée consumption. The study showed that the vegetable purée based on potatoes and red beetroot can be foamed using egg albumin as a foaming agent. In general, the drying of vegetable purée at a low temperature (50 °C) can better preserve the bioactive compounds (total carotenoids, β-carotene and lycopene) in foam-mat dried samples compared with non-foamed dried samples. *Lb. delbrueckii* subsp. *bulgaricus* Lb12 demonstrated good viability in the foam-mat dried samples (7.2 log CFU·g^{-1}) after 28 days of storage,. Textural analysis of the samples revealed that the vegetable purée reconstituted from foam-mat dried powder (PCSA) was more similar to the fresh samples (PCS) than the product dried by convection drying. With respect to colour, both drying methods produced very small changes of colour parameters. The results of the confocal microscopy were in accordance with the rheological and textural findings showing a weakening of the purée structure by drying.

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