Applicability of Foam Mat Drying Process for Production of Instant Cocoa Powder Enriched with Lavender Extract

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SUMMARY
The foam mat drying process is a simple and economical alternative to spray and freeze drying. It is considerably cheaper due to rapid drying at low temperatures, preservation of nutritional quality and easy reconstitution. Basic principle of the process is conversion of a liquid or a semi-liquid foodstuff to foam and thin layer drying of the foam.

This study explores the possibility of the foam mat drying process for production of instant cocoa powder enriched with lavender (Lavandula x hybrida L.) extracts. The aqueous extraction process of lavender was optimized using Taguchi orthogonal array design. Extracts obtained at optimal conditions were added to a mixture of egg white, cocoa powder, sugar and gelatine. Mixtures were blended for 4 minutes to obtain stable foam which was dried in a convective air dryer at three different temperatures (t=0, 60 and 70 °C) and milled into a powdered product. Drying rates were obtained from the experimental data using nonlinear model estimation. Flow properties, bulk density, particle size distribution, reconstitution and sensory properties of the final product were also assessed.

Based on the obtained data, the drying process was best described by Page’s drying model. Samples dried at lower temperature (t=50 °C) exhibited the best powder flow and reconstitution.

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properties. Sensory analysis resulted in similar findings: powders dried at lower temperatures had better appearance, colour and taste. Obtained data confirm the suitability of the foam mat drying process for production of lavender extract enriched instant cocoa powder.

**Key words**: foam mat drying, cocoa, lavender, powder flow, modelling

**INTRODUCTION**

Drying is one of the oldest and the most widespread food conservation method during which water is removed from the foodstuff resulting in dry food material with extended shelf life due to low moisture content (1). During drying, changes can occur in composition and texture of foodstuffs, including nonenzymatic browning, loss of bioactives or loss in rehydration capacity of the dried foodstuff (2). The food industry aims towards solving these problems by utilization of novel drying processes or the reinstallation of the existing, optimized to achieve minimal nutritive loss, minimal texture changes and the best sensory properties of the final product with the lowest possible economic cost of the drying process.

Foam mat drying is one of the re-emerging drying processes which has been known since 1959, but relinquished due to high economic costs of the first patented process (2). However, recent literature data states that the foam drying today is reported to be considerably cheaper than vacuum, freeze and spray drying methods (1,3). The advantages of the foam mat drying process include suitability for all types of juices, rapid drying at lower temperature, retention of nutritional quality, easy reconstitution and cost-effective for producing easily reconstitutable powders (3,4). There is literature proof of application of the foam mat drying process to fruit juices and pulps (5-13), shrimp puree (14), vegetable purees (15), fruit extracts (16,17) and even seed extracts (18), with most of them being categorised as sticky, high sugar content materials which usually cause problems when dried by any other drying method (e.g. spray or drum drying). The use of the foam mat drying process for the production of cocoa powder drink mixes still has not been explored, since these mixes belong into the group of high sugar content and sticky materials which are usually dried in foams. This paper, therefore, evaluates the possibility and the adequacy of the foam mat drying process for cocoa powder drink mix production.

One of the reasons for choosing the cocoa powder as a material for the foam mat drying process is its abundance in bioactive compounds, especially polyphenols (19). There are three groups of polyphenolics commonly occurring in cocoa products: flavonoids, anthocyanins and proanthocyanidins (20), known for their anti-cancerogenic, vasodilatory and anti-inflammatory effects (21-23). Interestingly, although abundant in bioactive compounds, cocoa powders and
other cocoa products are being used as vehicles for addition of other functional compounds such as vitamins, minerals or, more recently, herbal extracts. Herbal extracts are added to cocoa products not only because of their ability to enhance functional properties, but also due to their ability to affect taste and colour of such products (24,25).

Lavender, a plant from the Lamiaceae family, is known as a medicinal and an aromatic plant. It is mostly used for production of essential oils, which are further used in cosmetic and pharmaceutical industry. Another use, which is gaining popularity is as a tea plant, since recent studies revealed that, besides essential oils, it is rich in bioactive compounds such as ferulic acid, ursolic acid and kaempferol malonyl glucoside (26). In that way it can act as an aroma compound in food products and also as a bearer of functional properties. Although its extract can be added directly to food products, in order to preserve functional properties and stability of heat sensitive constituents, a microencapsulated form of the extract is often used.

This study explores the possibility of using the foam mat drying process for production of instant cocoa powder enriched with lavender (Lavandula x hybrida L.) extracts. The extract was added in two different forms: liquid and microencapsulated. Drying kinetics at three different temperatures (t=50, 60 and 70 °C) were described, as well as the physical, chemical and sensory properties of the foams and the final powdered products.

MATERIALS AND METHODS

Materials

Lavandula x hybrida L. dried plant material was used in this study. The plant material was obtained from a local manufacturer (Suban, Strmec Samoborski, Croatia), originating from the Međimurje county, Croatia, harvested during the 2015 flowering season. Liquid egg white was obtained from Elcon (Elcon prehrambeni proizvodi d.o.o., Zlatar Bistrica, Hrvatska), pork gelatine from Podravka (Podravka, Koprivnica, Croatia) and edible sunflower oil from Čepin (Čepin tvornica ulja, Čepin, Croatia). Sucrose and cocoa powder with 10–12 % fat content were obtained from Kraš (Kraš, Zagreb, Croatia).

Chemicals and reagents

Folin-Ciocalteu’s reagent and sodium carbonate were purchased from Kemika (Zagreb, Croatia). Trolox (6-hydroxy-2,5,7,8-tetra methylchromane-2-carboxylic acid) was obtained from Fluka (Buchs, Switzerland). Gallic acid (3,4,5-trihydroxybenzoic acid) and •1,1-diphenyl-2-picrylhydrazyl (DPPH) were obtained from Aldrich (Sigma–Aldrich Chemie, Steinheim, Germany), methanol was obtained from J.T. Baker (Philipsburg, SAD) and glycerol (85 %) from a local pharmacy (Gradska ljekarna Zagreb, Zagreb, Croatia).
Extract preparation
The extract was prepared by weighing $m=4$ g of herbal material which was then mixed with $V=200$ mL of distilled water. The glass containing the mixture was then put in an IKA Hbr 4 Digital oil bath (IKA Werke, Staufen, Germany) equipped with a magnetic stirrer set at 250 rpm and heated to $t=80$ °C. The extraction conditions were chosen based on a preliminary optimizing experiment using the Taguchi method (results not shown in this paper) (27). After 90 min, the mixture was taken out from the oil bath, cooled in a water/ice mixture and filtered through a cellulose filter paper (LLG Labware, Meckenheim, Germany) with 5-13 µm pore size. Half of the extract was used in further experiments as is, while the other half was used to prepare the microencapsulated extract.

Microencapsulated extract preparation
Matrix type microcapsules containing lavender extract were prepared by adding $m=0.8$ g of glycerol and $m=2$ g of gelatine to $V=20$ mL of liquid lavender extract. The solution was then left to cool in a refrigerator for 10 min. After 10 min the solution was heated to $t=80$ °C until all the gelatine was melted. The hot solution was then transferred in a syringe mounted on a NE-300 syringe pump (New Era Pump Systems, USA) with a flow rate of $q=1$ mL/min. The solution was pumped through a syringe containing a microcapilare tip ($d=50$ µm) into a glass filled with sunflower oil which was constantly cooled in an ice/water mixture. The formed microcapsules were stored in a refrigerator ($t=4$-6 °C) for 60 min after which the suspension was filtered through a kitchen sieve. Prepared microcapsules were stored in a refrigerator until use.

Foam mat drying of cocoa mixtures
Three sets of experiments were prepared for foam mat drying: control set without the addition of lavender extract (set 1, samples K50, K60 and K70), set containing the liquid lavender extract (set 2, samples L50, L60 and L70) and a set containing the microencapsulated lavender extract (set 3, samples M50, M60 and M70). All of the sets comprised of the same basic recipe: $m=150$ g of the basic cocoa mixture (cocoa/sucrose in a 30:70 ratio), $m=180$ g of egg white and 0.5 % ($m/m$) of gelatine. Sets 2 and 3 also contained extracts: set 2 contained 5 % ($m/m$) of the liquid extract and set 3 contained 5 % $m/m$ of the microencapsulated extract. The mixtures were prepared by mixing the liquid ingredients (egg white and extract, if contained) for 4 min using a kitchen blender (Philips, Amsterdam, The Netherlands). Dry ingredients were then slowly added until homogenous foam was obtained. After mixing, the foams were evenly spread ($h=4$ mm) into aluminium trays, put in a convectional air dryer (InkoLab, Zagreb, Croatia) and left to dry for 180 min at $t=50$, 60 and 70 °C. The drying temperatures were selected based on temperature stability of polyphenols and antioxidants, which indicated that
they are thermally stable at 50 °C and their disintegration starts above 60 °C. Drying time was not reduced for higher drying temperatures to evaluate the changes in quality of powders at the given conditions. Dried foams were milled (IKA Tube mill (IKA-Werke, Staufen, Germany) at 15000 rpm for 10 s in order to obtain a powdered product. The cocoa powders were stored in PE bags at t=4 °C until analysed.

**Modelling of the foam mat drying process**

During the drying process, experimental data for drying curves was obtained in the following manner: foam samples were taken from the dryer at 5 min intervals, weighed using a TE214S analytical balance (Sartorius, Götingen, Germany) and the moisture ratio was calculated according to Eq.1:

\[
MR = \frac{w - w_e}{w_0 - w_e}
\]

where MR is the dimensionless moisture ratio, \(w\) is the moisture content measured at time \(t\), \(w_0\) is the initial moisture content and \(w_e\) is the equilibrium moisture content on dry mass basis (28). The experimental data was used to calculate kinetic parameters of the drying process at 3 different temperatures (\(t=50, 60\) and 70 °C) using three different thin layer drying models: Newton (Eq.2), Henderson-Pabis (Eq.3) and Page (Eq.4), as described previously (28-30):

- Newton:
  \[
  MR = e^{-kt}
  \]
  (2/)

- Henderson-Pabis:
  \[
  MR = a \cdot e^{-kt}
  \]
  (3/)

- Page:
  \[
  MR = e^{-kt^a}
  \]
  (4/)

where MR is the dimensionless moisture ratio, \(k\) is the drying rate constant (1/min), \(t\) is time (min), \(a\) and \(N\) are empirical constants of the models. The adequacy of the models for the determination of the drying rates and the prediction of the moisture content at any given time of the drying experiment was assessed based on the determination coefficient (R\(^2\)) and root mean squared error (RMSE), as previously described by Benković *et al.* (28). Mathematical modelling of the experimental data was performed using the StatSoft Statistica v 10.0 software package (28,31).
Foam density and foam stability
Foam density was estimated as the ratio between mass and volume of the foam. Foam stability was measured as the ratio of foam volume immediately after mixing and after 2 hours of storage at room temperature (18).

Dry matter of the foams and the dried powders
Dry matter of the foams and the dried powders was determined based on a standard AOAC method (32) in convection oven (INKOLAB Zagreb, Croatia). All measurements were performed in triplicate.

Particle size distribution of the foam mat dried powders
Particle size distribution was determined by a laser diffraction method Malvern Mastersizer 2000 instrument with a Scirocco dry dispersion unit (Malvern Instruments, Malvern, United Kingdom). The laser obscuration was set to 2-6 %, feed rate to 60 % and air pressure at $p=100000$ Pa. All analyses were performed in triplicate.

Bulk density of the dried powders
Bulk density was determined according to a method previously described as Haugaard-Sorensen (33), using a laboratory made jolting volumeter. The bulk density of each sample was determined using the mass/volume relationship. Powder was poured into a graduated empty plastic container of predetermined tare weight, the mass and the volume of the sample in the container were recorded and bulk density was calculated by dividing sample mass with the sample volume, read after 10 vibrations, in order to minimise the error originating from uneven settlement of the powder surface in the measuring cylinder. Measurements were performed in triplicate.

Cohesion and caking of the dried powders
Cohesion and caking properties were assessed by a powder rheometer method (34). The cohesion test begins with two conditioning cycles to remove any stress history from the powder and to normalise the powder column after filling. The powder blade then moves down through the powder column using a "cutting" action to minimise compaction. The upward part of the cycle lifts the powder and the force of the powder on the vessel base is recorded. The negative area under the curve is the work required to move the blade through the powder column, which represents the cohesion coefficient. A cohesion index is calculated by dividing the cohesion coefficient by the mass of the sample (34).
The caking test begins with two conditioning cycles; the blade then levels the top of the powder column and measures the height of the column. The blade moves down through the column and compacts the powder to a pre-defined force (usually 750 g). When it reaches this force, it slices up through the powder and then repeats the compaction cycle four more times. The fifth time the target force is reached, the blade cuts through the cake of powder formed at the bottom of the vessel. This force is recorded as the cake strength and is the work required to cut the cake (g·mm) and the mean cake strength is the average force to cut the cake in grams (34).

Reconstitution properties
Reconstitution properties of the foam mat dried powders were assessed as solubility and dispersibility. Solubility was determined according to a modified method by Haugaard-Sorensen et al. (33). Approximately \( m = 2 \) g of sample was weighed and \( V = 10 \) mL of distilled water was added to the beaker containing the sample. The mixture was stirred with a spatula for 90 s and then left to settle for 15 min. After that, two 5-minute centrifugation cycles were performed (Type 2000, Hettich, Tuttlingen, Germany) at 2012 \( \times g \). After centrifugation, the volume of the sediment in the centrifuge tube (mL) represented solubility (35). Dispersibility was determined by a stirring test, as the time in seconds taken to disperse a given amount of powder into a given amount of water of a given temperature (33). \( V = 50 \) mL of distilled water (\( t = 24 ^\circ C \)) was poured into a beaker and \( m = 5 \) g of sample was added. At the same time, stop watch was started and manual stirring began (approximately 25 circular stirring movements within 15 s). Measurement was completed when all the lumps were dispersed (35).

Total polyphenolic content (TPC) and antioxidant capacity (AOC) of the foams and the dried powders
Total polyphenolic content (TPC) of samples was determined according to a modified method of Lachman et al. (36). Measurements were carried out in triplicate and the results were expressed as mg of gallic acid equivalents (GAE) per dry mass of sample and derived from a calibration curve determined for gallic acid (0-500 mg/L). Antioxidant capacity was determined using the DPPH method, previously described by Brandt-Williams et al. (37). Results were expressed as \( \mu \)mol of Trolox equivalents per dry mass of sample and derived from a calibration curve determined for Trolox (0–1 \( \mu \)mol/L). Measurements were performed in triplicate.
Sensory properties

Sensory properties of the formulated mixtures were evaluated according to a hedonistic scale. Panellists \((n=5)\), in the age from 25 to 40, three female and two male, trained according to a multi-step procedure presented by Silva et al. (38) were asked to evaluate the prepared drinks based on appearance, colour, odour, sweetness, aftertaste and lavender aroma. The drinks were prepared in the following manner: 5 g of cocoa powder was dissolved in 100 mL of milk with 2.8 % fat (Dukat, Zagreb, Croatia), previously heated to 90 °C. The prepared drinks were left to cool to 40 - 45 °C before they were served to the panellists in 100 mL plastic cups, starting from the sample set K, followed by the samples containing the liquid extract and ending with the powders containing the microencapsulated extract. Water was used for mouth rinsing. Extremely Sensory analysis was conducted at ambient conditions of 19 °C and a relative humidity of 45 %. Drinks were evaluated based on a scale in the range of 1 to 9 (1-dislike extremely, 9-like extremely).

Data analysis

Differences between measurements for a given property were analysed by ANOVA with \(p<0.05\) taken as the significance level. In order to estimate a combined effect of temperature and extract type on physical, chemical and sensory properties of foam mat dried powders, main effects ANOVA (MANOVA) was performed using the StatSoft Statistica software (28,31). Differences among samples were considered significant at \(p<0.05\).

RESULTS AND DISCUSSION

Applicability of the foam mat drying process for production of cocoa powder enriched with lavender extract, as well as the effect of three drying temperatures \((t=50, 60 \text{ and } 70 \text{ °C})\) and extract types (no extract, liquid extract and microencapsulated extract) on physical, chemical and sensory properties was estimated in this research.

Drying kinetics

For each drying temperature applied in this study, drying curves were constructed and mathematical models were used to calculate the kinetic parameters of the drying process. Results are shown in Table 1.

Table 1.

As visible from Table 1, set 1 (control samples, without the addition of lavender extracts) had a drying rate constants ranging from \(k=0.0070\) 1/min (at \(t=50\) °C) to \(k=0.0080\) 1/min (at \(t=70\) °C) calculated from the Newton model. For the Page model the calculated constants were as follows: \(k=0.0194\) 1/min for \(t=50\) °C, \(k=0.0322\) 1/min for \(t=60\) °C and \(k=0.0379\) 1/min for \(t=70\) °C.
9°C. Drying rate constants calculated using the Henderson-Pabis model were lower in comparison to the ones determined by the Newton and Page: $k = 0.0063 \text{ 1/min for } t=50 \, ^\circ\text{C}$, $k = 0.0060 \text{ 1/min for } t=60 \, ^\circ\text{C}$ and $k = 0.0068 \text{ 1/min for } t=70 \, ^\circ\text{C}$. It can be concluded that drying at higher temperatures resulted in higher drying rate constants due to better diffusivity of the moisture towards the surface of the foam as a consequence of increased kinetic energy (2).

An exception can be seen in the data for drying rate obtained by the Henderson-Pabis model, where the drying rate was the highest at $t=70 \, ^\circ\text{C}$, but the two lower temperatures did not show a rising trend of the drying rate constant with an increase of temperature. Since the difference is seen in the fourth digit behind the decimal point ($k = 0.0063 \text{ 1/min for } t=50 \, ^\circ\text{C}$ in comparison to $k = 0.0060 \text{ 1/min for } t=60 \, ^\circ\text{C}$ (with a standard error of 0.0002 1/min for $k$ at $t=50 \, ^\circ\text{C}$ and 0.0003 1/min for $k$ at $t=50 \, ^\circ\text{C}$)), the difference can be attributed either to experimental error or the approximation error used by the Levenberg-Marquardt algorithm in the Statistica software during modelling. In the case of the liquid lavender extract addition, the drying rate constants were higher compared to the drying rate constants without the extract addition. This can be explained by the higher initial moisture content of the foams, since the direct addition of the liquid extract leads to an increase in moisture content. Due to the presents of higher amounts of moisture in the foam, there is also more moisture which can be evaporated from the foams.

The highest drying rate constants were obtained for the drying process at $t=70 \, ^\circ\text{C}$ for the Newton and Henderson-Pabis model, while the Page model exhibited an exception at 50 °C with the highest $k$, detected for the sample with the microcapsules addition ($k = 0.0764 \text{ 1/min}$). When the microencapsulated extract was added to the samples, the drying rate constants did not exhibit a rise with an increase of temperature. E.g. the highest drying rate constants determined by the Newton and the Henderson-Pabis models were detected for $t=70 \, ^\circ\text{C}$, followed by the ones for $t=50 \, ^\circ\text{C}$ and $t=60 \, ^\circ\text{C}$, while for the Page model the highest drying rate was detected for the $t=50 \, ^\circ\text{C}$ drying temperature. The discrepancies in the results can be explained by the presence of gelatine as the matrix material for the microcapsules. Namely, gelatine is known as a polymeric substance which is very often used in the food industry as a gelling agent (39). According to literature data (40), at temperatures above $t=50 \, ^\circ\text{C}$ gelatine exists in solution as a monomer, while above $t=60 \, ^\circ\text{C}$ undergoes glass transition. During cooling, gelatine network is formed which affects the thermal properties of the solutions (40). Furthermore, an increase of the drying temperature of gelatine from $t=10 \, ^\circ\text{C}$ to $t=70 \, ^\circ\text{C}$ decreases the content of crystalline structures and increases the content of amorphous structures (41) which also affects thermal properties of the solution. A change in gelatine structure could be the explanation of the differences in the drying rate; however, this claim needs to be supported by at least an ESEM image, or DSC which is a subject of future research.
Based on the coefficient of determination values and RMSE, the best agreement between model predicted and experimental data was achieved for the Page model for all three sets of samples dried at all three tested temperatures (Table 1), confirming the applicability of the Page model for description of the thin layer foam mat drying process. Furthermore, the drying kinetics is influenced by both, the drying temperature as well as the type of extract used. The highest drying rate was observed for samples with liquid extract (set 2), followed by the samples with microcapsules (set 3) and the samples without the addition of lavender extracts (set 1).

**Foam physical properties**

Foam density, stability and dry matter content results are shown in Table 2.

Table 2.

Foam density is an important property which influences the drying process, as well as the properties of the final product. Generally, foaming enables incorporation of air in the material which is dried thus enhancing the drying process (9). Foam density values ranged from minimal $\rho=0.53$ g/mL (set 2 with the addition of liquid extract) to maximal $\rho=0.73$ g/mL (set 1, without extract addition) (Table 2). These ranges are in accordance with literature data for foam densities obtained for drying of cantaloupe using egg white and xanthan gum as foaming agents (12), sour cherry using egg-white and methyl cellulose (1 %) as foaming agents and stabilizers (10) and yoghurt using methyl cellulose and egg albumin (42). However, these values are higher when compared to research by (13), (15) and (17) where foams densities were much lower ($\rho=0.2 – 0.35$ g/mL) due to larger amount of air incorporated in the foam. It is visible that the addition of the liquid extract reduces the foam density values significantly ($p<0.05$), enabling the foam to be more porous. The microencapsulated extract addition had a similar effect on the foam density, but less pronounced compared to the liquid extract.

Foam stability values measured after 120 min of settlement at room temperature was 99.99 ± 0.01 % (Table 2) for all sample sets indicating that egg white is an excellent foaming agent and that the mixing of 4 min is sufficient to obtain a stable foam. According to literature data (4), a foam is considered mechanically and thermally stable to undergo the foam mat drying process, when there is no significant reduction of volume after one hour at room temperature, which was the case with all sample sets used in this research.

Dry matter content of the foams ranged from 53.21 to 54.99 % (Table 2), which exceeded the minimal requirements for the foam mat drying process set at 20 % of dry matter (2). The highest foam dry matter was detected for the samples containing the microencapsulated extract (set 3), followed by the samples with the addition of the liquid extract (set 2) and finally the control.
samples (set 1), which is a logical result since sets 2 and 3 contained additional dry matter from the extracts and the microcapsules.

Physical properties of the foam mat dried powders

Particle size distribution, bulk density, dry matter content, flow properties (cohesion index, mean cake strength) and the reconstitution properties (dispersibility and solubility) were analysed for the powders obtained after drying and the results are shown in Table 3.

Table 3.

Table 3.

Particle size is one of the most important property which affects the behaviour of powders during handling, transportation and storage (43). The median diameter ($d(0.5)$) of the foam mat dried cocoa powders ranged from 148.12 (set 1, $t=70\,^\circ C$) to 186.04 µm (set 3, $t=60\,^\circ C$) (Table 3). When looking only at the control set, the particle size of the powders drops significantly ($p<0.05$) with a rise in drying temperatures, which was an indication that higher drying temperatures produce brittle powders with less moisture. The same trend was observed for set 2 with the addition of the liquid extract. In case of the microencapsulated extract addition, the highest particle size was obtained for the powder dried at $t=60\,^\circ C$. As argued before, the explanation behind this effect can be attributed to gelatine properties, but these claims are still left to be confirmed in future research. Furthermore, the effect of the type of extract added on particle size was the most evident for the 60 °C treatment, where a significant rise in particle size was visible ($p<0.05$): the lowest $d(0.5)$ was detected for the control sample set, followed by the liquid extract (set 2) and the microencapsulated one (set 3). At 70 °C, only the control sample exhibited a significantly lower ($p<0.05$) value of $d(0.5)$ in comparison to the values detected for sets 2 and 3.

A drop in the bulk density values of the powders was detected with a rise in drying temperature for sets 1 and 2, as confirmed by the significant differences in the bulk density shown in Table 3. The powders with the microencapsulated extract (set 3) exhibited an opposite trend, with significantly lower bulk density values detected for treatments at 50 °C and similar values of bulk density for treatments at 60 and 70 °C, which can be attributed to gelatine properties. The effect of the type of extract was visible for treatments at 50 and 60 °C: the control samples had the highest values of bulk density, with the values dropping when a liquid extract was added towards the lowest values when the microencapsulated extract was added. Lower bulk density values mean that there is more air entrapped between or in the particle pores, which can be connected to the foam density values shown previously in Table 2. Namely, as argued before, addition of both types of extracts led to lower foam densities, entrapping more air in the voids between foam structures, which subsequently had an effect on lowering the bulk density of those powders.
The effect of the drying temperature on the dry matter content was the same for all three sets of experiments: increased drying temperature caused an increase in dry matter content of the dried powders, which is in accordance with literature data (42), since higher drying temperatures increase the kinetic energy of molecules of water which need to migrate from the matrix and therefore accelerate the heat and mass transfer processes. Powder flow properties were assessed rheometrically with two analyses: cohesion and caking. Cohesion index of the control samples (set 1) ranged from 13.47 to 14.92 mm, categorizing them in the range of easy flowing to cohesive samples (44). The control sample dried at $t=70\, ^\circ\text{C}$ exhibited the highest values of cohesion index, which can be connected to lower values of $d(0.5)$, since the literature states that powders with lower particle sizes usually exhibit poorer flow properties (45). Increased drying temperature also led to an increase in cohesion index values for all sets, which can once again be explained by a decrease in particle size. Namely, lower particle size values increase the specific surface area of the particles making them more reactive and prone to cohesion and caking (45). The effect of extract addition was also visible: sets 2 and 3 exhibited significantly higher ($p<0.05$) cohesion index values compared to the control set, which categorized those powders in the range very cohesive to extremely cohesive. Unlike the cohesion index, the mean cake strength values did not show the same trend of temperature and extract addition dependence. It was visible for all the samples that the samples dried at $t=70\, ^\circ\text{C}$ exhibited the highest mean cake strength values, with a significant rise ($p<0.05$) in mean cake strength values with extract addition. A rise in cake strength values with the addition of extracts was also detected for the $t=60\, ^\circ\text{C}$ drying temperature. However, an exact opposite was detected for the drying temperature $t=50\, ^\circ\text{C}$: mean cake strength value was the highest for set 1, followed by set 2 and 3. An interesting observation is also that the lowest mean cake strength values were visible for the powders dried at $t=60\, ^\circ\text{C}$. This could be explained by three adverse effects: firstly, the conformational changes of egg white appear at $t=60\, ^\circ\text{C}$, indicating possible protein coagulation (46) and thus an influence on caking properties. Second, the glass transition of sucrose is around $t=62-70\, ^\circ\text{C}$ (47), where structural changes of sucrose can affect caking behaviour and third the polymorphism of the fatty acids present in cocoa powder which are known to have polymorphic effects where melting occurs at $t=55\, ^\circ\text{C}$, then solidification up to $t=71\, ^\circ\text{C}$ where the fat melts again (48). Once again, we must emphasize that more research is needed to support these claims, preferably on simpler, model mixtures comprising of less components so each effect can be studied separately.

Reconstitution properties, estimated as dispersibility and solubility, ranged from 21 to 32 seconds for dispersibility and from 0.8 to 1.5 mL for solubility. Although significant differences were detected among samples, no confirmation of an undisputed rise or fall trend with an increase in drying temperature of the type of extract added could be drawn. In this case we
must emphasize that the methods chosen for the determination of solubility and dispersibility, although extensively used, in this case have proven to be too subjective (e.g. the readout of the volume of the sediment which was then shown as solubility was similar for all samples, as well as the visible estimation of whether the whole volume of the powder was dispersed in water at a given time readout), and we therefore, recommend different methods to be used for such types of powders.

**Chemical properties of the foams and the foam mat dried lavender enriched cocoa powders**

Experimental results describing the total polyphenolic content (TPC) and the antioxidant capacity (AOC) of foams and the foam mat dried powders are shown in Fig.1.

Data shown in Fig.1a describes the TPC of the foams prior to drying and the foam mat dried powders. The TPC content of the foams ranged from GAE=0.74 mg/g dm, detected for the control foam, to GAE=0.81 mg/g dm, detected for the foam with the microencapsulated extract, leading to a conclusion that the lavender extract addition contributed to the TPC of the foams. According to literature data, cocoa powder contains a certain amount of polyphenols (20), which is higher than the levels detected in this work. The reason for the reduced TPC of the mixtures used in this study is the addition of egg white as the foaming agent, which does not contain polyphenols. Furthermore, the addition of lavender extract could not make up for the addition of egg white, so the TPC content could not reach the levels present in pure cocoa powder. It can also be noticed that the TPC content of the powders after drying was lower than prior to drying, indicating a thermal degradation of phenolic compounds during the drying process. However, there are some studies available in the literature which have come to the opposite conclusions: a higher amount of total polyphenols after the drying process was obtained in the study by Lobo et al. (49) during the mango pulp drying. According to them, higher TPC is a consequence of heat treatment leading to a simplified extraction of the polyphenolic compounds from the food matrix. In control samples (set 1), higher drying temperatures resulted in powders with lower TPC content, which was also the case with the samples containing the microencapsulated extract. However, in sample set 2 higher drying temperatures resulted in higher TPC values of the final powders. A similar finding was reported by Wojdylo et al. (50), which conducted drying trials on cherries and concluded that the higher TPC content is a result of polyphenols being released from the cells during the heat treatment which aided the extraction process. In this case, a possibility remains that the liquid extract was bound to the foam matrix and remained protected through the drying process and, in a way, concentrated with the increase of dry matter during drying. However, in this case, we must emphasize that this still has to be confirmed by future research.
The highest antioxidant capacity values measured by the DPPH method (Fig. 1b) ranged from TE=4.20 μmol/g dm (foam control) to TE=2.78 μmol/g dm (foam M) detected for the foams prior to drying. After drying, the AOC values were significantly lower (p<0.05) when compared to the level of antioxidants detected in the foam control samples. Once again, the liquid extract proved to be more stable during the drying process in a given food matrix (egg white, sugar and gelatine) in comparison to the microencapsulated one. This could be explained by the fact that some polyphenols and antioxidants are known to bind and form stable complexes with proteins, which influences their physiological and chemical properties (51, 52).

**Sensory evaluation and consumer preferences of the foam mat dried lavender enriched cocoa powders**

Sensory analysis data for the foam mat dried lavender enriched cocoa powders is shown in Fig. 2.

Regarding the scores for drink appearance, the best graded sample was K50, dried at $t=50 \, ^\circ C$ and with no lavender extract addition. The lowest graded appearance was for sample L70, containing the liquid lavender extract and dried at $t=70 \, ^\circ C$. The samples also differed by colour grades, where the samples dried at the lowest temperature ($t=50 \, ^\circ C$) obtained higher grades in comparison to those dried at $t=70 \, ^\circ C$. According to literature data, the drying (roasting) process has a significant effect on the quality of cocoa: the choice of an adequate drying temperature influences the characteristic cocoa aroma, loss of water, volatile acids and tannin compounds, as well as deepening of the brown colour if the bean and release of gaseous compounds (53). In this case, since the cocoa used was already roasted, drying at higher temperatures had deteriorating effect on the colour, as well as on the flavour of the powders. The same was observed for odour and sweetness. As for the grades for aftertaste and lavender aroma, it could be concluded that the lavender aroma was very pronounced in samples with liquid lavender extract, and less pronounced in those containing the microencapsulated extract. There are two explanations for such a finding: first, microencapsulation is used to mask undesirable flavours, which could have been the case in this study. The second explanation is connected to the composition of the powders. Namely, the powders containing the microencapsulated extract also contained 5 % m/m of the microcapsules, but when taken into account that the microcapsules were made with the addition of 2 g gelatin per 20 mL extract, the concentration of lavender was smaller in those samples was slightly smaller. The most accepted samples based on aftertaste were once again those which were dried at lower temperatures. Based on these sensory scores, it could be concluded that lower drying temperature resulted in drinks which had higher acceptability for consumers, while the lavender aroma was very much a matter of user preferences: some consumers preferred to taste the...
lavender aroma in the cocoa drink, while the others did not like it as much. Furthermore, the microencapsulated lavender extract containing cocoa powders had a slightly damped lavender aroma which was more acceptable for consumers.

**Combined influence of the temperature and the extract type on physical, chemical and sensory properties of the foam mat dried lavender extract enriched cocoa powder**

Combined influence of temperature and extract type added was assessed using the main effects ANOVA (MANOVA). Results are shown in Table 4.

| Table 4. Significant influence of the drying temperature and the type of extract added to the mixtures was detected for the following properties: powder dry matter ($R^2=0.9823$), cohesion index ($R^2=0.7919$) and sensory properties: appearance ($R^2=0.9392$), colour ($R^2=0.9274$), odour ($R^2=0.7335$), sweetness ($R^2=0.7827$) and aftertaste ($R^2=0.8674$) (Table 4). When dried at higher temperatures, the dry matter content of the resulting material is lower. The influence of the drying temperature and the extract type on the cohesion index of the powder can be attributed to the initial moisture content, which, when higher, influences the drying rates, as well as the final moisture content of the powders. According to literature data, powder flow properties are highly dependent on the moisture content: higher moisture content causes flow difficulties (45). Interestingly, MANOVA did not show a significant simultaneous effect of temperature and extract type on the TPC and AOC content of the dried powders. However, as mentioned before, significant differences were detected between the foams prior to drying and the powders after drying. Influence on the drying temperature and the type of extract added on the sensory properties was observed in cases where the consumers preferred the powders dried at lower temperatures ($t=50 \degree C$) and the masking of the lavender aroma when the microencapsulated extract was added. Although not significant based on the MANOVA results ($p=0.06$), the influence of the lavender aroma cannot be completely excluded from the sensory analysis, since the lavender plant contains essential oils which are known to have a strong effect on the organoleptic properties of food (54).

**CONCLUSION**

The foam mat drying process was applied to produce lavender extract enriched cocoa powders. The effect of drying temperature was evident on the drying rate constants: higher drying temperatures increased the drying rate values (drying rate constants calculated from the Page model ranged from $k=0.0159$ 1/min to $k=0.0764$ 1/min at $t=50 \degree C$; from $k=0.0219$ 1/min to $k=0.0572$ 1/min at $t=60 \degree C$; from $k=0.0379$ 1/min to $k=0.0544$ 1/min at $t=70 \degree C$). The extract type also influenced the drying rates: lower constants calculated from the Page model
were detected for control samples (0.0194-0.0379 1/min) while higher values were obtained for liquid (0.0159-0.0572 1/min) and microencapsulated extracts (0.0219-0.0764 1/min). Powders with the addition of the microencapsulated extracts had the highest cohesion index values (from 19.06 to 26.57 mm). The combined effects of temperature and extract types were detected on the powder dry matter content, cohesion index, appearance, colour, odour, sweetness and aftertaste (with adjusted $R^2$ values between 0.7335 and 0.9823). Sensory properties depended on both the drying temperature and the extract type: the consumers preferred the powders dried at lower temperatures ($t=50 \, ^\circ C$) and the microencapsulated extract.

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CONFLICT OF INTEREST
The Authors have no conflict of interest to declare.

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LIST OF FIGURES

Fig. 1. Total polyphenolic content (a) and the antioxidant capacity (b) of the foams and the foam mat dried powders. Samples marked foam control represents the foam sample without extract addition, foam L the foam with the liquid extract addition and foam M the foam with the microencapsulated extract addition. Samples L50, L60 and L70 represent set 2 (set containing the liquid lavender extract dried at t=50, 60 and 70 °C), samples M50, M60 and M70 represent set 3 (set containing the microencapsulated lavender extract dried at t=50, 60 and 70 °C). Different letters above the column represent significant differences (p<0.05).

Fig. 2. Sensory evaluation of the drinks prepared with the foam mat dried lavender extract enriched cocoa powders. Samples K50, K60 and K70 represent set 1 (control set without the addition of lavender extract dried at t=50, 60 and 70 °C), samples L50, L60 and L70 represent
set 2 (set containing the liquid lavender extract dried at $t=50$, 60 and 70 °C), samples M50, M60 and M70 represent set 3 (set containing the microencapsulated lavender extract dried at $t=50$, 60 and 70 °C).
Table 1. Parameters estimated for Newton, Page and Henderson-Pabis models for foam mat drying at 50, 60 and 70 °C. The model which describes the experimental data the best is printed in bold.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temperature/°C</th>
<th>50</th>
<th>60</th>
<th>70</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Estimated parameter value</td>
<td>Standard error for</td>
<td>R²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>k 1/1/min; N/-; a/-</td>
<td>k 1/1/min; N/-; a/-</td>
<td></td>
</tr>
<tr>
<td>Set 1 (control)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newton</td>
<td>k = 0.0070</td>
<td>0.0002(k)</td>
<td>0.9760</td>
<td>0.0328</td>
</tr>
<tr>
<td>Page</td>
<td>k = 0.0194; N=0.7520</td>
<td>0.0018(k)</td>
<td>0.9967</td>
<td>0.0042</td>
</tr>
<tr>
<td>Henderson-Pabis</td>
<td>a = 0.9604; k=0.0063</td>
<td>0.0109(a)</td>
<td>0.9864</td>
<td>0.0112</td>
</tr>
<tr>
<td>Set 2 (liquid lavender extract)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newton</td>
<td>k = 0.0080</td>
<td>0.0002(k)</td>
<td>0.9882</td>
<td>0.0202</td>
</tr>
<tr>
<td>Page</td>
<td>k = 0.0159; N=0.8304</td>
<td>0.0017(k)</td>
<td>0.9964</td>
<td>0.0050</td>
</tr>
<tr>
<td>Henderson-Pabis</td>
<td>a = 0.9737; k=0.0075</td>
<td>0.0100(a)</td>
<td>0.9915</td>
<td>0.0014</td>
</tr>
<tr>
<td>Set 3 (microencapsulated lavender extract)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newton</td>
<td>k = 0.0090</td>
<td>0.0006(k)</td>
<td>0.7769</td>
<td>0.0947</td>
</tr>
<tr>
<td>Page</td>
<td>k = 0.0764; N=0.4697</td>
<td>0.0113(k)</td>
<td>0.9797</td>
<td>0.0050</td>
</tr>
<tr>
<td>Henderson-Pabis</td>
<td>a = 0.8716; k=0.0063</td>
<td>0.0279(a)</td>
<td>0.9021</td>
<td>0.0029</td>
</tr>
</tbody>
</table>
Table 2. Foam properties of the mixtures, determined only prior to drying. Different symbols in the same column represent significant differences ($p<0.05$) between the same parameter for different sets.

<table>
<thead>
<tr>
<th>Sample</th>
<th>$\rho$/(g/mL)</th>
<th>Foam stability/%</th>
<th>$w$(dry matter)/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1 (control)</td>
<td>$(0.73\pm0.10)^a$</td>
<td>$(99.99\pm0.01)^*$</td>
<td>$(53.21\pm0.55)^#$</td>
</tr>
<tr>
<td>Set 2 (liquid lavender extract)</td>
<td>$(0.53\pm0.04)^b$</td>
<td>$(99.99\pm0.01)^*$</td>
<td>$(53.26\pm0.77)^5$</td>
</tr>
<tr>
<td>Set 3 (microencapsulated lavender extract)</td>
<td>$(0.63\pm0.07)^c$</td>
<td>$(99.99\pm0.01)^*$</td>
<td>$(54.99\pm0.02)^5$</td>
</tr>
</tbody>
</table>
Table 3. Physical properties of the foam mat dried powders. Different letters (a,b,c) in the same row—significant differences for the same parameter but for different temperatures (→). Different symbols (*,#,$) in the same column—significant differences between same parameter but for different sets (↓).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temperature/°C</th>
<th>50</th>
<th>60</th>
<th>70</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Powder property</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>d(0.5)/µm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set 1</td>
<td></td>
<td>(169.74±0.54)ᵃ</td>
<td>(154.18±2.55)ᵇ</td>
<td>(148.12±2.21)ᶜ</td>
</tr>
<tr>
<td>(control)</td>
<td>ρᵥ/(g/mL)</td>
<td>(0.65±0.03)ᵃ</td>
<td>(0.64±0.02)ᵇ</td>
<td>(0.57±0.01)ᵇ</td>
</tr>
<tr>
<td></td>
<td>w(dry matter)/%</td>
<td>(95.73±0.03)ᵃ</td>
<td>(97.18±0.05)ᵇ</td>
<td>(98.49±0.21)ᶜ</td>
</tr>
<tr>
<td></td>
<td>Cohesion index/mm</td>
<td>(14.00±0.01)ᵃ</td>
<td>(13.47±0.03)ᵇ</td>
<td>(14.92±0.04)ᶜ</td>
</tr>
<tr>
<td></td>
<td>Mean cake strength/(g-mm)</td>
<td>(104.49±4.64)ᵃ</td>
<td>(47.43±4.99)ᵇ</td>
<td>(113.72±11.18)ᵃ</td>
</tr>
<tr>
<td></td>
<td>Disperability/s</td>
<td>(22.50±1.00)ᵃ</td>
<td>(26.50±1.00)ᵇ</td>
<td>(24.00±1.00)ᵃ</td>
</tr>
<tr>
<td></td>
<td>Solubility/mL</td>
<td>(1.20±0.03)ᵃ</td>
<td>(1.00±0.01)ᵇ</td>
<td>(1.50±0.03)ᶜ</td>
</tr>
<tr>
<td>Set 2 (liquid lavender extract)</td>
<td>d(0.5)/µm</td>
<td>(167.57±2.62)ᵃ #</td>
<td>(164.30±2.87)ᵇ #</td>
<td>(160.55±1.22)ᵇ $</td>
</tr>
<tr>
<td></td>
<td>ρᵥ/(g/mL)</td>
<td>(0.60±0.01)ᵃ #</td>
<td>(0.60±0.04)ᵇ #</td>
<td>(0.59±0.02)ᵇ</td>
</tr>
<tr>
<td></td>
<td>w(dry matter)/%</td>
<td>(96.14±0.02)ᵃ #</td>
<td>(97.21±0.11)ᵇ #</td>
<td>(98.61±0.05)ᶜ</td>
</tr>
<tr>
<td></td>
<td>Cohesion index/mm</td>
<td>(14.74±0.02)ᵃ #</td>
<td>(16.10±0.04)ᵇ #</td>
<td>(19.06±0.02)ᶜ #</td>
</tr>
<tr>
<td></td>
<td>Mean cake strength/(g-mm)</td>
<td>(93.41±3.88)ᵃ #</td>
<td>(60.33±5.16)ᵇ #</td>
<td>(155.36±4.00)ᶜ #</td>
</tr>
<tr>
<td></td>
<td>Disperability/s</td>
<td>(23.50±0.50)ᵃ #</td>
<td>(32.00±1.00)ᵇ #</td>
<td>(23.00±1.00)ᵃ</td>
</tr>
<tr>
<td></td>
<td>Solubility/mL</td>
<td>(1.20±0.03)ᵃ #</td>
<td>(1.50±0.05)ᵇ #</td>
<td>(1.50±0.05)ᵇ</td>
</tr>
<tr>
<td>Set 3 (microencapsulated lavender extract)</td>
<td>d(0.5)/µm</td>
<td>(166.76±2.27)ᵃ #</td>
<td>(186.04±1.00)ᵇ $</td>
<td>(158.79±2.15)ᶜ #</td>
</tr>
<tr>
<td></td>
<td>ρᵥ/(g/mL)</td>
<td>(0.53±0.02)ᵃ #</td>
<td>(0.58±0.01)ᵇ #</td>
<td>(0.58±0.02)ᵇ</td>
</tr>
<tr>
<td></td>
<td>w(dry matter)/%</td>
<td>(95.76±0.12)ᵇ $</td>
<td>(97.43±0.02)ᵇ $</td>
<td>(98.67±0.06)ᵃ</td>
</tr>
<tr>
<td></td>
<td>Cohesion index/mm</td>
<td>(19.06±0.01)ᵃ $</td>
<td>(19.25±0.02)ᵇ $</td>
<td>(26.57±0.06)ᵇ $</td>
</tr>
<tr>
<td></td>
<td>Mean cake strength/(g-mm)</td>
<td>(72.90±6.49)ᵃ $</td>
<td>(67.01±2.08)ᵇ $</td>
<td>(227.94±5.3)ᵇ $</td>
</tr>
<tr>
<td></td>
<td>Disperability/s</td>
<td>(28.50±1.50)ᵃ $</td>
<td>(24.00±0.50)ᵇ</td>
<td>(21.00±0.50)ᵇ #</td>
</tr>
<tr>
<td></td>
<td>Solubility/mL</td>
<td>(1.20±0.01)ᵃ</td>
<td>(1.45±0.01)ᵇ #</td>
<td>(1.50±0.02)ᵇ</td>
</tr>
<tr>
<td>Variable</td>
<td>Multiple R</td>
<td>Multiple $R^2$</td>
<td>Adjusted $R^2$</td>
<td>F</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------------</td>
<td>----------------</td>
<td>----------------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>Powder dry matter</strong></td>
<td>0.9956</td>
<td>0.9911</td>
<td>0.9823</td>
<td>112.1057</td>
</tr>
<tr>
<td>d(0.5)</td>
<td>0.7790</td>
<td>0.6068</td>
<td>0.2136</td>
<td>1.5431</td>
</tr>
<tr>
<td>Bulk density</td>
<td>0.7913</td>
<td>0.6262</td>
<td>0.2524</td>
<td>1.6751</td>
</tr>
<tr>
<td>CI</td>
<td>0.9465</td>
<td>0.8959</td>
<td>0.7919</td>
<td>8.6108</td>
</tr>
<tr>
<td>MCS</td>
<td>0.8832</td>
<td>0.7800</td>
<td>0.5600</td>
<td>3.5460</td>
</tr>
<tr>
<td>Dispersibility</td>
<td>0.6631</td>
<td>0.4397</td>
<td>-0.1206</td>
<td>0.7848</td>
</tr>
<tr>
<td>Solubility</td>
<td>0.7470</td>
<td>0.5580</td>
<td>0.1159</td>
<td>1.2623</td>
</tr>
<tr>
<td>TPC powder</td>
<td>0.8227</td>
<td>0.6768</td>
<td>0.3535</td>
<td>2.0938</td>
</tr>
<tr>
<td>DPPH powder</td>
<td>0.7718</td>
<td>0.6040</td>
<td>0.2080</td>
<td>1.5353</td>
</tr>
<tr>
<td><strong>Appearance</strong></td>
<td>0.9847</td>
<td>0.9696</td>
<td>0.9392</td>
<td>31.8846</td>
</tr>
<tr>
<td><strong>Colour</strong></td>
<td>0.9817</td>
<td>0.9637</td>
<td>0.9274</td>
<td>26.5625</td>
</tr>
<tr>
<td><strong>Odour</strong></td>
<td>0.9310</td>
<td>0.8668</td>
<td>0.7335</td>
<td>6.5061</td>
</tr>
<tr>
<td>Sweetness</td>
<td>0.9441</td>
<td>0.8914</td>
<td>0.7827</td>
<td>8.2056</td>
</tr>
<tr>
<td>Aftertaste</td>
<td>0.9663</td>
<td>0.9337</td>
<td>0.8674</td>
<td>14.0823</td>
</tr>
<tr>
<td>Lavender aroma</td>
<td>0.9223</td>
<td>0.8506</td>
<td>0.7011</td>
<td>5.6923</td>
</tr>
</tbody>
</table>

Table 4. Main effects analysis of variance on the simultaneous influence of temperature and extract type on physical, chemical and sensory properties of the foam mat dried lavender extract enriched cocoa powders. Significant influences are printed in bold.
Figure 1.
Figure 2.