Physical and sensory characteristics of edible foams obtained with nitrous oxide

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Abstract. The aim of the present study was to determine the physical and sensory characteristics of edible foams obtained with nitrous oxide. The recipe compositions of foams with the participation of yogurt, milk cream and fruit puree have been used. The edible foams, also called "espums" were obtained with two fruit puree concentrations - 15 and 25% of the liquid’s total mass. The foaming capacity (FC) and foam stabilizing (FS) properties of the products were determined by applying the "Syphon" method. The foaming capacity was highest for the control sample (252.00±7.52%), followed by the foams with 15% persimmon puree (220.00±4.09%). The foam's lowest foaming capacity values were obtained for the foam with chokeberry puree (180.00±2.19%). The foam stability was determined by the coefficient of foam stabilization, which was determined to be highest (100±9.55%) for the sample with 15% mango puree and lowest for the foam sample obtained with 25% physalis puree (95.77±0.24%). The sensory analysis revealed that the edible foam with 25% mango puree participation resulted in better sensory properties.

Keywords: edible foams, nitrous oxide, espuma.

1. Introduction
The development of food and nutrition science led to the introduction of new and innovative food production methods. A large part of the technological approaches for the diversification of product variety is a change in texture, the combination of flavors, aroma and food design [1, 2].

These changes are mostly associated with catering establishments, mainly restaurants, to present up-to-date techniques for changing the taste and textures [3] of familiar traditional foods. Changes in food structure are more often manifested in ethereal foams, which are complex colloidal systems composed of gas bubbles incorporated in a continuous phase containing surfactants [4].

From a physical point of view, they are thermodynamically unstable systems due to high surface energy [5]. For this reason and their products’ characteristics in real production conditions, many technological solutions are used, one of which is nitrous oxide using the "Syphon" method.

Various foam stabilizers are frequently added to the system in order to obtain stable edible foams [6]. They increase the viscosity of the medium and slow down the processes of destruction of air bubbles. Simultaneously, substances such as hydrocolloids or emulsifiers can be added to sustain interfacial bonding, creating additional attraction forces between the hydrophilic and hydrophobic zones in the food matrix. Surfactants have a stabilizing effect on the phases by increasing the films viscosity [5, 7].
In addition to surfactants, the foaming process is applied using inert gases. Foaming is achieved by adding air into the entire volume of the phase by various mechanical methods [7, 8] or by extruding the medium using a confectionery siphon with nitrous oxide. The gas is used with creams due to its ability to dissolve quickly in animal fat. It causes aeration of the boundary surface of the two phases during contact with fat and proteins. The siphon creates conditions for even distributing the protein film around the air bubbles [8, 9, 10].

In addition to its foaming properties, the inert gas also possesses antimicrobial properties, inhibits oxidative processes and creates a uniform dispersion of the air phase throughout the medium’s volume. Other gas types, such as compressed air, cause adverse effects of oxidation and destruction of the interfacial binding and destruction of air bubbles [4, 3].

The foam obtained by the Syphon method, generally called espuma, and has broad potential for scientific research. Due to the limited scientific data for applying the technique in culinary production and the high interest in its practical application, the aim of the present paper was to study the application of the “Syphon” method in the production of edible foams with the addition of fresh fruit. The edible foams obtained in this study could be used in the composition of dessert creams, garnishes and fillings for confectionery products.

2. Materials and methods

2.1. Materials
Standard raw materials such as milk cream (Olympus fat content 35%), yogurt (Vereya fat content 4.5%), granulated sugar (“Sladeya 40”), fresh fruits from the local market such as physalis (Physalis peruviana L.), persimmon (Diospyros kaki L.f.), mango (Mangifera indica L.), chokeberry (Aronia melanocarpa (Michx) Elliot) were used in the current study. All materials were authorized by the Ministry of Health as manufactured in Bulgaria.

2.2. Preparation of foams
Edible foams have been prepared in laboratory conditions (University of Food Technology - Plovdiv, Bulgaria) using the method of "Syphon" [11]. A KAISER siphon with a capacity of 0.5 L was used. The fruits were peeled (mango, persimmon) or mashed (physalis, chokeberry) using a Philips food processor - HR7776 / 90. Then, the fruit puree was mixed with the granulated sugar for 3-4 minutes until the sugar dissolves. The resulting fruit mass was added to yogurt and cream and then combined. The resulting lactic acid fruit mixture is placed in a siphon and closed. A cartridge with inert gas - nitrous oxide (10 cm³) was established and stored in refrigerated conditions (4 ± 0.2 ºC) for 3 hours.

2.3. Determination of dry matter of fruits
The fruits were peeled with the pulp, seed, and peel separated. Each fraction was weighed. The total soluble solids (TSS) was determined by the use of a refractometer (Carl Zeiss, Germany) [12]. A direct refractometer reading was taken from a few drops of thoroughly mixed sample, the results being reported as Brix degrees at 20 ºC.

2.4. Foam quality
The foam quality was determined by the ratio between the volume of inert gas and the resulting foam volume [13].

\[ FQ = \frac{\text{Gas volume}}{\text{Gas volume} + \text{Liquid}} \times 100 \]  

where \( FQ (\%) \) is the foam quality, gas volume and liquid volume.
2.5. *Foaming capacity and foam stability*  
Foaming capacity (FC) and foam stability (FS) of the samples were determined by the method described by Ferreira et al. [14].

\[
FC = \frac{FV}{ILV} \times 100, \quad \% 
\]  
(2)

where: FV – volume of foam and ILV – volume of the initial liquid phase.

\[
FC = \frac{ILV - DV}{ILV} \times 100, \quad \% 
\]  
(3)

where: DV – volume of drainage, ILV – volume of the initial liquid phase

\[
FC = \frac{LVM - LVS}{ILV} \times 100, \quad ml
\]  
(4)

where: LVM – volume of the liquid phase at t = 60 min after foaming was finished LVS – volume of the liquid phase at t = 30 s after foaming was completed [15].

2.6. *pH value*  
The pH value of edible foam samples was measured with pH-meter MS 2004 (Microsyst Ltd., Plovdiv, Bulgaria), equipped with combined pH recorder S 450 CD (Sensorex pH Electrode Station, Garden Grove, CA, USA) [16].

2.7. *Water holding capacity*  
The amount of free water was determined by the Grau-Hamm method [17]. A KERN moisture analyzer (model MLS-A) was used.

2.8. *Color properties*  
Colourimeter CR 410 (Konica Minolta Holding, Inc., Ewing, NJ, USA), supplied by Sending Inc. (Japan), was used to evaluate the CIE L*, a*, b* properties in edible foams [18].

2.9. *Sensory analysis*  
Edible foam samples were evaluated on a nine-point hedonic scale [19]. Hedonic sensory evaluation of edible foams was conducted with 35 volunteer tasters, students and lecturers at the University of Food Technologies, Plovdiv, Bulgaria. A consumer test was carried out in the lab of the Department of Nutrition and Tourism of the University of Food Technologies (Bulgaria). Attributes were scored on a scale varying from “9 = like extremely” to “1 = dislike extremely”.

3. *Results and Discussion*  
The physicochemical characteristics of *P. peruviana* L. (pH of 3.7, and 15 °Brix), *Diospyros kaki* L. (pH of 5.8 and 16.5 °Brix), *Mangifera indica* L. (pH of 5.2 and 19.3 °Brix), and *Aronia melanocarpa* (Michx) Elliot fresh fruit (puree) (pH of 3.9 and 19.9 °Brix) were determined. The edible foam’s recipe composition obtained with the "Syphon" method is presented in Table 1.
Table 1. Recipe composition of edible foams obtained with N₂O.

| Ingredients      | Quantity relative to the total volume of the liquid, [%] |
|------------------|--------------------------------------------------------|
|                  | Control sample | with 15 % fruit puree | with 25% fruit puree |
| Mik cream        | 65             | 54                     | 48                   |
| Yogurt           | 20             | 18                     | 16                   |
| Sugar            | 15             | 12                     | 10                   |
| Fruit puree      | -              | 15                     | 25                   |
| **Total fluid, cm³** | 500          | 500                     | 500                  |

The foam quality was represented by the ratio between the volume of nitrous oxide and the amount of liquid after mixing. In this case, the system could be defined as an easily movable matrix in which the individual air bubbles do not contact with each other. The values of FQ ranging between 1% and 52% demonstrated that the gas centers have a pronounced spherical shape [13]. The free water content in the interfacial space with an even distribution of air bubbles appeared as a hydrating barrier that protects the bubbles from breaking. The values of FQ from 52 to 96% showed that the air bubbles were in a close contact with each other and changes in their structural distribution and destruction of the surface protein film could be observed [20, 13].

Table 2. Physical characteristics of edible foams obtained with N₂O.

| Foam with:       | FQ¹, [%]       | Volume, cm³ | FC², [%] | FS³, [%] | pH | FW⁴, [%] |
|------------------|----------------|-------------|----------|----------|----|---------|
| Control sample   | 2.19±0.02      | 1260.00±2.33| 252.00±7.52| 99.44±0.55| 5.60±0.03| 15.13±2.11|
| Physalis 15      | 1.94±0.14      | 1080.00±4.07| 216.00±1.00| 99.11±1.13| 5.15±0.01| 10.66±1.55|
| Physalis 25      | 1.88±0.02      | 1040.00±2.25| 208.00±0.96| 95.77±0.24| 5.03±0.09| 15.89±1.05|
| Paradise apple 15| 1.97±0.00      | 1100.00±1.07| 220.00±4.09| 99.89±0.85| 5.78±0.01| 9.89±1.90|
| Paradise apple 25| 1.87±0.01      | 1000.00±3.00| 200.00±1.22| 99.88±0.12| 5.36±0.20| 15.64±0.09|
| Mango 15         | 1.94±0.03      | 1050.00±1.00| 220.00±1.00| 100.00±9.55| 5.34±0.25| 8.82±1.13|
| Mango 25         | 1.99±0.00      | 950.00±2.15  | 190.00±0.78| 99.96±0.55| 5.27±0.16| 14.10±2.17|
| Aronia 15        | 1.96±0.00      | 920.00±2.00  | 184.00±1.55| 99.67±0.44| 4.50±0.12| 8.98±0.84|
| Aronia 25        | 1.93±0.01      | 900.00±1.45  | 180.00±2.19| 97.77±0.33| 4.28±0.05| 11.60±0.52|

*FQ – foam quality; FC² – foam capacity; FS³ – foaming stability; FW⁴ – free water
The volume was highest for the control sample (1260 cm$^3$) and the lowest values were obtained for the edible foam samples obtained with 25% and 15% of chokeberry puree. Although the lower volume of the edible foams obtained with chokeberry puree, their stability (97-99%) was comparable to that of other foams, which was probably due to the low content of free water (8.98-11.60%) in the system. The amount of free water in the control sample was close to that of the foams obtained with 25% fruit puree participation.

The pH values of edible foam samples obtained in this study confirmed that the interfacial tension increased at lower pH [23]. In the presence of higher levels of free water in the system, the protein foam was unstable. According to the findings of [16, 21], lowering the isoelectric point of the protein decreases the surface tension, and the addition of hydrocolloids such as xanthan, carrageenan, gelatin in the presence of a medium with high protein participation would lead to a formation of a stable foam.

The edible foams’ internal structure was characterized by a polydisperse system (Table 3) due to the presence of fruit purees.

| Foam samples | Foam with physalis puree | Foam with paradise apple puree | Foam with mango puree | Foam with aronia puree |
|--------------|-------------------------|---------------------------------|----------------------|-----------------------|
| Control sample | 15%                     | 15%                             | 15%                  | 15%                   |
| 15%          |                         |                                 |                      |                       |
| 25%          |                         |                                 |                      |                       |

The microscopic analysis showed that the control sample and foam sample participated in 15% chokeberry puree and had a more uniform dispersed composition. The sample with 25% physalis puree had the most pronounced heterogeneous composition. The destruction of air bubbles in some parts of the sample was observed, confirming the low value of foam stability (FS) - 95.77%. Thicker films around the air bubbles were observed in the foam sample obtained with persimmon puree, which may be due to the fruit pulp’s dietary fiber, which may create conditions for dense but unstable protein film.

According to the findings of researchers [22, 23], the use of inert gases in food systems led to the stabilization of the pigments involved in the composition of plant cells. Therefore, the use of nitrous oxide in the composition of the edible foams was associated with the possibility of preserving the pigments and some biologically active components (Table 4).
Table 4. Color indicators of edible foams obtained with N₂O by the method "Syphon".

| Foam with:              | L*   | a*         | b*         |
|------------------------|------|------------|------------|
| Control sample         | 90.89±1.22 | -3.70±0.01 | 19.42±0.87 |
| Physalis 15            | 88.51±1.14 | -1.67±0.05 | 27.04±0.65 |
| Physalis 25            | 87.48±2.00 | -1.15±0.02 | 32.94±0.24 |
| Paradise apple 15      | 88.06±2.03 | -1.44±0.00 | 21.30±1.33 |
| Paradise apple 25      | 85.41±1.00 | -0.74±0.12 | 22.68±2.12 |
| Mango 15               | 88.74±0.77 | -3.62±0.00 | 24.46±2.00 |
| Mango 25               | 88.08±0.55 | -0.44±0.08 | 26.75±0.88 |
| Aronia 15              | 73.67±0.21 | 14.14±1.06 | 4.57±0.00  |
| Aronia 25              | 64.87±1.13 | 27.07±1.22 | 3.64±0.25  |

According to the findings of researchers [23, 24, 25], the use of inert gases in food systems led to the stabilization of the pigments involved in the composition of plant cells. Therefore, the use of nitrous oxide in the composition of the edible foams was associated with the possibility of preserving the pigments and some biologically active components (Table 4).

The differences in the color indicators of the edible foams obtained in this study were due to the fruit purees’ participation in different concentrations and different color pigments in the fruit’s composition. The brightness (L *) of the foams was the highest in the control sample (L* 90.89), followed by the foam sample with the participation of 15% chokeberry puree (L* 73.67). In all tested samples, a decrease in brightness with an increase in the percentage of fruit puree was reported. The values of the red (a*) and yellow (b*) components in the tested samples were specific, explained by the species diversity of the fruits used. The highest values of the yellow component (a*) were obtained for the edible foam samples with the participation of physalis puree.

The sensory evaluation related to the edible foams’ appearance showed that the foam sample with 25% mango puree participation had the highest sensory score. The lowest score was observed for the sample obtained with 25% chokeberry puree.

The foam’s density has a critical consumer value, as the highest score was obtained for the foam sample obtained with 15 and 25% mango puree.

According to the sensory results, the scores for the color indicator of the foam samples with 25% participation of chokeberry puree and 25% physalis puree were the highest.

The lower values of the foam’s overall sensory perception obtained with paradise apple puree were determined due to the visible fibers’ presence.

The edible foams’ odor with 15% persimmon puree and 15 and 25% mango puree participation was scored with “more likable” than that of the control sample.

The control sample was determined with the most substantial sweet taste, followed by the evaluators placing the sample with 25% mango puree ("I like it very much"). The sweetness of the one with 25% chokeberry syrup is rated the lowest ("I like it a bit").

The foam sample with 25% physalis puree was characterized with the lowest score for the aroma indicator. The scores for the indicator of the samples’ oiliness compared to the control sample were significantly different. The results for all foam samples were determined in the range of "like" and "a little like". The most pronounced oily taste was indicated in the control sample, followed by the samples with 25% mango and 15% chokeberry puree.

The aftertaste scores showed that the most pronounced residual aftertaste was observed for the foam sample with 25% mango puree and 25% persimmon puree.
4. Conclusions
The present study provided data on the possibility of using nitrous oxide in the production of edible foams. The highest foaming stability was reported for the foam samples obtained with 15% mango puree. According to the sensory evaluation, the foam sample with 25% mango puree and 15% physalis puree was best scored. The study could be useful to the researchers who aimed to evaluate the edible foams’ functional properties and the effect of inert gas on the colloidal systems’ oxidative processes. The use of the Syphon method in small establishments and restaurants is a common practice. Our findings may increase consumer awareness and expand the range of new food formulations and textures by summarizing data on applying the method in edible foams.

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