OPTIMIZATION OF FREEZE-DRYING PROCESS AND PACKAGING SOLUTIONS FOR MELON SHELF LIFE

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Abstract. The confectionary market consists of dried fruits, cereal bars, chocolate, gum and sugar confectionary. Nowadays, the issue of the healthiness of sweets is becoming increasingly topical. Freeze-drying raw materials in the manufacture of sweets makes it possible to obtain products of high nutritional value. Depending on the moisture content of the products, it is important to choose the suitable packaging materials and technology solutions, especially, if the product is made from raw materials with different humidity and active compounds, in that way packaging films with high moisture barrier properties could be a common practice. The environmental impact of the packaging chosen is also very significant today. The aim of this study was to find the optimal freeze-drying regime for melons grown in Latvia and the optimal packaging solution (packaging materials and packaging environment) for the packaging of freeze-dried melons. Experiments were carried out at the Faculty of Food Technology, Latvia University of Life Sciences and Technologies and RicBerry Ltd. Moisture content changes of 12 freeze-dried samples (4 packaging materials and 3 environments) were analysed before packaging and after 1, 2, 3, 4, 5 and 6-month storage at the room temperature 21 ± 1 ºC. MatteOPP/AL/PE packaging material in combination with modified atmosphere environment (30 %CO_2/70 %N_2) showed the most promising results for freeze-dried melon storage.

Keywords: packaging; shelf life; freeze-drying; melons.

Introduction

Plant-based foods are an integral part of a healthy diet and their frequent consumption aids in prevention of various diseases and micronutrient deficiencies. Therefore, the suggested daily consumption of fruits and vegetables is 400 g at minimum, as stated by the World Health Organization and the Food and Agriculture Organization [1; 2].

However, in many parts of the world the problem of fresh plant-based food availability for consumption throughout the year, as fruit and vegetables are a seasonal produce, and long-term storage is persistent due to high moisture content and absence of cold-storage equipment (especially in developing economies). Thus, such processing method as drying (dehydration) is widely used to allow additional storage time without food wastage [3; 4].

Drying, however, results in quality changes of food [5], of which such parameters as colour, aroma, texture, moisture content and water activity, bulk, flow and rehydration properties, as well as nutrient retention are mainly affected [2; 6].

Freeze-drying (also known as lyophilisation), the dehydration technique which is based on sublimation, allows to obtain products with higher quality in comparison to other dehydration methods. This is due to the low temperature and application of vacuum during processing, which retains flavour, colour, overall appearance of products, in addition to such thermolabile compounds as aroma volatiles and vitamins [2-4]. Freeze-drying of fruit, vegetables, tea and maple syrup has been previously described in literature [7-14].

The first step in freeze-drying is freezing of food products, which determines the rate of the drying process. Slow rate of freezing forms larger ice crystals which are easier to sublimate, increasing the rate of primary drying [2; 15].

Freeze-drying is rather expensive, with energy constituting as the mayor cost factor, regardless of the high-quality output [16; 17], therefore, it is usually reserved for pharmaceutical and other high market value products (nutraceutical etc.). Several investigations have been previously reported with the aim of optimising the freeze-drying process using both laboratory equipment and pilot plant facilities [18].

As freeze-dried products are very sensitive to moisture uptake after drying, it is important to ensure that the quality of the products is maintained during their storage [19], as well as to ensure optimal packaging of products in which freeze-dried products are used as a raw material. According to the research led by scientist Torres [20], packaging and the atmosphere conditions play an important role in the storage of dried products. Moisture changes, development of microorganisms, formation of free fatty acids and increased peroxide value can be avoided, if optimal packaging conditions are chosen [21], however, it is also important to consider packaging waste reduction [22; 23].

There are several producers offering freeze-dried cantaloupe or other melon variety slices/pieces on the market, however, only freeze-dried berries and fruits with lower moisture content have been previously investigated in Latvia. Therefore, the aim of this study was to find the optimal freeze-drying regime for melons grown in Latvia and the optimal packaging solution for the packaging of freeze-dried melons.

Materials and methods

In order to ensure an optimal freeze-drying process for fruits with a high moisture content – melons, the technological process of freeze-drying was developed. Melon varieties ‘Emir F1’ and ‘Gediz F1’, harvested in Latvia, were peeled and cut into 1 cm × 1 cm × 1 cm pieces, and a 2 cm thick layer was formed onto trays placed in the freeze-drying unit. The initial parameters of melons were moisture 95 %, sugar content 18 Brix.

The parameters characterising the freeze-drying unit used in the experiment were: maximum capacity of the working chamber for fresh product before drying – 100 kg, drying time from 72 to 120 hours, electricity consumption from 4.5 to 7 $kW \cdot kg^{-1}$ wet product, depending on the product (temperature at loading, humidity, sugar content, etc.), the optimum initial temperature is -40 ºC and the initial pressure in the working chamber – 1000 Mbar.

In order to ensure that the quality of freeze-dried melons is maintained after drying, the optimal packaging solutions were investigated. Freeze-dried melons were packed in 90 mm × 150 mm pouches, total weight per package – 10 ± 2 g. Samples were packed in air ambience, vacuum and modified atmosphere (MAP) as summarised in Table 1. MAP gas composition of 30 %CO_2 and 70 %N_2 was chosen, as it is the recommended retail packaging gas mix.

Table 1

Sample abbreviations of tested packaging materials and environment

Sample No	Packaging material	Thickness, µm	Gas composition
1	Polyethylene / polyamide (PE/PA)	65 ± 2	Air ambience
2			Vacuum
3			MAP (30 %CO_2/70 %N_2)
4	Ceramis®-PLA PLA coated with SiOx High barrier properties	65 ± 2	Air ambience
5			Vacuum
6			MAP (30 %CO_2/70 %N_2)
7	Matte oriented polypropylene / aluminum / polyethylene (MatteOPP/AL/PE)	105 ± 3	Air ambience
8			Vacuum
9			MAP (30 %CO_2/70 %N_2)
10	Metalized polypropylene (metPP)	45 ± 2	Air ambience
11			Vacuum
12			MAP (30 %CO_2/70 %N_2)

The samples were hermetically sealed by MULTIVAC C300 vacuum chamber machine and stored at room temperature of 21 ± 1 ºC, and approx. 40 % RH for 6 months under daylight conditions. The materials for experiments were selected with various thickness.

Moisture analysis of the samples during storage was performed using electronic moisture scales Precisa XM120 (Switzerland) to determine optimal packaging material and environment. The samples were analyzed for 6 months after 1; 2; 3; 4; 5 and 6 months of storage.

The obtained data were processed using *MS Excel* program ANOVA. Factors were assessed as significant, if the p value was less than 0.05.

Results and discussion

When developing technological processes, the aim is to use minimum power consumption and dry the product completely in the shortest possible time with the moisture remaining only at the 'internal cellular level', i.e. up to 3 %. At the same time, it is important to preserve long molecules without destroying the cell structure, because only then it is possible to preserve the maximum amount of biologically active substances in the product [3]. It is particularly important to find the limits, at which the costs are economically justified, i.e. optimal freezing temperatures, pressure and drying time, when the quality of the product no longer changes. A group of scientists led by Silbva-Espinoz [2] has come to similar conclusions about the process optimization.

Previous investigations showed that when sublimation was carried out at different temperatures with different regimes within the same process, using different product samples, each product required different regimes depending on their composition, and the main criteria that determined it were dry matter content and sugar content. The more sugar the product contains, the lower the temperature and the pressure is required to carry out deep-freeze and to prevent samples from boiling. Therefore, optimal regimes and their limits were defined, which are economically reasonable so that small fluctuations in the sugar content of products (also within different varieties) do not disrupt the sublimation process due to the product 'boiling'. This causes formation of product stalactites on the walls of the tunnel, the product flows over the sides of trays – on the walls and shelves of the unit, and then the product is no longer usable, the washing and maintenance time of the unit is very labor-intensive and lasts up to 3-4 days (defrosting, cleaning, washing, drying), making the process more expensive.

Previous freeze-drying experiments showed that the best and most gentle mode for raising the temperature in the working chamber should exceed 2 to 3 ºC, so the selected temperature increase step mode was 2 ºC. This resonates with the study of scientist Shivkumar [24]. The pressure in the sublimation process also plays a crucial role, as it significantly affects the final result of the product, both in terms of the chemical composition, consistency and organoleptic characteristics. Dynamics of pressure change at the beginning of the experiment in the freeze-dryer working chamber are shown in Fig. 1.

After deep freezing is completed (approx. 3-5 hours, depending on the product), the vacuum pump starts working based on the set maximum and minimum pressure limits in automatic mode and time.

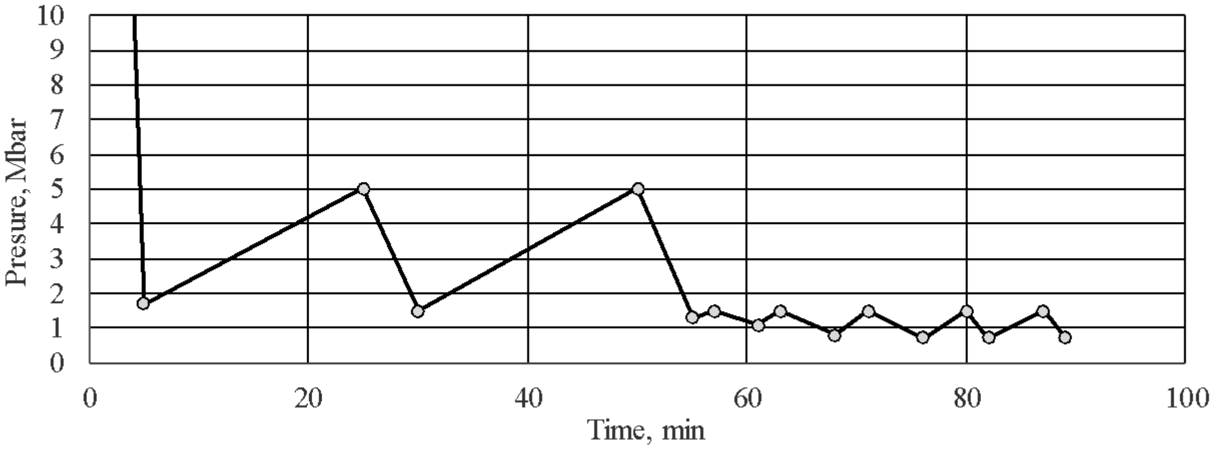

Fig. 1. **Dynamics of pressure change at the first stage of the experiment in the freeze-dryer working chamber**

Next, when the pressure reaches 0.7 Mbar, the temperature is raised by + 2 ºC. During this time, it is important to control the pressure rise (P) and keep it in the range of 1.5 – 0.7 Mbar.

The effect of temperature increase by 2 degrees on pressure changes, i.e. transition to stationary process in relation to the upper and lower pressure, can be observed in Fig. 2 and Fig. 3.

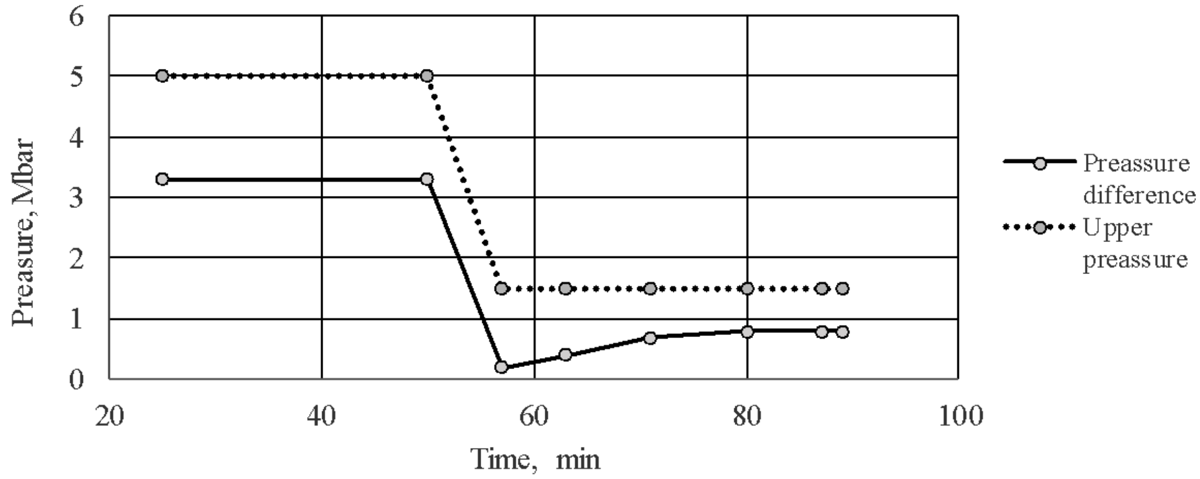

Fig. 2. **Upper pressure and pressure difference at the initial stage of the process**

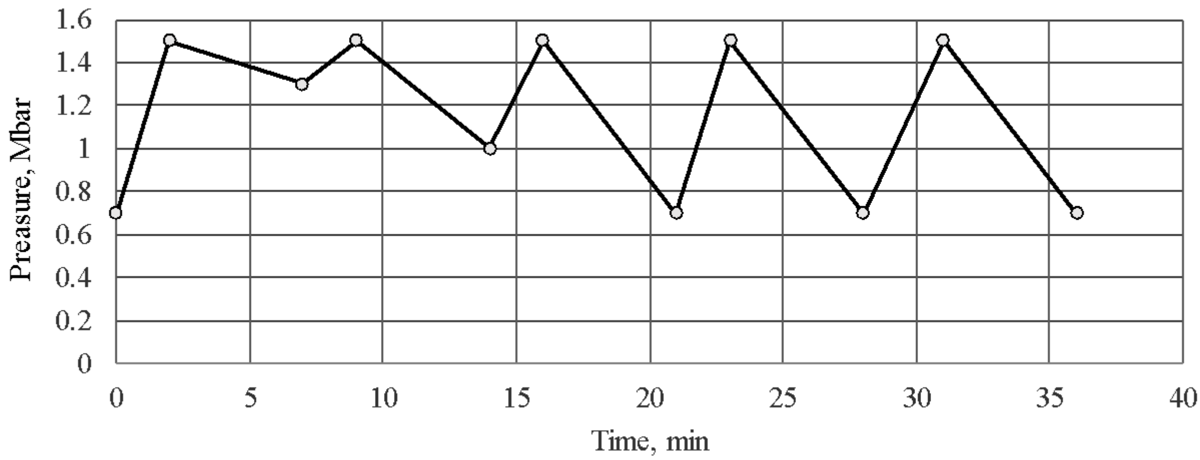

Fig. 3. **Dynamics of pressure normalization in the 2nd and subsequent stages**

At the beginning of the cycle, the pressure rises very quickly, because the humidity in the chamber is very high, water transitions from ice to gas state take place and as the result the pressure rises (up to 1 min), but it drops slowly. The pressure gradually decreases, however, if it takes for more than 5 min, the pump is switched off, the pressure reaches the maximum, and the process is repeated until the rate of pressure decrease is 5 min. At the end, these processes change places, it takes a long time for the pressure to rise to the upper limit (up to 20 min) and a very short time for the pressure to drop to the minimum limit. As long as this process lasts (sublimation takes place), the temperature is kept constant.

By gradually sublimating the product in this way, the process continues from -40 ºC to -8 ºC, at which time thermostatization is carried out – 6 h the product is held at a constant temperature within the pressure range of from 1.5 to 0.7 Mbar. Then the temperature is increased in the chamber and the second thermostatization is carried at -2 to -3 ºC, thus preparing the product for transition to temperature above 0 degrees. The raise of temperature is continued until it reaches 22 ºC to 28 ºC in order to equalize the temperature in the chamber with the room temperature. When it reaches 0 °C, the temperature continues to rise on the shelves as it did at minus until it reaches 22 ° C to 28 ° C, which is optimal to complete the process. As the product is completely dry, the heating process takes place relatively quickly. The pressure chamber is then equalized with the pressure in the room, it remains the same as at the beginning (1000 Mbar) before removing the product from the chamber.

If the outlet freezing temperature is -40 ºC, the outlet dry end product temperature must be between 22 ºC to 28 ºC, in very rare cases, where the room humidity is very high - up to 36 ºC, but it must not be lower than 17 ºC, as a dew point may form and water droplets may drip onto the product before it is removed from the vacuum chamber. This must be ensured to prevent moisture from being absorbed back into the finished product.

After freeze-drying, it is important to isolate the products from the environment, thus, it is necessary to find the best packaging solutions. As the results show, the investigated packaging solutions have different effects on product moisture changes during storage (Table 2).

Table 2

Moisture dynamics of freeze-drying melons during storage

Sample No	Storage time, mounts						
	0	1	2	3	4	5	6
	Moisture, %						
1	2.85 ± 0.09	2.96 ± 0.11	3.02 ± 0.23	5.92 ± 0.08	7.85 ± 0.05	8.25 ± 0.18	8.94 ± 0.08
2	2.85 ± 0.09	2.88 ± 0.09	2.99 ± 0.14	4.76 ± 0.12	5.91 ± 0.17	7.77 ± 0.15	8.85 ± 0.23
3	2.85 ± 0.09	2.85 ± 0.07	3.97 ± 0.09	4.97 ± 0.15	6.85 ± 0.13	8.14 ± 0.08	7.85 ± 0.11
4	2.85 ± 0.09	2.89 ± 0.09	2.90 ± 0.15	6.97 ± 0.13	9.13 ± 0.09	9.88 ± 0.15	10.73 ± 0.12
5	2.85 ± 0.09	2.86 ± 0.13	2.89 ± 0.05	7.15 ± 0.20	8.92 ± 0.11	9.74 ± 0.11	10.15 ± 0.15
6	2.85 ± 0.09	2.87 ± 0.20	2.85 ± 0.09	6.63 ± 0.16	8.76 ± 0.09	8.65 ± 0.07	9.95 ± 0.17
7	2.85 ± 0.09	2.85 ± 0.09	2.85 ± 0.07	2.98 ± 0.09	2.93 ± 0.08	2.93 ± 0.09	2.95 ± 0.09
8	2.85 ± 0.09	2.85 ± 0.10	2.86 ± 0.09	2.87 ± 0.12	2.88 ± 0.07	2.90 ± 0.10	2.90 ± 0.08
9	2.85 ± 0.09	2.85 ± 0.08	2.85 ± 0.11	2.87 ± 0.09	2.86 ± 0.09	2.87 ± 0.09	2.87 ± 0.10
10	2.85 ± 0.09	2.85 ± 0.08	2.99 ± 0.09	5.95 ± 0.11	8.85 ± 0.09	8.77 ± 0.08	10.35 ± 0.04
11	2.85 ± 0.09	2.89 ± 0.07	2.90 ± 0.11	6.05 ± 0.09	7.13 ± 0.07	9.84 ± 0.14	10.12 ± 0.16
12	2.85 ± 0.09	2.84 ± 0.14	2.85 ± 0.07	5.99 ± 0.10	6.92 ± 0.11	8.89 ± 0.09	10.45 ± 0.09

During the first two months of storage, no differences were observed between the studied samples. During further storage, the samples packed in metPP (samples 10, 11 and 12) and biodegradable Ceramis®-PLA (samples 4, 5 and 6) had the greatest changes in moisture, showing significant increase ($p > 0.05$). MatteOPP/AL/PE packaging material, regardless of packaging environment (samples 7, 8 and 9) was the most suitable packaging solution with minimal moisture changes throughout the storage ($p < 0.05$). Summarizing the obtained results, it can be concluded that the most suitable packaging solution is to use MatteOPP/AL/PE packaging material in combination with modified atmosphere environment (30 %CO_2/70 %N_2).

Conclusions

1. It is important to understand and develop an appropriate regime of the freeze-drying process for specific products using a certain equipment, as it allows to provide the necessary structure of the products and is energy efficient.
2. The most suitable packaging solution for long-term storage of freeze-dried melons is MatteOPP/AL/PE packaging material in combination with modified atmosphere environment (30 %CO_2/70 %N_2).

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