The Oscar Publishing Services
American Journal of Applied Science and Technology

VOLUME Vol.05 Issue 04 2025
PAGE NO. 41-43
DOI 10.37547/ajast/Volume05Issue04-10

Analysis of Raspberry Freeze-Drying Processes

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Received: 25 February 2025; **Accepted:** 21 March 2025; **Published:** 24 April 2025

Abstract: The objective of this study was to comprehensively investigate the technological and physicochemical aspects of freeze-drying (lyophilization) as applied to raspberries. Due to the delicate cellular structure and high moisture content of raspberries, they are particularly sensitive to conventional drying methods, which often result in significant degradation of organoleptic and nutritional qualities. Freeze-drying, by contrast, offers a promising solution by preserving the original morphology, flavor, and bioactive compounds through sublimation of ice under low-pressure conditions. This work aimed to optimize the key parameters of the freeze-drying process—specifically the duration of the sublimation phase and the final drying temperature—to achieve maximal retention of quality indicators while minimizing processing time. The findings can contribute to improving the industrial-scale production of high-value, shelf-stable berry products for functional food applications.

Keywords: Raspberry, freeze-drying, sublimation, low temperature dehydration, organoleptic quality.

Introduction:

Fruits and berries represent a rich and diverse source of essential micronutrients, including vitamins, minerals, antioxidants, and phytochemicals, which play a crucial role in maintaining human health and preventing various chronic diseases [1]. Their regular consumption becomes particularly vital under adverse environmental conditions and in populations affected by micronutrient deficiencies. However, the inherent seasonality, high perishability, and moisture content of such products pose significant challenges for year-round availability and long-term storage.

To address these limitations, various preservation techniques have been developed, among which drying is one of the most widely used. Dehydration effectively reduces water activity, thereby inhibiting the growth of spoilage and pathogenic microorganisms, enzymatic activity, and oxidative processes, ultimately extending the shelf life of the product without the use of chemical preservatives.

Among all known drying technologies, freeze-drying—or lyophilization—emerges as one of the most advanced and promising methods, especially for heat-sensitive and structurally delicate products such as raspberries. The core principle of freeze-drying is based on the removal of frozen water from the product through sublimation, which occurs under pressures below the triple point of water (611 Pa). In this process, water transitions directly from the solid (ice) phase to the vapor phase, bypassing the liquid state entirely. This mechanism enables the preservation of the product's structural integrity, nutritional profile, and organoleptic qualities, including color, aroma, taste, and texture [2].

Importantly, after the primary sublimation phase, a secondary drying phase at mild temperatures—typically below +40°C—is applied to remove residual moisture. This two-step process allows for minimal thermal degradation and a high degree of retention of the original (native) characteristics of the product, which is particularly advantageous when processing soft-textured fruits like raspberries. As a result, freeze-drying has garnered increasing attention in the food and nutraceutical industries for producing high-quality, shelf-stable fruit ingredients suitable for functional foods and specialized diets.

METHODS

Fresh raspberries of uniform size, color, and ripeness were selected for the experiment. Prior to freeze-drying, the fruits were carefully inspected to remove any damaged or overripe specimens to ensure consistency in the drying process and quality assessment.

The selected raspberries were evenly distributed on stainless steel trays and placed into the freeze-drying chambers. Each chamber was hermetically sealed with an airtight lid to maintain controlled pressure and temperature conditions throughout the process. Once sealed, vacuum pumps were activated to reduce the internal pressure of the chambers to below the triple point of water (611 Pa), thereby initiating the sublimation phase of the drying process.

During this phase, the moisture within the product, having been frozen beforehand, sublimated directly from solid ice to vapor without transitioning through the liquid phase. The vaporized moisture was subsequently desublimated—converted back into solid form—on the cold surfaces of the refrigeration system's evaporator coils. This step prevented re-condensation within the chamber and facilitated the continuous removal of moisture from the system.

Following the primary drying phase (sublimation), the product underwent a secondary drying stage to eliminate residual bound moisture. This was achieved using infrared (IR) heating lamps, with four lamps installed in each chamber to provide uniform low-intensity heat. The temperature during this stage did not exceed +40°C, preserving the thermolabile components of the raspberries while ensuring complete dehydration and product stability.

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RESULTS AND DISCUSSION

At first, the drying process was investigated by selecting the duration of the sublimation and final drying stages. The residual pressure was 400 Pa, the temperature at the final drying stage was +40°C. The duration of the first stage (sublimation stage) in different experiments was 5, 6, 7 and 8 hours, after which the infrared heating lamps were switched on and the residual moisture in the product was removed.

It was found that the time by which the total duration of lyophilization increases almost corresponds to the time of increase in the sublimation stage. To assess the quality characteristics of the obtained product, an organoleptic assessment of dried raspberries was carried out according to the following indicators: taste, color, smell and consistency, each of which was assessed on a 5-point scale. The results are summarized in Table 1. According to the results of the organoleptic assessment, the highest score was obtained with a sublimation stage duration of 7-8 hours and, accordingly, the least effect of temperature at the final drying stage. Based on the data obtained, the optimal duration of the sublimation stage is 7 hours.

Table 1

Results of organoleptic evaluation of dried raspberries

Indicator	Duration of the sublimation stage, h			
	5	6	7	8
Taste	4	5	5	5
Color	4	4	4	4
Smell	4	5	5	5
Consistency	4	4	5	5
Score	16	18	19	19

Further experiments were conducted to select the final drying temperature. The values of this parameter varied within the range from +30 to +60°C. The duration of sublimation was 7 hours. Table 2 shows the indicators of sublimation drying of raspberries at different final drying temperatures.

Table 2

Indicators of sublimation drying of raspberries

Indicator	Final drying temperature, °C			
	30	40	50	60
Drying time, h	10,5	9	8	7,5
Organoleptic assessment, points	20	19	17	15

As expected, with an increase in the final drying temperature, the duration of the drying process is reduced, but at the same time, the quality characteristics of the product also decrease, which is confirmed by the results of the organoleptic assessment, which is due to the more intense temperature effect of the infrared heating lamps.

CONCLUSION

Thus, as a result of the work carried out, the most favorable modes of sublimation drying of raspberries were established: the duration of the sublimation stage is 7 hours, the final drying temperature is +40°C. With the specified modes, the total dehydration time is 9 hours, and the organoleptic assessment is 19 points out of 20. The above data can be useful for engineers-technologists, food industry workers and researchers engaged in research in this area. Lyophilized berries can be used in the production of functional drinks, bakery products [3, 4, 5].

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