

RESEARCH ON THE DEVELOPMENT OF FUNCTIONAL PRODUCTS USING VACUUM IMPREGNATION

CERCETĂRI PRIVIND DEZVOLTAREA PRODUSELOR FUNCȚIONALE UTILIZÂND IMPREGNAREA ÎN VID

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ABSTRACT

The growing interest in functional food products in recent years has encouraged producers and researchers to develop new preservation techniques and processing methods that improve product quality. Vacuum impregnation is one such method, representing a non-thermal and non-destructive technology based on the hydrodynamic mechanism. Recently, it has been increasingly applied in the production of high-value food products through the incorporation of bioactive compounds into the food matrix. This study investigates the influence of vacuum impregnation treatment on the chemical composition of apple slices impregnated with apple juice and aronia berry juice, followed by convective dehydration. The results revealed superior values for the aronia-impregnated samples, characterized by increased contents of mineral compounds, dietary fiber, vitamin C, polyphenols, and anthocyanins compared with the apple juice-impregnated variant, which exhibited a less pronounced effect. The performed analyses confirmed that vacuum impregnation significantly influenced the chemical profile of dehydrated apples and demonstrated that this technique can be successfully used as a strategy for obtaining optimized functional food products.

REZUMAT

Interesul crescut din ultimii ani pentru produsele alimentare funcționale a determinat producătorii și cercetătorii să dezvolte diferite tehnici și procese noi de conservare care aduc îmbunătățiri calitative. Impregnarea în vid este una dintre ele, fiind o tehnologie nontermică, nedistructivă, bazată pe mecanismul hidrodinamic. A devenit utilizată în ultima perioadă pentru producerea alimentelor cu valoare ridicată, prin adăugarea de compuși valoroși în matricea lor. Această lucrare investighează influența tratamentului de impregnare în vid asupra compoziției chimice a rondelilor de mere care au fost impregnate cu suc de mere, suc de aronia și deshidratate convectiv ulterior. Rezultatele au evidențiat valori superioare pentru proba impregnată cu aronia, asociată cu creșterea compușilor minerali, a fibrelor, vitaminei C, polifenolilor și antocianilor comparativ cu varianta impregnata în suc de mere, care a avut un efect mai puțin pronunțat. Determinările efectuate au confirmat că impregnarea în vid a avut un impact important asupra profilului chimic al merelor deshidratate, putând fi utilizată ca strategie în obținerea produselor funcționale optimizate.

INTRODUCTION

Fruits and vegetables, through their multitude of nutrients and bioactive compounds, play a very important role in nutrition (Zingales et al., 2025). For people from the vegetarian, vegan and other groups, they constitute the basis of daily nutrition and can be considered functional foods in terms of health benefits. Their consumption contributes to hydrating the body, establishing energy balance and combating non-infectious diseases. Thus, cancer, cardiovascular and nervous diseases, type II diabetes and obesity can be combated through the mechanisms given by bioactive compounds active on free radicals and reducing the effects of oxidative stress (Frei et al., 2012; Pal M. and Molnár J., 2021; Sadowska et al., 2024). The potential for improving health and reducing the risk of disease through dietary diversification is thus observed (Fekete et al., 2025).

Consumer demand for good and healthy products has directed fruit and vegetable processing towards the development of new preservation methods and techniques that preserve quality and nutritional value for as long as possible (Ete et al., 2024; Sadowska et al., 2024). Therefore, innovative technologies such as immersion and vacuum impregnation have become increasingly investigated (Sorică et al., 2025).

The principle of immersion treatment is based on the absorption of solutions by whole, sliced or chopped fruits. The solutions are diversified and are used to improve the quality of the products (Sorică et al., 2025). The approach of preliminary treatment with calcium salts before storing the fruits at low temperatures has led to the reduction of losses caused by mechanical damage during cold storage (Aguayo et al., 2008; Serrano et al., 2004), the maintenance of firmness and the increase of resistance to mold attack (Silveira et al., 2011).

The absorption of solutions in the product matrix can be increased by vacuum impregnation technology. This is a processing technique based on the principle of hydromechanics. It involves rapid mass transfer through the diffusion of liquids into the target substrates, without affecting the fundamental structure of the material (Salvatori et al., 1998; Saeed et al., 2022). The immersion of the products can be done in solutions of different concentrations that are subjected to staged pressure differences. In the first stage, a vacuum is created as a result of the pressure reduction in the vacuum chamber. In this way, the air trapped in the pores of the material is extracted until equilibrium is reached. The second stage brings the restoration of atmospheric pressure and the migration of the external liquid into the empty spaces from which the air was extracted (Tylewicz et al., 2013). As the pressure is restored, the liquid is absorbed deeper into the material structure (Aykın-Dinçer & Dinçer, 2023). The procedure is characterized by low cost, ease of operation, depending on the characteristics of the impregnating liquid and the structure of the material (Zhang et al., 2022). Usually, carbohydrates with low molecular weight are used for vacuum impregnation, which enter the cells more easily. Materials with a porous structure that is very permeable to solutions are also used. Due to these properties, fruits and vegetables are considered very suitable for the process (Ashitha and Prince, 2018).

In this way, some bioactive elements such as essential oils, antioxidants, vitamins, minerals, phenols, probiotics can be introduced into the matrix without modifying its structure (Radziejewska-Kubzdela et al., 2014; Betoret et al., 2015; Panayampadan et al., 2022), improving nutritional, physicochemical, sensory characteristics and extending the shelf life. Studies on the incorporation of probiotics into fruit matrices have contributed to expanding the range of probiotic foods (Granato et al., 2010) and the infusion of blackcurrants on apple cubes has led to the absorption of a greater number of probiotic cells in the fruit (Diamante et al., 2014). Enrichment of apple tissue with black carrot extract brought improvements in the antioxidant profile, compared to untreated apples, and blueberry juice added to the apple matrix produced a natural snack with a significant anthocyanin content and high antioxidant capacity (Castagnini et al., 2015).

Vacuum impregnation can produce products with specific nutritional and functional properties (Saeed et al., 2022; Saleena et al., 2023), meeting the demand for foods with enriched functional attributes and the need for environmentally safe and energy-efficient processing methods (Saleena et al., 2021).

In this direction, this article presents research on apple slices vacuum-impregnated with natural fruit juices and the chemical analysis of the products obtained after dehydration.

MATERIALS AND METHODS

The experiment was conducted at the Research and Development Institute for the Industrialization and Marketing of Horticultural Products "HORTING". It was made by immersing apple slices from the *Golden Reinders* variety in natural apple and aronia berry juices, impregnating them in a vacuum and convective dehydration in a B. Master professional dryer.

The fruits came from the Research and Development Institute for Fruit Growing, Pitești-Mărăcineni. After washing and removing the core, using an electric slicer, they were sized in the form of 4 mm thick slices. Four containers with apples were formed in which, after weighing, juice was added. Apple juice was added to two containers and aronia juice to the other two (Fig. 1). The apple:juice ratio was 1:3.

The impregnation solutions were obtained in the pilot station and the laboratory of the Horting Institute.



Fig. 1 - Images from the preparation of the samples

The product containers were subsequently introduced into the experimental model developed by National Institute of Research - Development for Machines and Installations Designed for Agriculture and Food Industry – INMA, in the national research project (Fig. 2).

The experimental conditions were: vacuum of 700 mbar for 120 seconds, followed by expansion, for both samples. During the experiments, the vacuum pressure, holding time and equilibration time were determined based on the direct readings displayed by the system, using the indications provided by the pressure sensor and the software timer integrated in the process computer of the vacuum impregnation system.

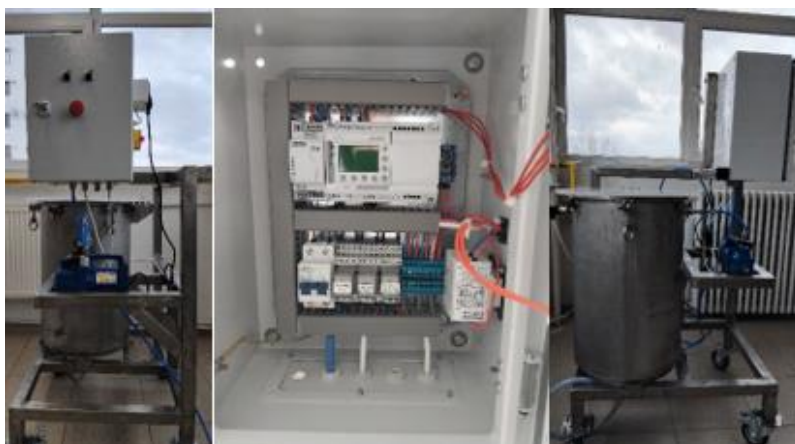


Fig. 2 - Experimental model of vacuum impregnation

The vacuum impregnation process involved two stages:

- **Stage I:** under the effect of the vacuum created, the air was removed from the fruit matrix.
- **Stage II:** during the restoration of atmospheric pressure, the solution entered the pore spaces.

The vacuum pressure and holding time were entered by the operator at the beginning of the impregnation process.

After the vacuum impregnation experiment was completed, the fruits were separated from the liquid phase and dehydrated (Fig. 3), at a temperature of 50 °C in a B Master convective dehydrator with the following characteristics: 400 V, 50/60 Hz, 5.2 kW. The dehydrator has a stainless steel structure with 4 compartments, 40 drying trays equipped with non-stick paper, an electric resistance heating unit and automatic ventilation.

A control sample of apple slices, without impregnation, was also carried out, which were dehydrated under the same temperature conditions. After dehydration, all apple products were chemically analyzed.



Fig. 3 - Aspects of the apple dehydration process

The analysis methods used were the following:

Moisture content, expressed as a percentage (%) was determined by the gravimetric method. This consisted of weighing the sample to be analyzed and drying in an oven at constant temperature until constant mass.

Sodium chloride (g/100g) was obtained by the Mohr method. The extracted sample was titrated with a silver nitrate solution in the presence of potassium chromate as an indicator.

Protein was determined by the Kjeldahl method.

Total ash (%) was obtained by dry calcination which consisted of: weighing the sample, carbonization and calcination in an oven at high temperatures. The inorganic mineral residue (ash) obtained was weighed after cooling in a desiccator.

Total fats (g/100g): the sample was initially subjected to hydrolysis with hydrochloric acid, followed by filtration, drying and repeated extraction with hexane in a Soxhlet apparatus. The solvent was subsequently evaporated and the fatty residue weighed.

Fiber (%) was determined by extraction with dilute solutions of sulfuric acid and sodium hydroxide, followed by filtration, drying, weighing and calcination. The mass loss on calcination represented the fiber.

Total carbohydrates (%) resulted from analytical calculation by subtracting the cumulative percentages of moisture, ash, protein and total fat.

Total invert sugar (%) was determined by the Bertrand method. Carbohydrates were hydrolyzed, treated with alkaline copper solution (Fehling's reagent) and chemically titrated. The amount of sugar was calculated according to the volume of solution used for titration.

Vitamin C (mg/100g) was determined by titration with 2,6-dichlorophenolindophenol.

Polyphenols (mg/100g) were obtained by their extraction and mixing with Folin-Ciocalteu reagent and sodium carbonate, followed by measuring the color intensity obtained with a spectrophotometer.

Anthocyanins (mg/100g) were weighed, extracted on a water bath with acidified ethyl alcohol solution, filtered and measured with a spectrophotometer.

The statistical analysis consisted of evaluating the variations (%) and the correlation between the obtained chemical parameters. Microsoft Excel functions were used in the determinations.

RESULTS

The impact of vacuum impregnation compared to the control sample in terms of the nutritional profile of the products is found in Figure 4. The results highlighted variations in composition depending on the treatment, the most pronounced change being observed in the case of the sample impregnated with aronia, where the carbohydrate content decreased and the ash content increased significantly.

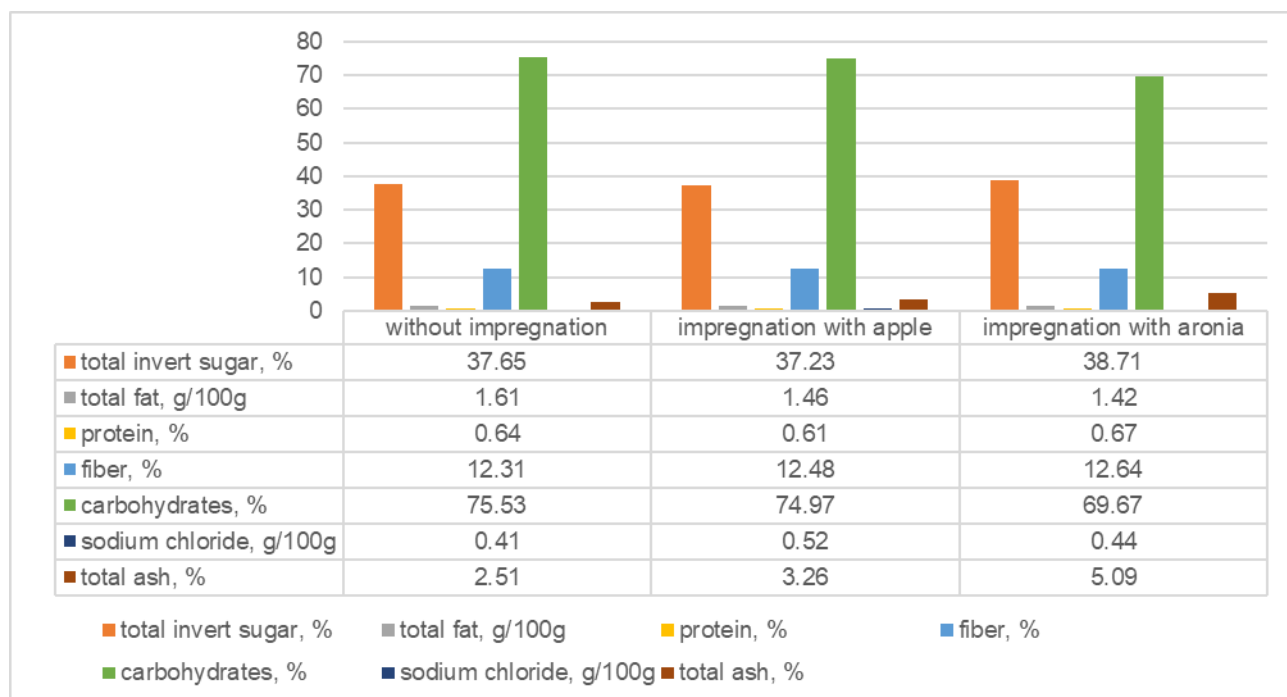


Fig. 4 - Nutritional profile of dehydrated apples

- **Carbohydrates:** A slight decrease was observed during impregnation. The aronia variant had the highest loss (-7.76%), compared to the apple variant (-0.74%).
- **Total invert sugar:** Levels remained relatively constant, with a slight increase in the case of the aronia variant (+2.81%), suggesting an own contribution of sugars from the fruit. Variability was low (between -1.12%), which showed that the impregnation process did not significantly modify the carbohydrate profile compared to the control sample.
- **Fiber:** There was a progressive increase trend. Aronia impregnation provided the highest increase (+2.68%) compared to apple (+1.38%).
- **Proteins:** The content was very low and remained stable in all three samples (between 0.61% and 0.67%).
- **Fats:** A slight decrease was observed in the fruit variants (- 11.80% for aronia berry and – 9.32% for apple). One explanation would be diffusion that diluted the original lipid component.
- **Total ash:** This was the most significant variation. The ash content doubled in the aronia berry variant (+102.79%) compared to the one without impregnation, indicating a substantial contribution of minerals brought by the aronia fruits.
- **Sodium chloride:** The values were low and showed minor variations, with a maximum in the case of apple impregnation (+26.83%).

The statistical analysis obtained showed a very strong negative correlation between carbohydrate content and ash ($r = - 0.9807$; Fig.5) and a strong positive correlation between fiber content and ash ($r = + 0.9669$; Fig.6). This meant that samples richer in minerals tended to have more fiber and that increasing ash (mineral) content led to a decrease in carbohydrate content.

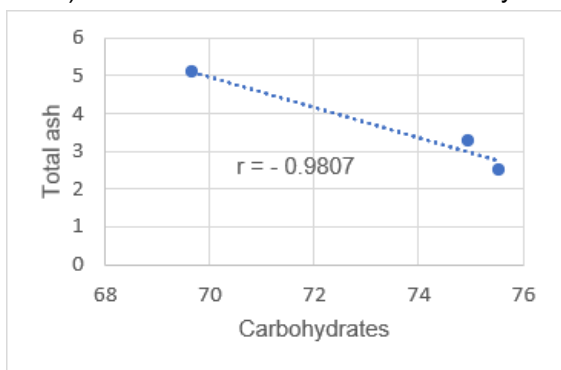


Fig. 5 – Carbohydrate – total ash correlation

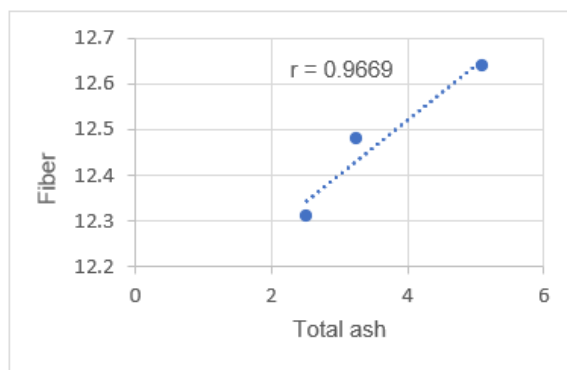


Fig. 6 – Fiber – total ash correlation

Table 1

Caloric value for dehydrated apples		
Without impregnation	Impregnation with apple	Impregnation with aronia
343.79 kcal 100g	340.42 kcal 100g	319.43 kcal 100g

According to Table 1, the highest caloric value was found in the apple variant without impregnation (343.79 kcal), which is explained by the interference of the impregnation solutions (apple or aronia).

Impact of impregnation:

- **Apple juice** had a slight reduction effect, decreasing caloric intake by approximately 1%.
- **Aronia juice** had the most significant impact, reducing energy value by approximately 7% compared to the control sample. The reduction in this case was mainly due to the reduction in carbohydrate content, an element that is taken into account when determining caloric value.

Caloric efficiency: The aronia variant was the "lightest" in terms of calories, making it a preferred option for diet products. The simple dehydration variant was the most energy-rich.

The transformation into energy value was achieved by using the standard conversion factor: 1 kcal = 4.184 kJ. The calculated values are found in Table 2, being in close correlation with the variation of caloric values for the variants taken in the experiment.

Table 2

Energy value for dehydrated apples

Without impregnation	Impregnation with apple	Impregnation with aronia
1452.94 KJ 100 g	1438.72 KJ 100 g	1349.44 KJ 100 g

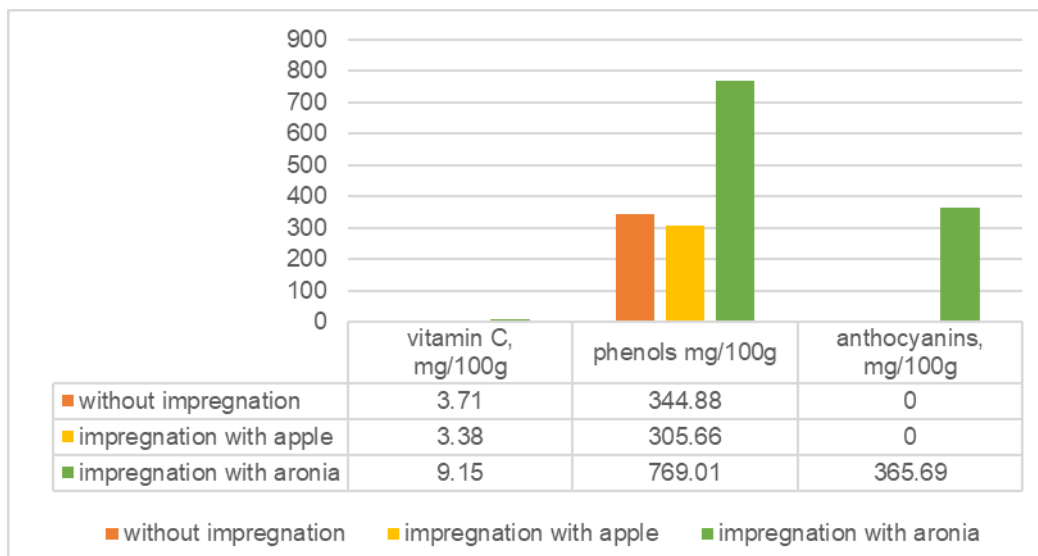


Fig. 7 - Antioxidant profile of dehydrated apples

The analysis of the data obtained (Fig. 7) highlighted important differences in the antioxidant profile of the dehydrated apple products in the three variants.

- **Vitamin C:** Impregnation with apple juice led to a slight increase (+8.9%) of the vitamin and the use of aronia juice generated an increase of +146.6% compared to the control sample.

- **Polyphenols:** The sample impregnated with aronia showed an increase of +122.9% without the control and +151.6% compared to the apple impregnation. The dehydrated product impregnated with apple juice showed a percentage decrease of -11.3% compared to the control, suggesting a diffusion process of the apple's own nutrients in the impregnation juice, without the apple juice reducing the loss.

- **Anthocyanins:** They represented the technological differentiator in the aronia berry sample (356.69 mg/100g) and were the most distinctive element. Since dehydrated apples and those impregnated with apple do not contain these pigments, impregnation with aronia juice transformed the apple from an ordinary fruit into a functional product, rich in antioxidants specific to berries.

The correlation analysis between polyphenols and vitamin C revealed an extremely strong relationship between them ($r = 0.9996$), which is graphically represented in Fig. 8. This revealed a very clear positive relationship between the biochemical compounds compared: the increase in one determined the increase in the other. Thus, a higher content in polyphenols corresponded to a higher content of vitamin C.

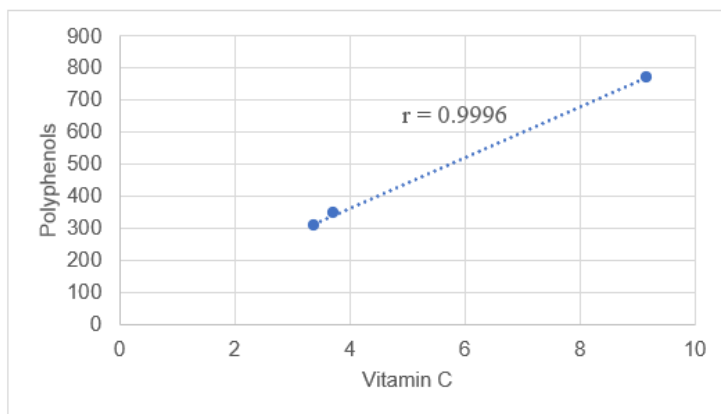


Fig. 8 - Polyphenols – vitamin C correlation

The dehydration times and moisture contents of the products are shown in Table 3. At similar moisture contents, the impregnated products required an 11% increase in dehydration time.

Table 3

Moisture content, times and dehydration temperature			
Dehydrated apples	Moisture content (%)	Dehydration time (hours)	Temperature (°C)
Without impregnation	7.40	18	50
Impregnation with apple juice	7.22	20	50
Impregnation with aronia berries juice	7.51	20	50

CONCLUSIONS

The results obtained are relevant for the development of functional products and for the optimization of technological processes.

The use of aronia as an impregnation agent represents an efficient strategy for obtaining products with a high content of fiber, mineral compounds, vitamin C, polyphenols and anthocyanins, thus contributing to increasing their value and diversifying the range of assortments with functional benefits.

From a technological perspective, the impregnation process provides flexibility in product formulation, allowing the composition to be adjusted according to nutritional requirements or consumption trends. In this context, the choice of raw material becomes a determining factor, influencing the final characteristics of the product.

Also, the reduction in carbohydrate content observed in aronia can be exploited in the development of products for consumers who require control of carbohydrate intake or food alternatives with an optimized nutritional profile.

The results indicated that aronia impregnation was useful in modifying the apple matrix and increasing the product value, compared to apple juice which had a limited impact.

The impregnation process proved to be an efficient method for optimizing the chemical composition.

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