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UTILIZAREA TEHNOLOGIEI DIC (DETENTĂ INSTANTANEE CONTROLATĂ) LA DESHIDRATAREA FRUCTELOR
THE USE OF DIC TECHNOLOGY (INSTANT CONTROLLED PRESSURE DROP) IN FRUIT DESHYDRATATION

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Abstract

Over time, many methods of preserving fruit by drying/dehydration applied at the industrial level (convection, microwave, high frequency currents, infrared radiation, lyophilisation, etc.) have been discovered and perfected to improve the quality of dehydrated products as well as their resistance to storage. The application of many of them is quite expensive, the parameters of the drying process (processing time and energy consumption) having high values. Technological progress in this field involves the development of new dehydration techniques, optimizing existing ones or combining them, aiming to increase energy efficiency, obtain healthy products with high rehydration capacity, reduce costs and negative impact on the environment. The paper presents a brief summary of the basic principles of the DIC (Instant Controlled Pressure Drop) process, as well as the advantages of its uses in industrial fruit dehydration technologies or as pre-treatment.

Cuvinte cheie: detenta instantanee controlată, deshidratare, fructe, textură.
Key words: instant controlled pressure drop, dehydration, fruit, texture.

1. Introduction

Food consumption is essential for people, providing the vital elements for life support. Population healthy eating and food safety are inseparable, being one of the current top priorities both in the European Union and in other developed countries around the world. For human health and well-being to be optimal, people must be both well fed and free of foodborne diseases (Nordhagena Stella et al. 2022).

Fruit, along with vegetables, are some of the most consumed foods because they contain a variety of micronutrients that support the physical and mental function of the human body (Chang et al 2016, Kaplan et al. 2007). It is protected by antioxidants (vitamin C and carotenoids) against oxidative stress, responsible for the appearance and evolution of several serious diseases, such as neurodegenerative diseases, chronic inflammatory diseases, atherosclerosis, some cancers and some forms of depression (Brookie et al. 2018).

Fruit can contain more than 80% water, being classified as highly perishable goods, with a high rate of rapid deterioration. Large losses are mainly due to poor post-harvest handling, lack of processing infrastructure and marketing (Hasan M.U. et al 2019). Drying can be a feasible alternative to capitalize on the surplus fruit on the market. This is one of the oldest physical methods of storing and preserving fruit, over 2000 years ago sun exposure or the action of air heated by it being used. Today, the products resulting from the application of various industrial dehydration technologies, retain their nutritional value, have a much longer shelf life, can be stored in a small space, and handling and transportation costs are low compared to those for fresh fruit (Nwankwo S. C et al. 2021).

Through the drying process, the water is removed from the fruit by vaporization or sublimation, thus inhibiting the reactions of chemical, enzymatic or microbial degradation, in which it would have participated. Transfer mechanisms, such as air temperature and speed, vapour and drying air pressure, moisture diffusion in the product, the surface exposed to drying and its thickness, influence the drying speed. Because the water is removed from both the fruit and its surface, the drying process combines heat transfer with the mass one, which requires energy. The flow of warm air over the fruit that need to be dehydrated, is the most used method to transfer heat, the process being done by *convection* (Guiné R. 2018).

Convective drying (using hot, natural or artificial air currents) is the most common method of drying fruit. Other fruit dehydration technologies have been studied and developed, using methods such as: osmotic and osmo-convective, vacuum, solar drying, microwave, freeze drying etc. (Radojčin M., et.al. 2021).

Among the innovative fruit dehydration techniques, studied and developed to preserve the quality and protect against damage to the resulting products, is also the DIC - Instant Controlled Pressure Drop (orig. Fr. Détente Instantanée Contrôlée), considered a treatment of HTST (High- Temperature Short-Time) type. The paper presents a summary of DIC basic principles and applications in fruit dehydration, as well as future trends regarding it.

2. Material and methods

The *Instant Controlled Pressure Drop* process consists in performing a short-term heat treatment (several tens of seconds) completed by ultra-fast pressure drop (<200ms) in vacuum. The process takes place in a very short time (<60s), by going through several stages, determined by pressure variation as a function of time. The steps shown in Figure 1 are as follows: 1. *Preliminary vacuuming* of the raw material, which is initially at atmospheric pressure; 2. *Injection of water vapour* under pressure ($T < 200^oC$, $P < 20$ bar); 3. *Instant Controlled Pressure Drop* achieved by sudden pressure drop; 4. *Return to the atmospheric pressure* of the product (Hamoud-Agha M. and Allaf K. 2019).

The theoretical principle of the process: the raw material consisting of fruit, initially at atmospheric pressure is vacuumed, to ensure a maximum contact surface between it and the dehydrating agent (vapour), to improve the heat transfer. To achieve high processing pressure, the raw material is heated for a short time (10-60 s) by injecting saturated (dry) water vapour under pressure (up to 1 MPa). As the temperature of the product increases and the condensation of vapours occurs, they result in an increase in the moisture content of the product by 0.1 g H_2O/g basic dry product. After this heating, the treatment period with constant temperature takes place, the high value of which corresponds to the saturated vapour pressure. Then, the product is applied to the *Instant Controlled Pressure Drop*, achieved by the sudden decrease of the pressure by 5 bar/s, towards the vacuum (3–5 kPa), in a very short time (10-60 ms), which implies the self-evaporation of the water from the product and its cooling. This takes place with the production of a quantity of vapour and with the expansion of the product. Cooling takes place quickly, preventing thermal degradation of sensitive compounds and thus ensuring the high quality of the treated products. The process ends by equalizing the pressure with the atmospheric one (Hamoud-Agha M. et al. 2019). It should be noted that for certain foods, it may be possible to apply more than one DIC cycle, depending on the purpose and characteristics of biological matrices (Pech-Almeida J.L et al. 2021).

DIC type equipment (reactor) (fig.2) consists mainly of: the processing vessel, which is an autoclave with a heating jacket in which the product to be treated is placed (1); the pneumatic valve (2), which ensures an almost instantaneous release of the vapour pressure contained in the treatment vessel, in the vacuum tank equipped with cooling jacket (3). To this is added a vacuum pump (c), the two elements forming the vacuum system. The volume of the tank is usually 100-130 times higher than the volume of the processing vessel. A water ring pump maintains the pressure in the tank at about 2.5–5 kPa. It is related to an extract collection trap, used for condensate recovery (Hajji W. et al.2018, Hamoud-Agha M.et al. 2019).

Initially, DIC was designed to obtain products from dehydrated fruit and vegetables, characterized by high rehydration speed and to preserve the colour and texture characteristics of the fresh product, in conditions of lower unit processing costs. The process invented by Allaf and Vidal, has been studied, developed and used especially in France and China, to obtain crunchy products, using equipment that differs mainly in the way of completing (performing) the stages. Thus, for the French DIC equipment, the fruit was heated by the steam injected directly into the chamber, the pressure and temperature of the processing vessel reaching up to 0.1–0.6 MPa and 150^0C, respectively. For the Chinese DIC equipment, the fruit was heated by radiation from the steam pipes inside, as a result, the temperature of the processing vessel could reach $100\text{-}110^0C$. The air was pumped into the processing chamber using an air compressor, the pressure having the possibility to vary from atmospheric pressure to 0.6 MPa. Due to the different heating mode applied, the moisture content of the products before the pressure drop was 0.12–1.30 kg/kg dry basis (db) in the case of French technology and 0.2–0.5 kg/kg db respectively, in the case of Chinese technology. For DIC France, during decompression, due to the self-vaporization of the remaining water, the products suddenly cooled, having a temperature lower than 40^0C. Cooling would set the food in an expanded state, and in the final drying stage of the process a moderate hot air drying was applied ($40\text{–}50^0C$, 1.2 m/s). For DIC China, the partially dehydrated samples, with a high relative humidity content (0.2–0.3 kg/kg db), were then subjected to the swelling phase. In order to avoid the collapse and hardening of the structure, vacuum drying was adopted in the processing vessel, so without vacuum interruption (Jian Lyu et al.2021).

To improve the process parameters as well as the quality of the resulting products, convective hot air drying (CAD) was coupled with DIC, under the name of “Swell-drying” (Mounir S. et al.2012, Maritza A.-M. et al. 2012). This type of drying involves the application of DIC after a conventional hot air drying stage (fig.3), when the product has an elastic texture (the water content being 20–30 g H_2O/100 g dry) or between two drying stages with air. The combination is considered an innovative, flexible and easy to achieve alternative for intensifying the drying process, and can be applied to several types of food, including fruits (Hamoud-Agha M. et al. 2019, Pech-Almeida J.L et al. 2021).

In figure 3, W_0 is the initial humidity of the product, W_D is the humidity at the end of the hot air drying stage (20–30% dry basis), W_E is the humidity at the end of compression, after applying the saturated steam from the DIC process, W_F is the final humidity of the dry product, T_0 is the initial temperature of the product, T_B is the hot air drying temperature, T_E is the DIC processing temperature depending on the processing pressure, and T_F is the product temperature at the end of the DIC process, usually reaching the value of approx. 32°C *(Hamoud-Agha M. et al. 2019).*

3. Results and discussions

“Swell-drying” was applied and studied for apple (*Malus domestica*) to obtain an aerated texture of the finished product. The initial water content of this fruit is high, being between 4 - 7 g H_2O/g d.b. (dry basis) or being 80% - 87.5% (wet basis). To obtain a final water content of 0.04 g H_2O/g d.b., a first CAD pre-drying step was applied for a product water content of 0.14 g H_2O/g db, followed by the step of texturing by applying the DIC process and a final CAD drying step. For the products subjected to DIC, the post-drying stage took place very quickly. Decreasing the humidity from 0.14 to 0.04 g H_2O/g d.b., required only 1 h, compared to 6 h for untreated products. Also, for the products subjected to a DIC treatment characterized by p=300 kPa and t=80 s, there was a significant increase in the content of quercetin (which acts as an antioxidant) in the final products, 5-7 times, compared to the initial amount, before treatment (Pech-Almeida J.L et al. 2021).

Following the application of this type of drying for the apples divided into pieces, the effect on the characteristics of the polysaccharides in the cell wall was studied, as well as the relationship between them and the texture of the resulting chips. The apples were peeled and cut into slices 10 mm thick and 20 mm in diameter, evenly, being pre-dried to a moisture content of 0.3 kg/kg wb, by hot air drying at 70°C. After this preliminary drying, the products were wrapped in polyethylene bags and stored in a thermostatic chamber at 20°C for 24 h. Prior to the application of DIC, they were equilibrated at 90°C for 10 min at atmospheric pressure, applying then the pressure drop to 3kPa. Finally, the apple slices were dried under continuous vacuum at 65°C for 2 hours. The results showed that by coupling CAD with DIC, apple chips with a crunchy texture and a honeycomb-like structure can be obtained, which, however, show some instability during industrial production, because of pectic polysaccharides in the cell wall (Xiao M. et al.2018).

The same type of three-step drying was used to obtain dried apple products, in the form of cubes, with a crunchy texture. Fresh apples were cut into cubes with a side of 1.7 cm. The experiments showed that the best swelling (expansion) of the apple cubes was obtained for the pre-dried CAD (T=80^0 C, the air speed being 2.4 m s^{-1}) to a water content between 0.134-0.248 g H_2O/g d.b. The apple cubes were then placed on trays and placed in the expansion tank at 95°C for 10 minutes at atmospheric pressure. Subsequently, by applying the pressure drop, it decreased to 0.002 - 0.004 MPa. The final drying was performed in vacuum (60°C) for 2 h. The results showed that the instant vaporization of the water on decompression provided the driving force for the expansion of the pores inside the apple cube. If after the preliminary drying stage, the water content does not fall within the mentioned range, the results regarding the texture of the dried apple cubes are not satisfactory (Li X. et al. 2021).

By combining partial air drying, DIC process, freezing and thawing, the aim was to minimize the loss of firmness of the texture of frozen/thawed apples. The fresh apple samples (water content 700% d.b.) were completely frozen at -30^0C at two freezing speeds, then thawed at 4^0C. Samples of partially dehydrated apples by CAD (air temperature, air velocity and air relative humidity of 45 °C, 2 m/s, and 12%, respectively) to a water content of 200, 100 and 30% dry basis (d.b.) and then treated by DIC (0.2 MPa, 25 s) were frozen and thawed under the same conditions. Thus compared to untreated apples, the application of partial air drying followed by DIC, as freezing pre-treatment resulted in a reduction of thawing time by 65% and 93% respectively for samples with 200% and 100% d.b. water content, respectively. For the untreated frozen/thawed apples the water exudate was 12%, for the treated ones, having a content of 100% d.b., it was less than 2%. The firmness of the thawed apples was higher, the lower the water content, the speed of freezing not having a significant impact. It manifested itself on water exudate only for conventionally frozen samples, without pre-treatment (Ben Haj Said L. et al.2021).

“Swell-drying” was also applied for strawberries (*Fragaria vesca* var. *vesca*). They were manually cut into 2 cm thick pieces, then pre-dried under CAD at 50°C to a water content between 0.05 and 0.20 g H_2O/g d.b. After that, the DIC treatment was applied, followed by a final drying at 50°C, to a water content of 0.05 g H_2O/g d.b. The obtained results showed that due to the application of DIC, at a pressure between 220-350 kPa, the expansion rate of dried fruits is 2.4 times higher than that of untreated fruits, and the drying time is reduced by up to 63%. In addition, the highest levels of phenols, flavonoids and anthocyanins, as well as antioxidant activities of dehydrated strawberries are obtained when DIC is applied at a pressure of 350 kPa for 10 s (Alonzo-Macías M. et al.2013).

The effect of combined drying on bananas *(Musa paradisiaca)* was also studied. The fresh fruit was cut into pieces of approx. 16x16x2 mm, being initially hot air dried at a temperature of 50^0C, to a water content of 0.25 g H_2O/g d.b. Then, they were subjected to the DIC process, followed by a final hot air drying at a temperature of 70^0C, to a water content of 0.075 g H_2O/g d.b. At the end of drying, the banana pieces were ground. Following the application of DIC, it was found that the diffusivity of water in rehydrated products increased by 23%. Also, following the statistical analysis, a 2.9-fold increase in water retention capacity was found for products subject to DIC, reaching 7.8 g H_2O/g db compared to 2.0 g H_2O/g d.b. for samples untreated. In addition, the application of DIC in the banana drying process inhibited the transformation of starch into reduced sugar. However, from the point of view of the capacity to retain banana oil, a decrease was found for the samples treated by DIC, this being 0.60 g oil/g d.b., compared to a value of 1.30 g oil/g d.b., recorded for untreated samples (Setyopratomo P. et al. 2012).

Zaghloul dates (*Phoenix dactylifera* L.) were dried using SD (Swell-drying). The fruit samples (Zaghoul dates) were initially dried to a water content of 12% on a dry basis, and then subjected to the DIC process. For this, the main parameters were varied, the saturated vapour pressure (p = 0.2-0.6 MPa) and the time (t=9-35 s), then evaluating the effect on the colour, texture and sensory qualities of the finished product. Thus, for a DIC treatment, characterized by p = 0.6 MPa and t = 22 s, optimized textural characteristics were identified, but with a slight yellowing. The best colour properties were obtained for the application of DIC at p = 0.2 MPa and t = 22 s. For the samples of dates to which SD was applied, regarding the texture, the expansion ratio was 46% higher, and the hardness was 262% lower than for the samples of dates dried with hot air flow (Mounir S. et al. 2019).

4. Conclusions

Following the study of the effects of applying the combination of convective hot air drying (CAD) and the DIC (Instant Controlled Pressure Drop) process, performed as "Swell-drying" for fruit species, more consumed worldwide, it was found a substantial reduction in drying time and improvement of the overall quality of finished products, dried fruit. Their swollen (expanded) texture responds to consumer demand for healthy foods, kept free of chemical additives or preservatives. By adopting this type of drying, farmers can reduce the loss of fresh fruit. In addition, DIC also performs a decontamination of dried fruits, due to the thermal impact combined with the mechanical one manifested on the treated fruits and implicitly on the microorganisms.

Further studies are needed on the coupling of the DIC process with other technologies, such as microwave or infrared drying, in order to continuously improve the parameters of the drying process and the quality of dried fruit.

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Figures

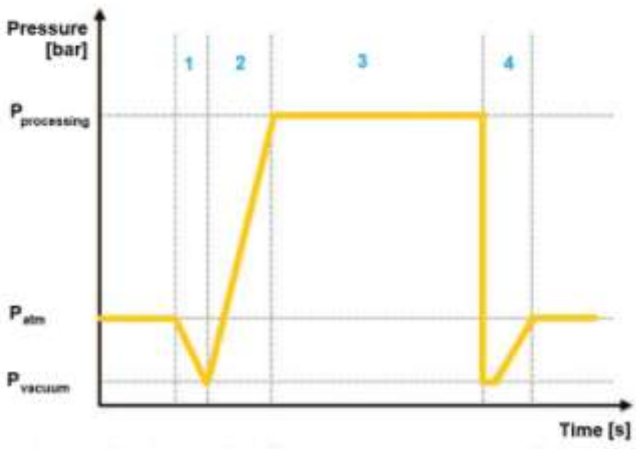

Fig. 1. Pressure variation of as a function of time, in the DIC process (Hamoud-Agha M. et al. 2019)

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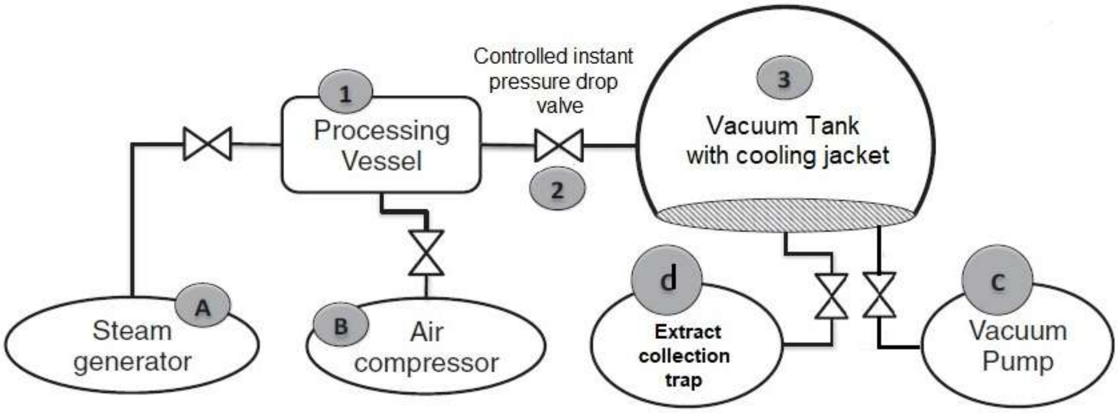

Fig. 2. Diagram of a DIC type equipment (Hajji W. et al.2018)

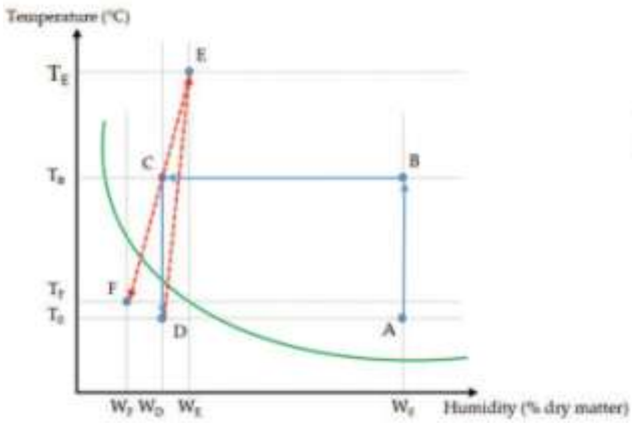

Fig. 3. The DIC and hot air drying process with regard to the glass transition curve (Hamoud-Agha M. et al. 2019)