Impacts of air drying and rehydration processes on DIC pretreated and dehydrofrozen apple texture.
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Abstract
The aim of this research work was to compare the effect of different apple processing methods on textural properties at equal water content (100% db dry basis). Pre-dried samples were treated by instant controlled pressure drop (DIC), completely frozen and thawed. In order to reach a final water content level of 100% db, the samples were post dried or rehydrated. Freezing had significant detrimental effect on firmness for high initial water content samples. This effect disappeared and firmness kept constant regardless of the initial water content once sample initial water content is lower than 115% db. Significant initial water content effect appeared after freezing/thawing for DIC untreated samples. However, by inserting DIC prior to freezing, the textural effect of final water content became insignificant after freezing/thawing.

Keywords: Air-drying; instant controlled pressure drop; dehydrofreezing; rehydration; texture.

1. Introduction
Dehydrofreezing is a variant of freezing defined as a preservation process that involves partial dehydration to desirable water content before freezing [1-13]. Dehydrofrozen products are often post-dehydrated or rehydrated, prior to their consumption and use, in order to attain the water content adequate to their future utilization. Very few research works concerning the processing and the use of dehydrofrozen fruits and vegetables were found. Giannakourou and Taoukis [14] studied the impact of cooking on textural characteristics of dehydrofrozen peas. They reported that hardness of osmo-dehydrofrozen peas were 20% to 30% higher than the respective frozen samples when measured after thawing, and 10% to 15% when measured after they were cooked by boiling for 10 min. Nevertheless, no research study investigated the use of airflow drying and rehydration as possible ulterior treatments to dehydrofreezing and thawing processes and their eventual impacts on final fruit texture [15]. Here, these two techniques were applied as water content homogenization treatments after dehydrofreezing and instant controlled pressure drop (DIC) pretreatment of apple fruits up to an optimized water content level of 100% db [16].

On the other hand, airflow drying normally triggers shrinkage that causes a detrimental deformation of natural structures. To prevent this negative effect, DIC-texturing was coupled to airflow drying thus defining swell-drying process. For these reasons, coupling DIC with dehydrofreezing operation was carried out in order to improve the process performance and final frozen-thawed product attributes considered at predefined final water content [16].

Nevertheless, no work has been reported in literature on using airflow drying and/or rehydration processes to acquire the water content level required for the practical use of finished dehydrofrozen apples. Hence, the main objectives of this research work were to (i) evaluate the efficacy of rehydration and post drying techniques for dehydrofrozen apple processing, (ii) assess the impacts of DIC treatment and dehydrofreezing on dehydration/rehydration and textural characteristics of apple fruits at final water content brought to 100% db, and (iii) optimize DIC conditions adequately with dehydrofreezing with respect to both rehydration/dehydration kinetic and texture firmness preservation.
2. Materials and methods

2.1. Raw material and sample preparation

Apples (Golden delicious) were purchased from a local market in La Rochelle, France. The fruits were then stored at 4 °C until analysis. Discs, 10.0±0.2 mm thick, were cut perpendicular to the main axis of the apple. The initial water content was determined according to AOAC official method 934.06 at 105 °C for 24 h. The initial water content was about 700±10% db (dry basis).

2.2. Pre-drying

Partially drying experiments were conducted in a pilot airflow dryer at 45 °C air temperature, 2 m/s air velocity and 12% air relative humidity. Drying was stopped when desired water content levels were attained (200, 166, 115, 64, and 30% db).

2.3. DIC treatment

Partially dried apple slices were treated by DIC equipment (ABCAR-DIC Process, La Rochelle, France). DIC operating parameters studied were ranged as: (1) the saturated steam pressure (P) from 0.1 to 0.3 MPa, (2) the total thermal treatment time (t) from 5 to 45 s, and (3) the initial sample water content (W) from 30 to 200% db implying 5-level DoE.

The statistical treatment of experimental results was executed using the analysis design procedure “Statgraphics Plus software for Windows” (1994, version 4.1, Levallois-Perret, France). Analysis of variance (ANOVA) is performed to determine significant differences between independent variables at a confidence level of 95%. Pareto chart is usually introduced to identify the significance effect of each studied parameter. When one or some parameters are significant, general trends, response surface, empirical model coefficients, R² and optimal point are also determined.

2.4. Freezing and thawing processes

Fresh, and differently treated (partially dried and/or DIC treated) apple samples were frozen in a conventional freezer (Whirlpool Model AFG 363/G, Italy) at -30 °C for 600 min as a practical freezing time (PFT). Then, they were thawed in a refrigerator (FAR Model RT 140, Romania) at 4 °C overnight.

2.5. Texture measurements

2.5.1. Water content homogenization

To perform a comparative study of the impact of different processing methods on textural behavior of apple, texture measurements were carried out on dehydrofrozen/thawed samples at the same water content level of 100% db. Thus, depending of initial water content, these samples were subjected to post drying or rehydration before texture assessment properly said.

DIC treated and/or frozen/thawed apple discs (with initial water content higher than 100% db) were post dried in the same conditions described in the section 2.1.2. (45 °C air temperature; 2 m/s airflow velocity and 12% air relative humidity), and recovered at desired water content level of 100% db [16]. Samples of apple discs whose initial water content lower than 100% db were rehydrated by immersion in distilled water kept at a constant temperature (25 °C). The weight ratio of apple slices to that of the medium (distilled water) was maintained at 1:25. At 5 min time intervals during the first 15 min and at 15 min time intervals until the end of the operation, samples were removed from the rehydration solution, blotted with tissue paper to remove superficial water and then weighed. All the rehydration experiments were performed in duplicate and average values were reported.

2.5.2. Firmness measurements

Firmness of differently treated apple samples at homogenized water content of 100% db was evaluated as the maximum force recorded to puncture test [16]. Measurements were performed with an Instron Universal Testing machine (Model 5543, USA) using a cylindrical puncture probe of 2 mm in diameter at a constant speed of 5 mm/s [6]. For each experiment, texture measurement were applied on three different samples and repeated five times for each sample. Means and standard deviations of the $3 \times 5 = 15$ measurements data were calculated.

2.5.3. Statistical analysis

Bifactorial analysis of variance (ANOVA) was carried out to estimate significant differences (Least Significant Difference (LSD)) of independent factors on the response variable values, at a confidence level of 95% (p<0.05). The multiple range test (Student-Newman-Keuls or SNK test) was also used to determine possible homogeneous groups existing among the response variable values. The statistical evaluation was done using the Statistical Package for Social Sciences (SPSS) version 20.
3. Results and discussion

3.1. Texture properties for apples with water content stabilized at 100% db: Freezing/thawing impacts

Pre-dried and dehydrofrozen/thawed apple samples were subjected, according to their initial water content, to rehydration or post-drying in order to attain a homogenized water content of 100% db. The maximum puncture force values, as indicator of firmness, of the differently treated samples were measured through puncture test at a constant speed of 5 mm/s (Figure 1). Maximum puncture force values were expressed versus initial water content, whose effect was studied through statistical analyses (ANOVA and tests).

Figure 1. Freezing/thawing effects on maximum puncture force of pre-dried and dehydrofrozen apples at equal water content of 100% db. (Data are expressed as the mean standard deviation. •Values for the same treatment (drying or drying-freezing) having the same letter (A, B and C) for significantly similar maximum puncture forces. •Values for the same initial water content having the same letter (a, b and c) for maximum puncture force are not significantly different at a confidence level of 95%).

As it is shown in Fig. 1-A, initial water content has insignificant effect on maximum puncture force (firmness) of partially dried samples subjected to water content homogenization treatments (until 100% db) by post-drying for samples with water content higher than 100% db and by rehydration for samples lower than 100% db. Values of textural measurements were subjected to ANOVA and LSD tests. Significant initial water content effect appears after freezing/thawing processes. In addition, according to the result of the simple range tests (SNK test) carried out for the maximum puncture force values after freezing/thawing, three homogeneous groups were identified. The first includes post-dried products. The rehydrated product with initial water content of 64% db formed the second group; while rehydrated samples with initial water content of 30% db built the third group.

Statistical results prove that freezing/thawing had significant effect on firmness of apples with homogenized water content (100% db). As it is shown in Figure 9-B, the maximum puncture force ratio \( f = \frac{F_{\text{Dehydrofrozen-thawed}}}{F_{\text{Partially dehydrated}}} \) value was constant and much inferior to 1, indicating the significant effect of freezing on firmness when the initial water content samples is high. The lower the initial water content, the higher the value of \( f \). This reached the value of about 0.9 to ≈1 for rehydrated samples with initial water content from 64% db to 30% db, thus revealing the absence of freezing effect \( f = \frac{F_{\text{Dehydrofrozen-thawed}}}{F_{\text{Partially dehydrated}}} = 1 \).

Very few data were found concerning the textural properties of dehydrofrozen products during their ulterior use and consumption. Giannakourou and Taoukis [14] reported that hardness of osmo-dehydrofrozen peas were 20% to 30% higher than the respective frozen samples when measured after thawing, and 10% to 15% when measured after they were cooked by boiling for 10 min.

3.2. Texture properties for apples with water content stabilized at 100% db: DIC impacts

Apple samples were subjected to successive stages of 1) partial airflow drying, 2) DIC (according to 3-parameter, 5-level central composite rotatable design of experiments (DoE), with 22 trials implemented with \( 2^3 \times 6 \) factorial trials, \( 2^3 \times 6 \) star points, and 8 central points), 3) freezing at -30 °C, and 4) thawing at 4 °C for 24 h. These treatments were followed by rehydration or post-drying of differently treated apple samples with equal final water content of 100% db. The Response Surface Methodology (RSM) of the firmness (maximum puncture force) of the processed samples was explored as the main response variable. Values of maximum puncture force are shown in Table 1.
Table 1. Maximum puncture force of partially dried and dehydrofrozen apples with equal final water content (100% db) previously DIC pretreated under different operating conditions.

<table>
<thead>
<tr>
<th>Post-treatment</th>
<th>DIC operating conditions</th>
<th>Maximum puncture force (N)</th>
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<tbody>
<tr>
<td></td>
<td>W(% db)</td>
<td>t (s)</td>
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<td>Post-drying</td>
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<td>200</td>
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<td>Post-drying</td>
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<td>115</td>
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<td>Rehydration</td>
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<td>30</td>
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W: Initial water content; t: Total treatment time; P: Saturated steam pressure.

Figure 2. Statistical analysis of the impact of DIC parameters on maximum puncture force for post-dried/rehydrated apples with equal water content (100% db) before freezing. A) Standardized Pareto chart; B) Trends; C) Iso-responses of maximum puncture force and D) Response surfaces of W and P at treatment time of 25 s.
The effects of the sample water content (W), DIC saturated steam pressure (P) and total processing time (t) on the maximum puncture force before freezing process are illustrated by the Standardized Pareto chart (Figure 2). It is deduced, from Figure 2, that the factor W (initial water content % db) was the only significant DIC operative parameter on firmness of apple with homogenized final water content at 100% db. Its positive effect means that an increase of initial water content results in an increase of firmness. The other operating parameters had insignificant effects.

After freezing/thawing processes, the effects of W, P, and t on maximum puncture force are illustrated in Figure 3.

Figure 3. Statistical analysis of the impact of DIC parameters on maximum puncture force of apple samples with equal water content (100% db) after freezing/thawing and post drying/rehydration processes. A) Standardized Pareto chart; B) Trends; C) Iso-responses and D) Response surfaces of W and P at treatment time of 25 s.

P was the only significant DIC operating parameter on firmness of apple samples with equal water content of 100% db after freezing/thawing. Its negative effect means that higher P implied a decrease of firmness. The other operating parameters had insignificant effects on frozen/thawed apple firmness.

The empirical model of maximum puncture force F versus P, W, and t for non-frozen (Eq. 12) and frozen (Eq. 13) apples are listed below:

\[
F = 7.92 - 0.01W - 0.08t - 0.0003W^2 + 0.16WP + 0.0002Wt + 43.67P^2 + 0.49Pt - 0.001t^2
\]  
Eq. 1

\[
F = 5.56 + 0.01W - 23.14P + 0.01t - 0.0005W^2 - 0.03WP + 0.0008Wt + 29.23P^2 + 0.22Pt - 0.002t^2
\]  
Eq. 2

With F is expressed in N, W in g H2O/100 g db, t in s, and P in MPa.

4. Conclusions

Post-drying and rehydration were investigated in order to compare the effects of different dehydrofrozen apple processing methods during their ulterior industrial use and consumption on textural properties at the same level of water content (100% db). Effects of DIC pre-treatment operating conditions assisted to dehydrofreezing on drying/rehydration and textural characteristics were investigated. Freezing/thawing had significant effect on firmness of apples with homogenized water content (100% db) when high initial water content samples were tested (subjected to post-drying). This effect disappeared and kept constant regardless of the initial water content once sample initial water content is lower than 115% db (samples subjected to rehydration). Significant initial water content effect appeared after freezing/thawing processes for DIC untreated samples. However, the initial water content of
differently DIC treated samples with equal final water content became insignificant after freezing/thawing processes.

In conclusion, both DIC pretreatment and dehydrofreezing/thawing processes allow the improvement of drying/rehydration operations. They are considered as relevant ways for intensifying the internal resistance to water transfer during the final manufacturing and use of the processed products with a good preservation of the textural properties assessed at the same final water content level of the apple fruits.

5. References