HAL
open science

Characterization of pure cheese snacks and expanded granule powders textured by the instant controlled pressure drop (DIC) process

Mounir, Halle, Allaf

To cite this version:

Mounir, Halle, Allaf. Characterization of pure cheese snacks and expanded granule powders textured by the instant controlled pressure drop (DIC) process. Dairy Science & Technology, 2011, 91 (4), pp.441-455. 10.1007/s13594-011-0023-8 . hal-00930582

HAL Id: hal-00930582

https://hal.science/hal-00930582

Submitted on 11 May 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Dairy Sci. & Technol. (2011) 91:441–455
DOI 10.1007/s13594-011-0023-8

ORIGINAL PAPER

Characterization of pure cheese snacks and expanded granule powders textured by the instant controlled pressure drop (DIC) process

Sabah Mounir · Denis Halle · Karim Allaf

Received: 24 May 2010 / Revised: 31 January 2011 / Accepted: 1 February 2011 /
Published online: 19 April 2011
© INRA and Springer Science+Business Media B.V. 2011

Abstract In this study, a new concept of pure cheese crispy snacks has been defined. The process used is the *Détente Instantanée Contrôlée* (DIC), for instant controlled pressure drop treatment, inserted between two air drying stages. Such cheese snacks can reach low water content (W<3 g H_2O/100 g dry basis) and achieve high crispness level. A final simple grinding allows expanded granule cheese powders to be obtained. This paper investigates the impact of this process in terms of physical and structural properties such as specific density, expansion ratio, compressibility, etc. Cheese pieces can be expanded to a volume ca. 3,500% of original size, with a sharp decrease in the specific density of pieces from an initial value of 1,118±5 kg.m^{-3}, for untreated samples, which is close to the intrinsic density value, toward 33±5 kg.m^{-3} for the most expanded samples. The values of specific density strictly depend on the DIC processing parameters; the higher the DIC steam pressure, the higher the expansion ratio, and the higher the porosity (results not shown), the lower the specific density of the cheese snacks. The final powder granules can have small size (around 250 μm), an expanded structure, and thus a low bulk density and a high specific surface area. The results revealed the high capability of the DIC process to produce expanded perfectly dried cheese snacks and powders.

S. Mounir · K. Allaf (✉)
Laboratory Transfer Phenomena and Instantaneity in Agro-industry and Building LEPTIAB—Pole Science and Technology, University of La Rochelle, Av. Michel Crépeau, 17042 La Rochelle Cedex 01, France
e-mail: kallaf@univ-lr.fr

S. Mounir
Food Science Department, Faculty of Agriculture, Zagazig University, Zagazig, Egypt

D. Halle
L.C.D.F. Compagnie des Fromages & Richesmonts, Centre de Recherche et Développement Pâtes Molles, 93 rue du Pont de Soulles, 50211 Coutances Cedex, France
e-mail: denis.halle@cf-r.com

瞬间控制压降法生产的纯干酪点心的特性和膨松干酪颗粒粉的质地

摘要：本研究提出了纯干酪酥点心的概念。在干酪酥点心的加工过程采用瞬间控制压降(DIC) 的方法，即在两步空气干燥阶段的中间采用了瞬间控制压降的处理过程。干酪酥点心粉碎后还可以生产出膨松的干酪颗粒粉。本文研究了瞬间制压降(DIC) 方法对干酪点心物理和结构特性的影响，如比重、膨胀率、可压缩性等等。 DIC处理使得干酪片的体积膨胀了3500%，未处理干酪片的密度为1118±5 kg.m^{-3}，干燥后干酪片的密度降到了33±5 kg.m^{-3}。密度值的大小取决于瞬间控制压降过程的参数 瞬间控制压降的蒸汽压越高，膨胀率越高，孔隙度也越高，干酪点心的密度越低。将干燥后的干酪片粉碎到粒度为250 μm的小颗粒，得到了具有膨松结构、低密度、高表面积的干酪粉。因此，DIC 方法可以生产出膨松的干酪酥点心和干酪颗粒粉。

Keywords Pure cheese snacks · Cheese powder · Drying · Instant controlled pressure drop (DIC) · Texture · Specific surface area · Expansion ratio

关键词 纯干酪点心 · 干酪粉 · 干燥 · 瞬间控制压降(DIC) · 质地 · 比表面积 · 膨胀率

Nomenclature

m_1	Mass of a volume V of the cracking powder (kilograms)
m_2	Complementary mass of cracking powder poured on the product to reach the same volume V (kilograms)
m_{samp}	Mass of the sample (kilograms)
P	Saturated steam pressure during heating phase of DIC treatment (megapascal)
t	Thermal treatment time of DIC treatment (seconds)
W	Water content dry basis
X	Powder compressibility
ε_a	Absolute expansion ratio
ε_r	Relative expansion ratio
$\rho_{cracking\text{-}powder}$	Apparent density of the cracking powder (kilograms per cubic meter)
ρ_{spec}	Specific density of the dried cheese sample (kilograms per cubic meter)

1 Introduction

Powdered cheese is popular in various food industries for making sauce bases, dips, dressings, biscuits, and chips, as well as flavoring used in hot dishes such as spaghetti and soups. Cheese powders are normally made from a single cheese variety or a blend of various cheeses, or a blend of cheese with other dairy ingredients (i.e., whey, non-fat dry milk, etc.), food ingredients, and/or dye. The product has to be dehydrated (by hot air drying) from the usual 82 g H_2O/100 g dry basis moisture content down to 5 g H_2O/100 g dry basis moisture, before grinding. This makes water activity close to 0.35–0.45 and the powder shelf-stable. However, the very compact form and large particle size of the final dried material do not allow it to be

of high functional quality because of low value of specific surface area thus induced (Dairy Management Inc. TM (DMI) 2005).

Another main method of producing cheese powder is spray drying, where the cheese is first converted into a pumpable fluid, atomized, and finally dried and cooled to form a powder. This is done by a conventional melting process where the cheese is disintegrated, during heating and agitation, and enriched with salts such as phosphates and citrates (together with water) (Písecký 2005) in order to restore the emulsifying capacity of the milk proteins. At a temperature of about 75 °C, this liquid form with a total solid content of about 35% is not too viscous for spraying. In a conventional spray drier, the temperature of inlet air is about 180–190 °C. Cooling of the powder is generally achieved in a fluidized bed supplied with ambient air in the first section and cold dehumidified air in the last section. In the production of cheese powder, a certain amount of aroma is inevitably lost during drying, and in order to avoid aroma problems, the exhaust air must be filtered through activated carbon filters. The reconstitution in water of such a powder is too difficult and requires intensive mixing, before it is totally dissolved. Agglomeration processes usually adopted for solving this issue would raise the cost of this drying process.

In this paper, an innovative process for cheese powder production was investigated. It consists in inserting a texturing process, the instant controlled pressure drop (DIC) treatment, into traditional hot air drying processes in order to obtain low-cost/high-quality powder with open microstructure particles. Such porous particles promote improved reconstitution, solubility, and functional characteristics. DIC process is defined as a swell-drying operation followed by a grinding stage. Pieces of dried cheese (with water content of about 8–10 g H_2O/100 g dry basis) are transformed into snacks through an expansion process by DIC treatment; they are then dried and crushed using an appropriate mechanical system.

As known, expansion plays a fundamental role in improving the final quality of dried foodstuffs. It generally aims to provide better functional (short-time dehydration, large specific surface area, and high capacity and rate of rehydration) and sensorial (appearance, texture, color, flavor) characteristics of air-dried products (Louka et al. 2004; Louka and Allaf 2002). The principle of expansion by DIC is based on autovaporization of the moisture present in a food product; this intervenes by dropping instantaneously the steam pressure toward vacuum. Therefore, the vapor thus generated can create micro-stresses in various points of the products. An internal porous structure results depending on the viscoelastic and diffusivity of the material.

Early studies carried out on the expansion of foodstuffs by decompression dates back to 1950. Potato cubes were expanded after treatment at 163 °C for a few minutes, followed by a rapid pressure release from a vapor pressure of 0.667 MPa to atmospheric pressure (Harrington and Griffiths 1950).

There are several techniques for expansion of foodstuffs, which include the explosion-puffing technique using rotating guns, the continuous explosion-puffing technique (Heiland et al. 1977; Sullivan and Craig 1984; Sullivan et al. 1982, 1980), the high-temperature fluidized bed (Chandrasekhar and Chattopadhyay 1989; Kim and Toledo 1987; Torreggiani and Toledo 1990), and others using soluble gases such as carbon dioxide (De La Burde et al. 1981; Payne and FA Saputra 1987; Saputra et al. 1991; Sykes et al. 1985; Tabeidie et al. 1992a, b) or Freon, which is used in tobacco expansion (Fredrickson 1981), and a static expansion technique to produce

expanded rice cakes (Hsieh et al. 1989, 1990; Huff et al. 1992). Finally, there is expansion by frying in hot oil (Highlands and Getchell 1956; Wells 1989), or using microwaves (Yamaguchi et al. 1988).

The DIC toward vacuum (Allaf et al. 1992; Allaf and Vidal 1989) has been defined and developed since 1988 firstly as an expansion process perfectly adequate for heat sensitive foodstuffs, such as fruits, vegetables, milk, and milk products. The DIC technology is a high-temperature–short-time treatment followed by an abrupt pressure drop (pressure drop rate >0.5 $MPa.s^{-1}$) toward vacuum (about 0.005 MPa). The expansion effect was related to the amount of water deeply autovaporized, which depends directly on the difference in temperature between the two states: just before and just after the pressure drop. The advantages of dropping toward vacuum were related to the greater amount of vapor generated, the lower treatment temperature, and the lower final temperature (Louka 1996; Louka and Allaf 2002). Inserted in a conventional hot air drying process, such a treatment, has already been used in various industries for swell-drying pieces of fruit, vegetables, and biological products. Recently, DIC treatment was coupled with spray drying in a novel innovative process (Mounir and Allaf 2008) for production of various dairy products. This treatment overcomes the shrinkage effect and greatly enlarges the exchange surface area thanks to the controlled alveolation. It intensifies the kinetics of the final stage of drying, thus reducing the cost and allowing the operation to be a more environment friendly process (Allaf et al. 1995). Simultaneously, this process contributes to the preservation of a large part of the sensorial, nutritional, and microbial quality of the end product (Allaf and Vidal 1989). The specific problems linked to the spray drying of cheese and the difficulty to grind and get a good quality powder from conventional hot air-dried cheese should encourage the study of direct expansion of cheese pieces in order to obtain snacks and by grinding expanded granule powders.

2 Materials and methods

2.1 Raw materials

Although preliminary experiments were performed on a large variety of types of cheese, trials carried out in this study were limited to Leerdammer only. It is a semi-hard cheese made from cow's milk (supplied from a local hypermarket, Carrefour, La Rochelle, France), with a chemical composition as follows: 28 g of proteins, 0 g of carbohydrates, 27.5 g of lipids, 950 mg of calcium, 43.2 g of water, and 1,506 kJ in 100 g of fresh cheese. Fresh cheese is cut into 50×10×5 mm pieces. The samples were dried in an oven by air flow containing moisture at 260 Pa as partial pressure, 27 °C, and 1 $m.s^{-1}$ until their water content reached a level of 7 g H_2O/100 g dry basis, in about 24 h.

2.2 Treatment equipment and process

The operating protocol used in different trials has been previously described (Allaf and Vidal 1989; Mounir and Allaf 2008); it comprises a first stage of air drying at low temperature and high air flow rate (27 °C/1 $m.s^{-1}$), a DIC treatment, a second

stage of air drying performed under the same conditions as stage one, and a grinding process.

The DIC system comprises three main parts: a processing vessel, a vacuum tank, whose volume is 100 times greater than the processing vessel, and an appropriate vacuum pump used to reach a vacuum level of 5 kPa. The instant pressure drop is ensured thanks to a pneumatic valve between the vacuum tank and the processing vessel; it can be opened in less than 0.2 s, which ensures an "instant" pressure drop within the treatment vessel.

To texture the partially dried cheese pieces using the DIC process, the samples are exposed to steam pressure (between 0.2 and 0.6 MPa, determined with a precision of ±0.002 MPa), which is kept constant throughout the treatment (between 10 and 30±2 s), until abruptly dropping the pressure toward vacuum reaching 5 kPa. Some preliminary DIC experiments were carried out with various moisture contents under different operating conditions. It allowed us to achieve the present experiments with water content maintained constant (7±0.2 g H_2O/100 g dry basis) while the saturated steam pressure and processing time were varied simultaneously between 0.2 and 0.55 MPa and 10 and 30 s, respectively. These operating parameter ranges were identified to allow cheese to expand dramatically. Such a level of saturated steam pressure resulted in a processing temperature between 120 °C and 152 °C. The time of DIC processing was defined in order to ensure the homogeneity of water and temperature in the sample (Mounir et al. 2011). A central composite rotatable experimental design method (described in Table 1) was adopted with five levels. Surface responses were obtained by using the analysis design method of Statgraphics (Plus 5.1 software for Windows; 1994—4.1 version, by StatPoint, Inc. SIGMA PLUS; 6 rue Collange 92300 Levallois-Perret, France).

Following DIC treatment, convective drying was achieved for 2 h using air stream containing moisture at 260 Pa as partial pressure, 27 °C, and 1 m.s^{-1}; the final water content was close to 3 g H_2O/100 g dry basis. The dried samples were then recovered for various characterizations. The transformation of dried cheese snacks into powder was carried out by grinding using a laboratory knife grinder (Retsch Grindomix, Model GM200, F. Kurt Retsch GmbH and Co. KG, Haan, Germany) for 30 s at 4,000 rpm.

2.3 Assessment and characterization protocol

Cheese samples taken at various moments during the drying, mostly just before and just after the DIC treatment, as well as the final textured and untextured dried cheese were characterized in terms of water content, density, and structure. Water content, expressed as g H_2O/100 g dry basis, was determined by the desiccation method in a

Table 1 Experimental design of the DIC treatment of cheese pieces, with steam pressure and processing time as the main operating parameters

	$-\alpha$	-1	Central point 0	1	$+\alpha$
Steam pressure (MPa)	0.2	0.27	0.38	0.48	0.55
Processing time (s)	10	14	20	27	30

Mettler Toledo LP-16 Infrared Dryer/Moisture Analyzer with Mettler Toledo PE360 Balance—Bishop International Akron, OH, USA. The measurement of water content by calibration with the standard method using a drying oven at 105 °C/24 h was carried out twice. The precision of such measurements was estimated as ±0.2%.

The cheese intrinsic density ρ_{int} (i.e., the skeletal density or true density) expressed in kilograms per cubic meter was measured using a Helium Pycnometer (AccuPyc 1330 Pycnometer, Micromeritics, Norcross, USA). The pycnometer method (Bachelor and Lynch 1977) is based on Archimedes' principle of fluid displacement and Boyle's law to determine the volume. It was performed on powder samples completely dried in a hot air oven at 27 °C for 24 h, and the intrinsic density was determined with ±5 kg.m^{-3} precision.

The specific density ρ_{spec} was determined to calculate the expansion ratio of dried, expanded, or compact pieces of cheese. Because of their possible interaction in water, the standard method using water was not possible to be carried out, and an alternative technique in which cheese samples were submersed in a powder bath was used. Its principle is to measure the mass of a predetermined constant volume (100 cm^3) of 80 μm specific mineral powder with and without the sample submersed in it. A regular mechanical tapping (100 taps) ensures better precision (±10 kg.m^{-3}), and the specific density ρ_{spec} is calculated according to the following equation (Louka et al. 2004):

$$\rho_{\text{spec}} = \rho_{\text{cracking powder}} \left(\frac{m_{\text{samp}}}{m_1 - m_2} \right) \tag{1}$$

The absolute expansion ratio ε_{a} is quantified by determining the ratio between the intrinsic density and the specific density of cheese piece. The effect of a texturing treatment was much better interpreted through the relative expansion ε_{r}, i.e., the absolute expansion ratio of the dry matter of the end product compared with the non-expanded product.

$$\varepsilon_{\text{a}} = \frac{\rho_{\text{int}}}{\rho_{\text{spec}}} \tag{2}$$

$$\varepsilon_{\text{r}} = \frac{\left(\rho_{\text{spec}}\right)_{\text{untreated}}}{\left(\rho_{\text{spec}}\right)_{\text{expanded}}} = \frac{(\varepsilon_{\alpha})_{\text{expanded}}}{(\varepsilon_{\alpha})_{\text{untreated}}} \tag{3}$$

The densities used to characterize the powders are the apparent (or aerated) bulk density ρ_{a} and the tapped bulk density ρ_{p}; ρ_{a} and ρ_{p} are calculated (kilograms per cubic meter) by measuring the volume occupied by a given powder mass, before and after 100 successive taps.

The powder densities ρ_{a} and ρ_{p} are used to identify the powders compressibility (X%), which describes the aptitude of the powder to lose volume by packing or tapping according to the definition of (Carr 1985).

$$\text{X\%} = \frac{\rho_{\text{p}} - \rho_{\text{a}}}{\rho_{\text{p}}} \times 100 \tag{4}$$

Micro-structural observations were made using an environmental scanning electronic microscope (JSM—5410/5410 LV JEOL Ltd., Tokyo, Japan). The powdered samples were placed on a covered stud using carbon adhesive; the observations were made in a partial vacuum (7 Pa) with an accelerating voltage of 20 kV.

The granulometry and statistical distribution of granule size were measured and calculated using the mechanical sieving method. The sieve makes it possible to screen the powder by weighting the different parts corresponding to each specific sizes. Therefore, an amount of approximately 100 g of powder was separated, and the specific size was sorted through a laboratory sieving system with vertical vibrations (Model Pro, FRITSCH Gmbh, Idar-Oberstein, Germany). The operation was carried out at 2.5 mm as amplitude for 5 min. The sieves used were of 50, 71, 200, 600, 1,000, 1,400, and 1,700 μm, identified by the lower value. A precision balance with ±1 mg (Sartorius GENIUS ME235S balance; 91127 Palaiseau, France) was used to measure the mass of different parts of powder. Three repetitions allowed the measurement of percentage of mass to achieve a precision of ±2.5%.

3 Results and discussion

3.1 Physical characterizations

The intrinsic density of untreated (control) and differently DIC treated cheese (pieces or powder form) did not depend on the operating DIC parameters. The Pareto chart value of all the results for samples treated according to the experimental design confirmed this observation (Fig. 1a). The value of intrinsic density ρ_{int} was considered as constant (1,185±5 kg.m^{-3}; Fig. 1b) and was independent of DIC operating conditions.

Conversely, the specific density ρ_{spec} of cheese snacks varied significantly depending on the operating DIC conditions (Fig. 2a, b); it sharply decreased from an initial value of 1,182±5 kg.m^{-3} for unexpanded air-dried cheese, close to the intrinsic density value, to 33±5 kg.m^{-3} for the most expanded samples; it shows a very high expansion ratio reaching up to 3,580%. The saturated steam pressure, revealing the processing temperature, acted as the main operating parameter while the effect of heating time was negligible. The higher the pressure, the lower the specific density varying between about 70 and 33 kg.m^{-3}. The microstructure analysis (Fig. 3) showed a porous structure revealing the presence of alveoli generated by DIC autovaporization. It is similar to the one obtained by Mounir and Allaf (2008) using the DIC for treating sodium caseinate pieces, whose expansion ratio could reach a value of 1770%.

Figure 4a, b shows the presentations of the expansion ratio. As the apparent density of dried cheese had the same value of the intrinsic density, it is worth noting that both the absolute and relative expansion ratios ε_a and ε_r of cheese pieces had the same values. As such, it is possible to establish prediction models for steam DIC processing parameters, which are the steam pressure and the processing time. High R^2 values (0.94 and 0.87 for steam pressure and processing

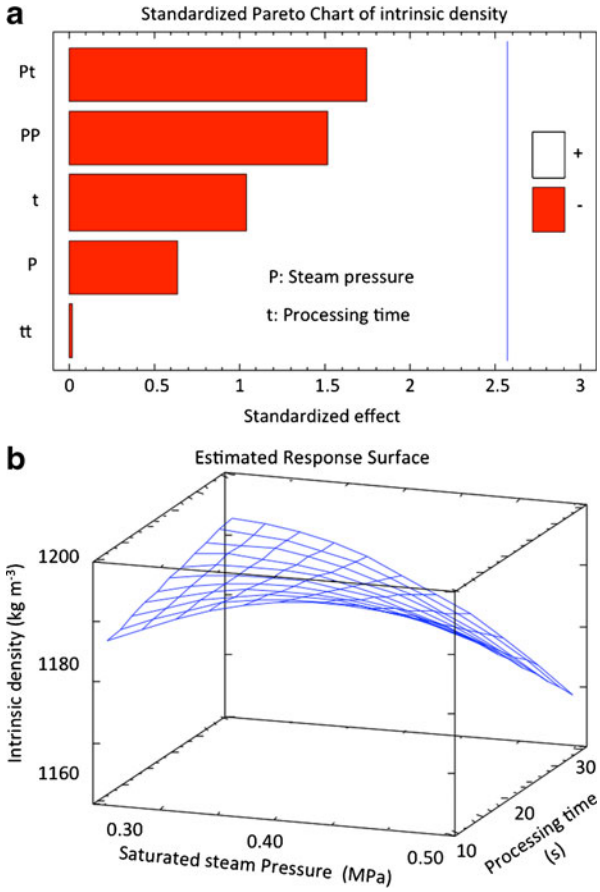

Fig. 1 Pareto chart (**a**) and response surface (**b**) from statistical analysis by response surface method of the impact of the operating parameters, of the instant controlled pressure drop DIC (saturated steam pressure, in megapascal, and processing time, in seconds) on the intrinsic density ρ_{int} expressed in kilograms per cubic meter of the dried DIC-textured cheese

time, respectively) show that the steam DIC process is well suited to controlled swelling of cheese:

$$\rho_{\text{spec}} = 252.878 - 753.946P - 4.562t + 735.672P^2 + 4.096Pt + 0.064t^2 \quad (5)$$

$$\varepsilon_{\text{a}} = \varepsilon_{\text{r}} = -51.9978155 + 250.477872P + 2.404535t - 247.431132P^2 - 0.73752614Pt - 0.0480907t^2 \quad (6)$$

There are many parameters that affect the degree of swelling, normally related to both the composition of the raw material (Chen and Yeh 2001; Jones et al. 2000) and processing conditions (Chandrasekhar and Chattopadhyay 1990; Owusu-Ansah et al. 1984). Expansion of the DIC-textured cheese snack products was depended on the saturated steam pressure (which determined the vessel temperature) and the processing time. The results show that steam pressure had the most significant influence, and processing time only had a slight effect; the higher the steam pressure, the higher the expansion ratio (Fig. 4a, b).

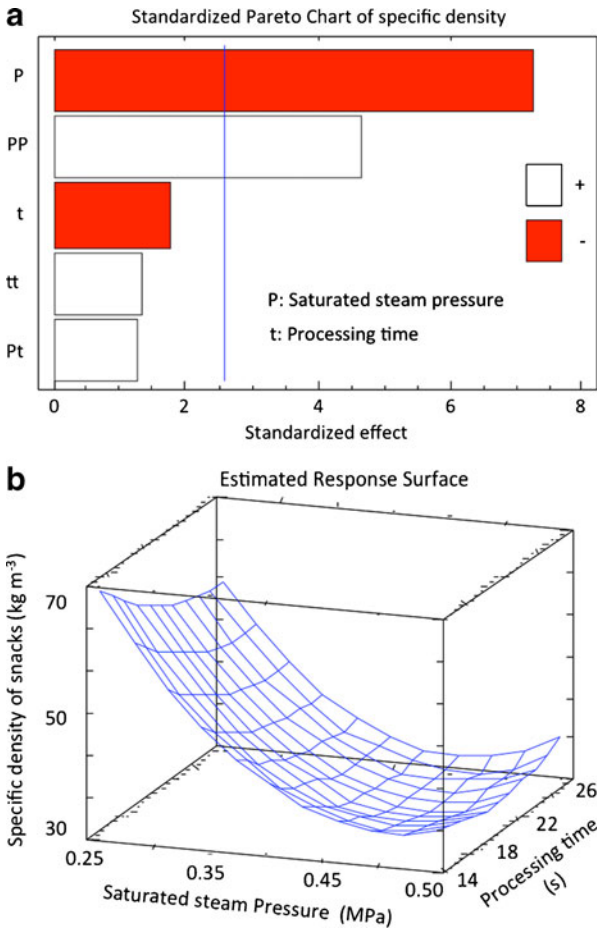

Fig. 2 Pareto chart (**a**) and response surface (**b**) from statistical analysis by response surface method of the impact of the operating parameters of the instant controlled pressure drop DIC (saturated steam pressure, in megapascal, and processing time, in seconds) on the specific density (ρ_{part}) expressed in kilograms per cubic meter of the dried DIC-textured cheese

This new texture can be explained mainly by physical and structural modifications of proteins (Yada 2004), as a result of thermal and mechanical effects (Mounir and Allaf 2008), depending on rheological behaviors in terms of viscosity, elasticity, and glass transition, which can intervene for expanding material with appropriate treatment conditions. Different levels of material expansion can be achieved under various steam DIC conditions, but the maximum expansion was achieved at 0.5±0.01 MPa as saturated steam pressure for 22±2 s. The impact of this increase was direct in terms of the main functional and technological properties (drying kinetics).

Concerning the cheese powder obtained from grinding, Fig. 5a, b shows the effect of operating steam DIC conditions on the bulk density. As expected, the steam pressure has the greatest influence. The bulk density of cheese powder obtained from the grinding of textured cheese snacks is much lower than the one obtained from the non-textured cheese. By improving the expansion ratio, the powder has a higher porosity of granules with lower bulk density. The empirical prediction model of bulk

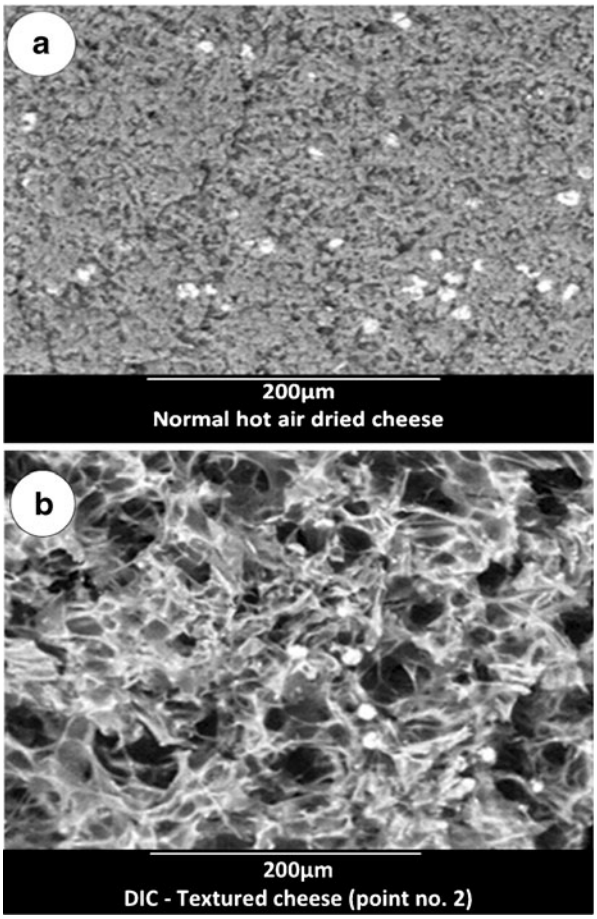

Fig. 3 Microstructure of cheese snacks and powder, obtained by **a** a conventional air drying, **b** a swell-drying including a DIC treatment at 0.55±0.02 MPa saturated steam pressure for 20±2 s

density related to the DIC processing parameters, steam pressure, and processing time is as follows with R^2=76%:

$$\rho_a = 759 - 1646.64P - 3.91773t + 1951.46P^2 - 13.5486Pt + 0.266474t^2 \quad (7)$$

The expanded cheese snacks previously treated by DIC are easier to grind and had a smaller granule size (Fig. 6b, c: DIC-textured samples treated at saturated steam pressure of 0.55±0.02 MPa for 20±2 s and 0.38±0.02 MPa for 30±2 s, respectively) compared with untextured dried cheese (Fig. 6a). Nevertheless, the compressibility of powder is one of the most important functional properties and whatever the DIC conditions, the compressibility of such expanded granule powders at 3 g H_2O/100 g dry basis is higher than for untreated ones, at 5 g H_2O/100 g dry basis. Here too, the DIC steam pressure is the most important DIC operating parameter (Fig. 7a, b). Indeed, these high values of compressibility would be linked to the variability of expansion ratio, but they are mainly due to the capability of small-size granules to fill the voids and cavities between the large granules by

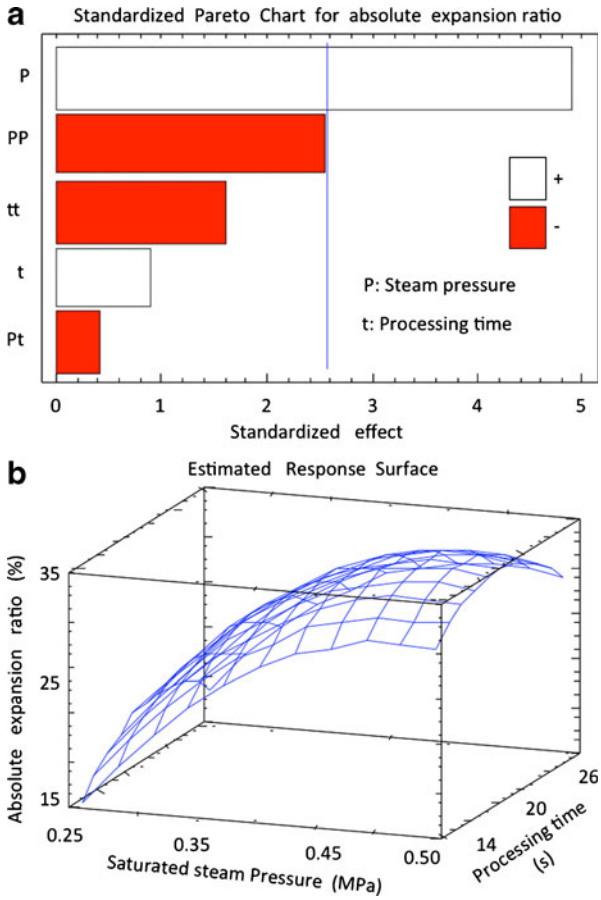

Fig. 4 Pareto chart (**a**) and response surface (**b**) from statistical analysis by response surface method of the impact of the operating parameters of the instant controlled pressure drop DIC (saturated steam pressure, in megapascal, and processing time, in seconds) on the absolute expansion ratio of dried DIC-textured cheese

tapping or compression. A certain degree of deformation could also be involved, as suggested by Moreyra and Peleg (1981) and Schubert (1987).

Overall, it is worth noting that the lower the bulk density, the higher the powder compressibility. The empirical prediction model of compressibility versus the steam DIC processing parameters, steam pressure, and processing time is as follows with R^2=75%:

$$X\% = 49.864 - 9.21885P - 2.26t + 1.616P^2 - 0.01422t + 0.05155t^2 \quad (7)$$

The powder granules obtained by grinding are usually too large with a particle size more than 1400 μm; this is due to the compactness and hardness of cheese pieces normally dried by hot air. Conversely, following their expansion through steam DIC, grinding cheese provides powdery granules of small size with approximately normal distribution (Fig. 6), without being too fine (size between 100 and 700 μm). This behavior can be explained by the friability and the high expansion ratio of DIC-textured pieces; the open cell texture could facilitate grinding. Specific size distribution affects the bulk density, compressibility, and flowability (Barbosa-Canovas et al. 1987) and also improves the main functional

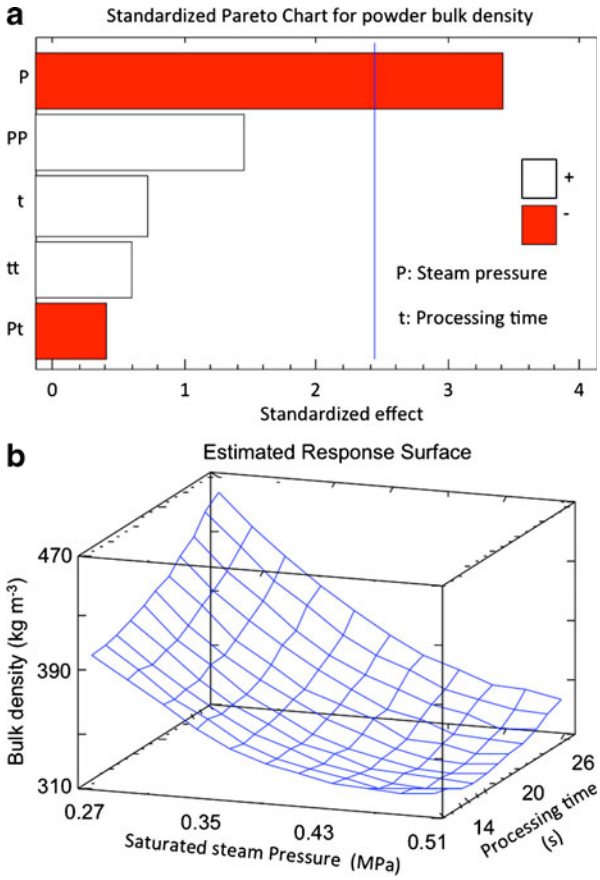

Fig. 5 Pareto chart (**a**) and response surface (**b**) from statistical analysis by response surface method of the impact of the operating parameters of the instant controlled pressure drop DIC (saturated steam pressure, in megapascal, and processing time, in seconds) on the bulk density of cheese powder issued from grinding of dried DIC-swelled cheese

properties of the powder such as solubility and wettability. It is generally considered that powders with particle sizes larger than 100 μm are free flowing, while fine powders are subject to cohesion and their flowability is more difficult although of particle density (Dairy Management Inc. TM (DMI) 2005; De La Burde et al. 1981; Geldard 1973). For this reason, the DIC treatment and grinding process have to be optimized to meet the desired characteristics.

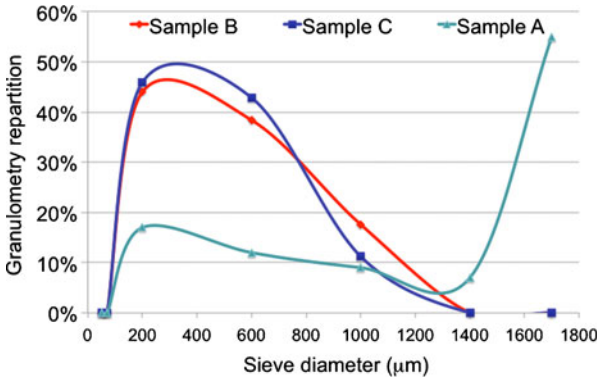

Fig. 6 Change in the particle size distribution of cheese powder after grinding: sample **A** classically dried; sample **B** textured by DIC at saturated steam pressure of 0.55±0.02 MPa for 20±2 s; sample **C** textured by DIC at saturated steam pressure of 0.38±0.02 MPa for 30±2 s

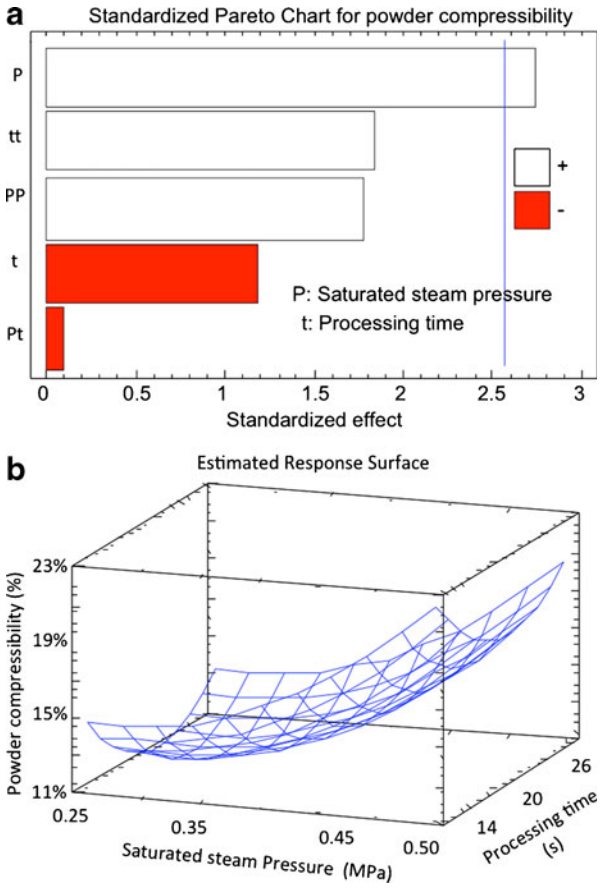

Fig. 7 Pareto chart (**a**) and response surface (**b**) from statistical analysis by response surface method of the impact of the operating parameters of the instant controlled pressure drop DIC (saturated steam pressure, in megapascal, and processing time, in seconds) on the compressibility of cheese powder issued from grinding of dried DIC-swelled cheese

SEM images of cheese powder particles revealed significant structural differences as a function of steam DIC treatment. Before DIC treatment, the granule produced by hot air drying has a dense internal structure (Fig. 3a). DIC texturing radically changed the microstructure of the pieces and consequently of the powder granules (Mounir et al. 2010). DIC-textured powders have very porous granules made up of numerous cavities of different sizes (Fig. 3b). The granule size repartition and the large specific surface area of DIC cheese allowed the powders to get good functional behaviors (wettability…).

The possible sterilization effects due to the steam DIC treatment and the very low water activity linked to low water activity should ensure that cheese snacks and powders have a long shelf life. These results corroborate those obtained from the DIC decontamination as described by Allaf et al. (2011).

4 Conclusion

This paper has aimed to characterize cheese snacks and powders obtained by grinding dried cheese pieces before and after texturing by the DIC process. This

study has led to the refinement and optimization of an industrial process of manufacturing pure crispy cheese snacks as well as expanded granule powders. The treatment induces many micro-structural and physical modifications in cheese snacks and powder. The open cell structure and expanded matrix allow the product to be ground much more easily compared to conventionally dried products, whose structure is more dense and compact. The expansion ratio reaches up to 36 times greater than those of the untreated product.

The main steam DIC processing parameters can be easily controlled. Pure cheese crispy snacks as well as cheese expanded granule powders can be made with controlled properties to meet the needs of customers and the international quality standards.

Acknowledgments This research work would not have been possible without the essential support of many individuals. The personal support and interest of the general manager and the director of the Division of Technology at ABCAR-DIC Process Cie allowed the research team to mobilize its collective energy and capacity in the best way possible.

References

Allaf K, Vidal P (1989) Feasibility study of a new process of swell-drying by instant decompression toward vacuum of in pieces vegetables in view of a rapid re-hydration. In: Gradient activity plotting University of Technology of Compiegne UTC N° CR/89/103, industrial partner SILVA-LAON

Allaf K, Louka N, Bouvier J-M et al. (1992) Définition d'un nouveau procédé de traitement thermomécanique par détente instantanée contrôlée TTMDIC. French patent, no. 920, 4940

Allaf K, Louka N, Bouvier JM et al. (1995) Methods for processing phytogenic materials to change their texture, apparatus therefor, and resulting materials. Patent WO9504466 (A1)

Allaf T, Besombes C, Mih I, et al. (2011) Decontamination of solid and powder foodstuffs using DIC technology. In advances in computer science and engineering, book edited by: Matthias Schmidt, ISBN: 978-953-307-173-2, Publisher: InTech. (in press)

Bachelor RL, Lynch TJ (1977) Pycnometer, as United States patent 4095473, application number: 05/797648, publication date: 06/20/1978; filing date: 05/16/1977

Barbosa-Canovas GV, Malave-Lopez J, Peleg M (1987) Density and compressibility of selected food powders mixture. J Food Process Eng 10:1–19

Carr RL Jr (1985) Evaluation flow properties of solids. Chem Eng 72:163–168

Chandrasekhar PR, Chattopadhyay PK (1989) Heat transfer during fluidized bed puffing of rice grains. J Food Process Eng 11:147–157

Chandrasekhar PR, Chattopadhyay PK (1990) Studies on microstructural changes of parboiled and puffed rice. J Food Process Preserv 14:27–37

Chen CH, Yeh AI (2001) Effect of amylose content on expansion of extruded rice pellet. Cereal Chem 78:261–266

Dairy Management Inc. TM (DMI) (2005) Cheese: varieties, definitions. Available at: http://www.innovatewithdairy.com/NR/rdonlyres/5496B51D-5DFC-44AD-A22E-4F9A3682B141/0/Cheese_Spec.pdf

De La Burde RZ, Aument PE, Utsch FV (1981) Novel tobacco product and improved process for the expansion of tobacco. US patent 4,258,729

Fredrickson J (1981) Process for increasing the filling capacity of tobacco. US patent 3,524,451

Geldard D (1973) Types of fluidisation. Powder Technol 7:285–292

Harrington WO, Griffiths FP (1950) Puffs potatoes. Food Industry 22(1872):2005–2006

Heiland WK, Sullivan JF, Konstance RP, Craig JC, Cording JR, Aceto NC (1977) A continuous explosion puffing system. Food Technol 31(11):32–36

Highlands ME, Getchell JS (1956) A new snack item––French fried potato dice. Me Farm Res 4:10

Hsieh F, Huff HE, Peng IC, Marek SW (1989) Puffing of rice cakes as influenced by tempering and heating conditions. J Food Sci 54:1310–1312

Hsieh F, Hu L, Peng IC, Huff HE (1990) Pretreating dent corn grits for puffing in a rice cake machine. J Food Sci 55:1345–1348
Huff HE, Hsieh F, Peng IC (1992) Rice cake production using long-grain and medium-grain brown rice. J Food Sci 57:1164–1167
Jones D, Chinnaswamy R, Tan Y, Hanna M (2000) Physiochemical properties of ready-to-eat breakfast cereals. Cereal Foods World 45:164–168
Kim MH, Toledo RT (1987) Effect of osmotic dehydration and high temperature fluidized bed drying on properties of dehydrated rabbiteye blueberries. J Food Sci 52:980–989
Louka N (1996). Maîtrise de la qualité des produits agro-alimentaires séchés; modification texturale et réduction du coût énergétique par détente instantanée contrôlée "DIC" vers le vide. Conception et réalisation d'un nouveau procédé industriel. Ph.D. dissertation, Université de Technologie de Compiègne, France
Louka N, Allaf K (2002) New process for texturizing partially dehydrated biological products using controlled sudden decompression to the vacuum: application on potatoes. J Food Sci 67:3033–3038
Louka N, Juhel F, Allaf K (2004) Quality studies on various types of partially dried vegetables texturized by controlled sudden decompression: general patterns for the variation of the expansion ratio. J Food Eng 65(2):245–253
Moreyra R, Peleg M (1981) Effect of equilibrium water activity on the bulk properties of selected food powders. J Food Sci 46:1918–1922
Mounir S, Allaf K (2008) Three-stage spray drying: new process involving instant controlled pressure drop. Drying Technol 26:452–463
Mounir S, Schuck P, Allaf K (2010) Structure and attribute modifications of spray-dried skim milk powder treated by DIC (instant controlled pressure drop) technology. Dairy Sci Tech 90:301–320
Mounir S, Besombes C, Al-Bitar N, Allaf K (2011) Study of instant controlled pressure drop DIC treatment in manufacturing snack and expanded granule powder of apple and onion. Drying Technol 29(3):331–341
Owusu-Ansah J, van de Voort FR, Stanley DW (1984) Textural and microstructural changes in maize starch as a function of extrusion variables. Can Inst Food Sci Technol J 17:65–70
Payne, FA Saputra D (1987) Puffing green bell peppers. ASAE paper no. 87-6508, ASAE, St Joseph, MI
Písecký J (2005) Spray drying in the cheese industry, review. Int Dairy J 15(6–9):531–536, The Fourth IDF Symposium on Cheese: Ripening, Characterization and Technology
Saputra D, Payne FA, Cornelius PL (1991) Puffing dehydrated bell peppers with carbon dioxide. Trans ASABE 34:475–480
Schubert H (1987) Food specific technology part I: properties of specifics and particulate food systems. J Food Eng 6:1–32
Sullivan JF, Craig JC (1984) The development of explosion puffing. Food Technol 38:52–55, 131
Sullivan JF, Konstance RP, Egoville MJ, Aceto NC, Craig JC (1980) Continuous explosion puffing of apples. J Food Sci 45:1550–1555
Sullivan JF, Craig JC, Dekazos ED, Leiby SM, Konstance RP (1982) Dehydrated blueberries by the continuous explosion-puffing process. J Food Sci 47:445–448
Sykes LM, Snow RG, De La Burde RZ et al (1985) Process for expanding tobacco. US patent Re 32,014
Tabeidie Z, Payne FA, Cornelius PL (1992a) Effect of hydrogen and calcium ion concentration on the CO2 puffing of diced green bell peppers. J Food Sci 57:1147–1151
Tabeidie Z, Payne FA, Cornelius PL (1992b) Puffing potato pieces with CO2. Trans ASAE 35:1935–1940
Torreggiani D, Toledo RT (1990) Simultaneous puffing and dehydration of osmotically pretreated apple cubes in a high temperature fluidized bed (HTFB) drier. In: 10th international congress of chemical engineering, chemical equipment design and automation. Aug 26–31; Praha, Czechoslovakia
Wells AW (1989) Method of dehydrating and puffing food specifics. US patent 4,857,347
Yada RY (2004) Proteins in food processing. Lavoisier, Paris, 04-2004, 686 pp
Yamaguchi N, Shibuya K, Kubo T (1988) Food material for puffing. US patent 4,734,289