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INFLUENCE OF HYDROTHERMAL TREATMENT ON RHEOLOGICAL AND COOKING CHARACTERISTICS OF FRESH EGG PASTA

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Abstract.

The effect of D.I.C. processing conditions on rheological and cooking properties of commercial fresh egg pasta was studied. The mechanical properties of pasta before and after cooking were evaluated by empirical test and characterized by maximal apparent force (F_{max}) and apparent relaxation coefficient (ARC). Structural (apparent density) and cooking quality were evaluated by determining mass ratio (W/Wo), optimal cooking time (OCT), swelling index (SI), solid, soluble and total cooking losses (TCL) and compared to untreated pasta. The hydrothermal treatment caused a reduction in firmness and relaxation capacity of treated pasta. The increase of processing conditions induced a decrease of F_{max} and the processing time has an influence when it is associated to the low pressures. The values of ARC vary from 51% (untreated pasta) to 37% (D.I.C. treated pasta). The increase of processing time from 30 to 60 s does not seem to have a significant influence on ARC. The apparent density of treated pasta is function of processing pressure and time but it is always lower than untreated pasta density. Treated pasta had a higher quality score based on water sorption and SI and matter losses (TCL values and solid and soluble losses) as compared to untreated pasta.

Abbreviations:

ARC, Apparent Relaxation Coefficient;

D.I.C, “Détente Instantannée Contrôlée”: instantaneous controlled pressure drop

DM, Dry Matter

OCT, Optimal Cooking Time

SI, Swelling Index

TCL, Total Cooking Losses;

1. Introduction

Pasta, is one of the most consumed foods in the whole world, and it is a traditional product obtained from semolina. The most appropriate cereal for the production of high quality pasta products is durum wheat (*Triticum durum*) (Feillet and Dexter, 1996). The commercial fresh pasta is most often made with durum wheat, pasteurised fresh egg and water, about 35% on a wet basis, and therefore is called fresh pasta to distinguish it from the dry pasta (11.5% w.b.). The eggs in the pasta brighten its color, add flavour, and give more nutritional value to pasta (Iametti et al., 1999).

Quality of dried pasta has been improved by some hydrothermal treatment and several studies have been made on dried pasta treated by thermal process. Abecassis et al. (1986) noted that pasta previously dried at 37 °C, had an improved cooking quality and color after a short hydrothermal treatment at 90 °C. According to many authors, (Baiano et al., 2006; Güler et al., 2002; Zweifel et al., 2000; Abecassis et al., 1989; Dexter et al., 1983) high temperature drying improved cooking quality of dried pasta. This quality has been shown to be highly influenced by starch gelatinization and protein network formation (Riva et al., 2000; Yue et al., 1999; Fardet et al., 1999; Resmini and Pagani, 1983). The structure of cooked pasta is largely governed by the presence of a structured protein network (Walsh and Gilles, 1971). Zweifel et al., 2000 showed that the high temperature dried pasta exhibited a smoother and more compact surface and a higher breaking strength than low temperature dried pasta. According to these authors, the formation of a tight protein network improves the embedding of the starch granules on the surface and it results in a stronger structure.

However, these studies were made on dried pasta and only few published papers exist on the application of hydrothermal treatment of fresh pasta. Alamprese et al. (2005a) have studied the influence of egg pasteurisation and the thermal treatment of fresh egg pasta on the protein network. The authors found that the industrial pasteurization of eggs does not affect the rheological and functional characteristics of pasta, but the double thermal pasteurisation of egg pasta deeply influenced its structural characteristics. The study carried out by Alamprese et al. (2005b) showed a great variability in rheological and functional characteristics of commercial fresh egg pasta. The authors attributed it to the difference of the intensity of heat treatments undergone by pasta during the production process. Maache-Rezzoug and Allaf (2005) have studied the effect of a hydrothermal treatment called D.I.C. (Instantaneous Controlled Pressure Drop) on fresh pasta. This recent process has been developed and patented by Allaf et al (1993) and consists in a short pressurisation of product followed by a sudden pressure drop towards vacuum pressure. This treatment was used in a first time to obtain puffed dried vegetables or fruits with quick rehydration (Louka, 1996; Nouviaire et al., 2001). Indeed, the decompression towards vacuum during D.I.C. treatment induces a rapid modification of the thermodynamic equilibrium reached during the pressurisation (P_1,T_1) towards an other equilibrium state (P_2,T_2). This change of thermodynamic equilibrium state can create a complex process of micro-alveolation within the matrix. The effect of D.I.C. treatment was also studied on hydration of various materials as schleroglucan (Rezzoug et al, 2000). Applied on fresh egg pasta, it has shown some great modifications on their quality: the water absorption, cooking time and colour quality were improved and a modification of their internal structure was observed (Maache-Rezzoug and Allaf (2005).

The cooking behaviour, which is a critical step for quality perception is an essential stage of follow-up of pasta cooking quality and the most important characteristics include several parameters. The weight of cooked pasta indicates the water uptake and corresponds to a macroscopic event involving a complex molecular modification of starch and proteins (Del Nobile and Massera, 2000; Piazza et al., 1994). The cooking loss, related to solid leaching during cooking is widely used as an indicator of the overall cooking performance (D'Egidio et al., 1982; Dexter et al., 1983). The texture of the cooked product has also an essential role in the final acceptance by consumers (D'Egidio and Nardi, 1996; OH et al., 1983) and it is characterized by its firmness and resilience.

Firmness of cooked pasta represents the degree of resistance to the first bite and is sensorially defined as the force required to penetrate pasta with the teeth (D'Egidio and Nardi, 1996). Many testing instruments have been developed to measure pasta textural characteristics. Walsh (1971) measured the firmness of cooked spaghetti with the Instron Universal Testing Instrument. Using the same testing machine, Edwards et al. (1993) compared the texture of cooked noodles pasta prepared from durum wheat semolina of variable protein content, to provide samples with a different cooking quality. The Instron peak force measurement was found to be a more precise indicator of noodle firmness than was peak energy. The effect of cooking time on the textural properties has been studied by Gonzalez et al. (2000). The peak force which characterized firmness, decrease with increase cooking and holding time. OH et al. (1983) showed that the maximum cutting stress and resistance to compression of cooked noodles measured on the Intsron Universal Testing Instrument were well correlated with sensory evaluation of firmness and chewiness of noodles. Cuq et al. (2003) describe the mechanical properties of spaghetti pasta as a function of water content at different temperatures. The authors showed that an increase in temperature or in water content induces a plasticizing effect on mechanical properties of pasta, which is controlled by a phenomenon based on molecular mobility.

The objective of the present study was to complete previous study on D.I.C. treated pasta with mechanical, structural and cooking quality measurements. Fresh pasta (30% humidity) were treated with saturated steam (1 to 4 bar) during short time (30 and 60 s) followed by an abrupt decompression toward the vacuum (50 mbar). The effect of the two selected process parameters (steam pressure level and processing time) on the mechanical characteristics of pasta before and after cooking, and on the structural and cooking quality properties was studied.

2. Materials and methods

2.1. Raw material

Commercial fresh egg pasta (1.3 mm thickness) from a single commercial source (LUSTUCRU) was used in all experiments. The “*tagliatelle*” pasta shape was composed from semolina of durum wheat, water, fresh eggs at a rate of 140 g/kg of semolina, and salt (0.8%). The average moisture content of fresh egg pasta was 33.5±0.5 g/100 g. The *tagliatelles* pasta were cut into 50 mm length pieces and conditioned in sealed bags at 4 °C. The delay between the pasta processing and experiments was about 2 days.

2.2. Methods

Analyses of mechanical and functional characteristics of treated pasta were made according to the following diagram (Fig. 1).

2.2.1. D.I.C. hydrothermal treatment

The equipment and procedure of D.I.C. hydrothermal treatment for pasta were described previously by Maache-Rezzoug and Allaf (2005). During D.I.C. treatment, pasta was placed on treatment reactor in a single layer without superposition.

A vacuum of 50 mbar is established. This initial vacuum facilitates the diffusion of steam into product and allows its rapid heating (Zarguili, 2006). During a determinate processing time, saturated water steam is then introduced until a fixed pressure level. The pressurisation is followed by a sudden decompression towards the vacuum that induces a rapid cooling and a micro-texturation of the product.

It’s the difference between the high pressure level and the vacuum which determines the amount of steam generated by flash vaporization and thus the intensity of the mechanical constraints responsible for the micro-alveolation phenomenon. After D.I.C. treatment, pasta moisture content slightly increased due to absorption of condensed steam on the surface of product during the treatment.

Typical pressure and temperature-time profiles in the D.I.C reactor and the pressure in the vacuum tank are presented in Fig. 2. The applied conditions were: processing pressure of 1.5, vacuum pressure of 50 mbar and processing time of 30 s. The temperature was measured on-line during DIC treatment by a thermocouple. In this study, the processing pressure was varied from 1 to 4 bar (corresponding at 99.93 °C to 143.63 °C) at two processing time conditions (30 and 60 s).

2.2.2. Moisture content

Moisture content of pasta was determined according to the AACC (1995) method adapted for pasta (i.e., weight measurements after drying at 105 °C for 10 h, milling and drying at 105 °C for 1h). The moisture content of pasta was measured for each sample after D.I.C. treatment, before and after mechanical analysis, after oven drying. Results are the average of three determinations and are expressed as % w.b.

2.2.3. Mechanical properties of pasta after D.I.C. treatment.

Mechanical properties of D.I.C. treated pasta was determined as a function of processing conditions by using an empirical test described by Cuq et al. (2003) and using an Instron Universal Testing Machine 5543 (Instron, France). The measures were carried out at room temperature using a 10 N compression cell for treated pasta and 1 kN for untreated pasta. Five samples of pasta (cut into 50 mm length pieces) were placed in a parallel position onto the measurement plate of the Instron. A Plexiglas straight probe (Fig. 3) was moved perpendicularly to the plate. To avoid perturbation of measure due to irregular form of pasta (side deformation principally), numeric acquisition started at yield force of 0.6 N. The apparent force was determined at constant speed of 0.1 mm/s until 0.5 mm compression, the probe was stopped and maintained at constant deformation during 35 s to measure the relaxation force.

The mechanical properties of pasta were estimated by maximal apparent force F_{max} (i.e. force at 0.5 mm compression).The viscoelastic properties of pasta were evaluated by an apparent relaxation coefficient (ARC): ARC = $(F_{max}-F_{30})/F_{max}$, where F_{30} is the force (N) recorded after 30 s relaxation. Standard deviation was evaluated from 3 measurements on each sample.

2.2.4. Drying stage

After D.I.C. treatment, all samples were dried by natural heat convection in a laboratory oven (Airlabo, AC 240) at 35 °C until reaching a constant weight. The moisture content of pasta was reduced fewer than 10% w.b. The samples were then stored at room temperature in hermetic bags.

2.2.5. Measurement of structure properties

Measure of apparent density of treated and untreated pasta is made after the oven drying. Because of hydrophilic characteristic of products, we used pycnometer with fine powder (80 µm diameter) at fixed density (0.96 g/cm^3). About 3 g (M_1) of pasta are placed in the pycnometer which is then tapped down mechanically (Autotap, Quantachrome) during the filling of the powder until a volume of 29.35 cm^3 before being weighed (M_2). Pasta apparent density is calculated as: $\rho \times M_1/(M_2 - \rho V + M_1)$. Three measurements were made for each sample.

2.2.6. Cooking properties

2.5 g of DIC treated pasta were placed in perforated box and cooked in 100 ml of distilled water at 100°C during 20 min. Each minute, the perforated box is taken out of boiled water and weighed (time of weighing is not taken into account). The same protocol is repeated for all samples to compare their rehydration rate. The water absorption for each sample is determinate as the mass ratio between cooked and uncooked pasta (W_i/W_0). W_i is the weight of cooked pasta at various cooking time and W_0 the weight of uncooked pasta. OCT (Optimal cooking time) is graphically determinate for each sample as the time when $W_i/Wo=2.27$ (Maache-Rezzoug and Allaf, 1999).

OCT of untreated pasta corresponds to 5 min of cooking time. This time is then taken as reference and all cooking properties of pasta were measured at this time. Mass ratio (W/W_0) where W is the weight of 5 min cooking pasta is determinate for each sample.

Swelling index (SI) was evaluated by drying the 5 min cooked pasta to constant weight at 105 °C (Fardet, 1998). SI was expressed as (g of water/g of dry pasta). Total cooking losses (TCL) were calculated as (DM uncooked pasta – DM cooked pasta)/DM cooked pasta; where DM is the dry matter ratio (g of matter / 100g). At 5 min of cooking, the cooking water was centrifuged at 5400 rpm for 15 min and dried at 105 °C until reaching a constant weight. The residue was weighed and reported as a percentage of dry matter of original pasta to calculate solid loss. The supernatant was diluted until 200 ml with distilled water and 2 ml of this solution was dried during 2 hours at 130 °C. The residue was weighed and reported as a percentage of dry matter of original pasta to calculate soluble losses.

2.2.7. Mechanical properties of pasta during cooking

Mechanical properties of pasta (D.I.C. treated and untreated) are measured as a function of cooking time. 2.5 g of pasta were cooked in boiling distilled water (100 ml) at fixed cooking time (3, 4, 6, 8 and 10 min). Pasta was rapidly cooled during 1 min in fresh water, drained during 2 min on filter paper to equilibrate, weighed and placed on Instron measurement table. The mechanical properties were measured according to described method in paragraph 2.2.3. F_{max} (i.e. force at 0.5 mm compression) and ARC (Apparent Relaxation Coefficient) were determined as function of cooking time and processing pressure. After rheological tests, samples were weighed again to verify that water content did not change during analyses. Three independent replications were made for each test.

3. Results and discussion

3.1. Mechanical properties of D.I.C treated pasta.

The effect of hydrothermal treatment on mechanical properties of fresh egg pasta is illustrated by the differences between the experimental force-time curves of treated pasta, at specific processing conditions, by comparison with curve of untreated pasta (Fig. 4). Pasta was characterized by apparent “force-time” curves performed at crosshead speed. The first part of curves shows the increase of force value during the compression of pasta. Strength increases until a maximum value (F_{max}), then the deformation is suddenly stopped and the change of force as a function of time is recorded. A typical relaxation curve was obtained, the force decreases gradually until reaching an equilibrium value. These relaxation curves are characteristic of solid viscoelastic behaviour, and the relaxation of materials depends on their molecular structure.

The maximal apparent force F_{max} is represented as a function of processing pressure for the 30 s and 60 s treatments in Fig. 5. The results show that the increase of pressure conditions induces a decrease of maximal apparent force (F_{max}). For untreated pasta, F_{max} was of 16 N whereas for treated pasta F_{max} ranged between 3 and 6 N. Although the processing time were very short (30 and 60 s) the effect of D.I.C. treatment on F_{max} was important, and mainly at the time it was associated to low pressures levels. The reduction is very drastic even when the pressures applied were about 1 bar. The consequence of D.I.C. treatment is the reduction of firmness of treated pasta which behaves as soft materials especially when pressure is higher.

In the same way, the apparent relaxation coefficient is represented as a function of processing pressure for 30 s and 60 s treatments in Fig. 6. The fresh and hydrothermal treated pasta behave as a viscoelastic material. The ARC of fresh egg pasta was of 51%. This value is close to that obtained by Cuq et al. (2003) on spaghetti at 30% of moisture content (close to 50%). For DIC treated pasta, ARC values vary from 46% to 37%. These results show that D.I.C. treatment reduces apparent relaxation coefficient. The same tendency is observed at 30s and 60 s treatments: increase of processing pressure involves a decrease of ARC until a pressure value where ARC is minimal and above which, ARC tendency is inverse (increase with pressure increase). However, increase processing time to 60 s has an impact on the ARC of pasta that becomes lower than for 30 s treatment.

Statistical analysis have been realised with Statgraphics software without taken into account results for untreated pasta. The multifactor variance analysis shows that parameters (pressure and time) have significant effect on maximal force changes (P-value of 0.0005 and 0.0163 respectively) and on ARC (P-value of 0.0051 and 0.0185 respectively for pressure and processing time). The relationship between mechanical properties (maximal force or apparent relaxation coefficient) and processing pressure can be described with a second degree polynomial model.

$y(P) = a + b \times P + c \times P^2$ Eq (1)

Coefficients of the model are resumed in Table 1. The model fitted well experimental data. The model shows that minimal values of force and apparent relaxation coefficient are obtained at the same pressure, 3.6 and 2.8 bar for the processing time of 30 and 60 s, respectively (Fig. 5 and Fig. 6).

In order to make sure that observed variation on F_{max} and ARC are only due to the effect of D.I.C. processing conditions (pressure and time), we have verified that moisture content was not modified by the hydrothermal treatment. Moisture content was carried out just before Instron analysis and the results showed that D.I.C. treatment modified moisture content of pasta but only in low proportion (from 33.16% to 36%

w.b.) (data not shown). This increase is due to absorption of condensed steam on the product surface during the treatment. However, no tendency seems to be apparent between moisture content and the evolution of F_{max} or ARC. According to Cuq et al. (2003), this interval of moisture contents variation does not have a significant effect on these two parameters.

It is known that pasta firmness is based on protein structure (Alamprese et al., 2005b) and composition formed during pasta production (Gianibelli et al., 2005). The hydrothermal treatment involves a decrease of firmness and elasticity when the D.I.C. conditions were intense. The high DIC conditions associated to high moisture content cause an excessive swelling of starch granules (Loisel et al., 2006). According to Resmini et al. (1988) the excessive swelling of starch granules has a consequence on the break down of the protein network and a decrease in the cooking performance. We can suppose that network protein is modified by swelling starch granules during D.I.C. treatment.

The D.I.C. is a thermal treatment at high pressure but it’s also associated to a mechanical effect obtained by a sudden decompression towards vacuum. This mechanical effect could induce a mechanical distortion of protein network that is not present with classic thermal treatment, it would be more important than the pressure level is high.

3.2. Structural properties of D.I.C. treated pasta.

In Fig. 7, the apparent densities are presented as function of processing pressure for 30 and 60 s of processing time and the value of untreated sample is used as reference.

For all D.I.C. conditions, treated pasta, even for the lighter conditions (1 bar and 30 s), has lower density than untreated pasta (1.2 g/cm^3). These results show that a micro-alveolation was created during decompression. The tendency for 30 s and 60 s treatments are the same until 3 bar: the apparent density decreased slightly as processing pressure increased. Above a certain pressure (3 bar), results of apparent density are opposite for 30 s and 60 s treatment. Whereas apparent density increase for 4 bar 30 s (0.92 g/cm^3), it seems to stabilize at lower value (0.73 g/cm^3) for 4 bar 60 s. The structure of pasta treated at 4 seems to be more sensitive to the treatment time.

Effect of processing pressure and processing time on this micro-alveolation was studied by a statistical analysis. The results show that processing pressure has a significant effect on apparent density (P-value of 0.0297) whereas processing time has no significant effect (P-value of 0.2083). Fitting of curves was made with a mathematical model of second degree polynomial type without taken into account untreated pasta. Equations of model and regression coefficients are given in figure 7 for 30 s and 60 s treatments.

This phenomenon of alveolation is due to the pressure drop involving a thermodynamic disequilibrium. This phenomenon is more important when the difference between high and vacuum pressures is important. For 4 bar of processing pressure, mechanical effect could have more impact than thermodynamic effect of alveolation, all the more that short processing time (30 s) is not sufficient to allow to the product to reach the equilibrium temperature before pressure drop. The nonhomogeneous heating of the product can create a collapse of the structure instead of its expansion. This time to reach the equilibrium temperature was estimated in a previous study by Zarguili et al. (2006) on standard maize starch at 80, 70 and 60 seconds for respectively, 1, 2 and 3 bar, for a thickness of 0.5 cm. Then, at the opposite, for 60 s treatment, temperature equilibrium is reached and pressure drop has an expansion effect. Thymi et al. (2005) showed in the same way that the increase of temperature can cause the decrease of the density of extruded corn's grits, resulting higher porosity.

As density increase, firmness and ARC of pasta decrease. The modification of apparent density during D.I.C. treatment can have an impact on maximal force and apparent relaxation coefficient. The increase of density is due to the creation of alveolation. The presence of cavity and little air bubbles involve a structure less compact and lead to a decrease of firmness. The apparent relaxation coefficient seems to evaluate as density: it decrease until 2.8 bar and increase for 3 and 4 bar for 30 s treatment. Air within pores created during D.I.C. treatment could improve elasticity of product. A study of porosity (distribution, size, type) is necessary to determinate direct impact of density on mechanical properties.

3.3. Cooking quality of D.I.C. treated pasta

The results of cooking performance of D.I.C. treated pasta compared to the control using the optimal cooking time (OCT) and pasta characteristics at 5 min cooking: mass ratio (W/Wo), swelling index (SI), solid and soluble losses, total cooking losses (TCL) are presented in Table 2. The mass ratio (W/W_0) represents the capacity of pasta to increase its global mass at 5 min cooking. W/W_0 takes into account of water absorption but also the total cooking losses. We can observe that, for 60 s treatment, W/W_0 increases when the processing pressure increases until 2 bar, and for higher pressures an opposite effect occurred. These results confirm a previous study reported by Maache-Rezzoug and Allaf (2005) who explains this decrease by the disruption of protein network when high pressure is applied. As matter loss does not increase with increase of processing pressure whereas mass ratio decreases for pressures higher than 2 bar, that can signify that beyond the pressure of 2 bar the water sorption capacity was reduced for treated pasta.

A recent study (Zarguili, 2006) on DIC treatment of standard maize starch showed a reduction in the sorption capacity of treated starch for 2 bar and 30 min of treatment time. According to Mazza and Lemaguer (1980), cited by Al-Muhtaseb et al. (2004) the decrease of sorption capacity is due to a reduction in the total number of active sites for water binding, consequences to the physicochemical modifications induced by temperature.

For the two studied processing times (30 and 60 s), the optimal cooking time (OCT) follows the same tendency. OCT of treated pasta was reduced as processing pressure increases until 2 bar for 30 s and 3 bar for 60 s of treatment time. Beyond these pressures, OCT increases but its value remains below that of untreated sample that is equal to 5 min corresponding to a ratio of 2.27. Baiano et al. (2006) has showed that quality characteristics of pasta during cooking were improved as drying temperature increased. These authors suggest that pasta dried at high temperature (90 °C) absorbs at the optimal cooking time less water than those dried at low (60 °C) and medium temperature (75 °C) thanks to the gluten network that made less available to imbibitions.

The values of swelling index (SI) of treated pasta at 30 s showed a slight difference with untreated pasta. If we take account of mean absolute error, the pressure level associated with a processing time of 30 s does not affect SI, but at 60 s, SI decreases with increasing pressure until 4 bar. From this pressure value, SI becomes constant and almost identical to SI values obtained at 30 s. The determination of pasta cooking quality is more dependent on a continuous protein network than the physicochemical properties of gelatinized starch (Riva et al., 2000). Swelling of cooked pasta is mainly due to the hydration of protein. During the cooking, the protein network is impacted by starch swelling. Few studies exist on the protein network changes of fresh pasta during cooking.

Globally, matter losses of treated pasta are lower than raw pasta. In contrast to the previous study carried by Maache-Rezzoug and Allaf (2005), the matter losses (solid and soluble losses) are not more important at high pressures, but they decrease regularly as a function of pressure. According to Alamprese et al. (2005a), the heat treatment of pasta causes denaturation of proteins, leading to a stiffening of pasta structure, with a consequent reduction in the matter loss during cooking. The influence of treatment time is effective on solid and soluble losses (Table 2). At the same pressure values, these losses are more important at 60 s than 30 s of treatment time.

At the two treatment times, the increase of pressure leads to a decrease of total losses. When SI increases or stabilizes with the increase of pressure whereas total losses decrease, this signifies that pasta absorb more water and lose less dry matter.

3.4. Mechanical characteristics of D.I.C treated pasta during cooking

Study of mechanical properties as a function of cooking time was primary carried out on fresh pasta. Fig. 8 represents the typical curves of untreated pasta cooked at different time (3, 4, 6, 8 and 10 min). As expected, when cooking time increase, F_{max} of fresh pasta decreased from 5.13 N to 3.19 N. It is due to the absorption of water during cooking. During the beginning of cooking, absorption of water involves swelling of starch granules embedded in protein network. As cooking time increase, gelatinisation of starch will increase and some granules will disrupt involving leaching of amylose. This leaching material forms a new network with protein and this modification induces a decrease of firmness in pasta. ARC values also decrease during cooking from about 45 % to 31 %. This decrease shows a modification of viscoelastic properties during cooking. According to Feillet (1988), semolina proteins are linked together by disulfide, hydrogen, and hydrophobic bonds to form a matrix, which gives cooked pasta its viscoelastic properties. The continuity and strength of protein matrix is depend on the nature of inter- and intramolecular bonds. During cooking, the swelling of starch granules and the dilatation of protein chains may give more elasticity to the entire network.

To see the influence of processing pressure in maximal apparent force (F_{max}) and apparent relaxation coefficient (ARC) during cooking at various time (3, 4, 6, 8 and 10 min), results of four D.I.C. treatments at different pressures and at fixed treatment time (60 s) are resumed in Table 3. It shows that F_{max} and ARC of D.IC. cooked pasta also decresase during cooking but they are always lower than untreated pasta. Indeed, F_{max} of treated pasta minimal values vary from 3.98 N for 3 min cooking to 2.62 N for 10 min cooking. ARC values minimal values vary from 34.63% for 3 min cooking to 29.19% for 10 min cooking. The influence of D.I.C. treatment on mechanical properties can be linked to the modification of water kinetics absorption. As treated pasta rehydrate faster than untreated pasta, at the same cooking time, water content of D.IC. pasta are higher and have “overcooked” mechanical properties (lower firmness and ARC) compared to untreated pasta. The influence of processing pressure is not the same for F_{max} and ARC. Whereas processing pressure is significant for F_{max} variation (Pvalue at 0.004), it is not really significant for ARC variation. For short cooking time, F_{max} seems to be lower for low processing pressure than for high pressure. We have seen that increase of pressure at 60s involves an increase of alveolation, but also a decrease of swelling index (SI) and total cooking looses (table2) probably du to the stiffness of pasta under highest pressure. This tendency seems to be confirmed with the highest values of firmness obtained generally at 2 and 3 bar.

4. Conclusion

The analyses carried out on D.I.C. treated pasta showed that the rheological, structural and cooking properties of fresh egg pasta were modified considerably after hydrothermal treatment. Rheological measurements on treated pasta indicated a decrease in firmness and relaxation capacity of pasta when the processing pressure increases in comparison with untreated pasta. As expected the processing pressure had the greatest effect on mechanical, structural and cooking characteristics. Maache-Rezzoug and Allaf (2005) already showed by using response surface methodology that this parameter had a significant effect on all the response variables investigated. Under studied pressure conditions, the fresh pasta was undergoing physical modifications resulting in improvement of water absorption, and thus cooking time and colour quality. Increasing of pressure level induces a high apparent viscosity. Microscopic observations showed that the DIC treatment affects the internal structure and the state of starch granules.

After cooking, treated pasta behaved differently than untreated pasta. They had a high rehydration capacity and at same cooking time, their firmness was lower than raw pasta. Matter losses were reduced whereas absorption capacity and swelling coefficient were improved. In addition to pasta mechanical and functional changes, structural modifications were observed with powder pycnometer analysis. Micro-alveolation is created in the pasta and density is function of processing conditions.

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Figure Captions

Fig. 1. Diagram of the different characterisation steps applied to the pasta after DIC treatment.

Fig. 2. Typical pressure and temperature-time profile of a D.I.C. processing cycle. Processing pressure, 1.5 bar; treatment time, 30 s.

Fig. 3. Plexiglas straight probe used to estimate the mechanical properties of pasta.

Fig. 4. Compression-relaxation curves of D.I.C treated (1 and 4 bar processing pressure at 30 s of processing time) and untreated fresh egg pasta.

Fig. 5. Influence of D.I.C. treatment on maximal apparent force (F_{max}).

Fig. 6. Influence of D.I.C. treatment on apparent relaxation coefficient (ARC).

Fig. 7. Apparent density of untreated and D.I.C. treated pasta for two processing time (30 and 60 s). Model regression for 30 s: y = 0,1115x2 - 0,6051x + 1,5648 (R^2 = 0.98), and for 60 s: y = 0,054x2 - 0,3545x + 1,3065 (R^2 = 0.88)

Fig. 8. Force versus time of untreated pasta measured with Instron Universal Testing Machine (INSTRON) after different cooking time (3, 4, 6, 8 and 10 min).

Figure 1.

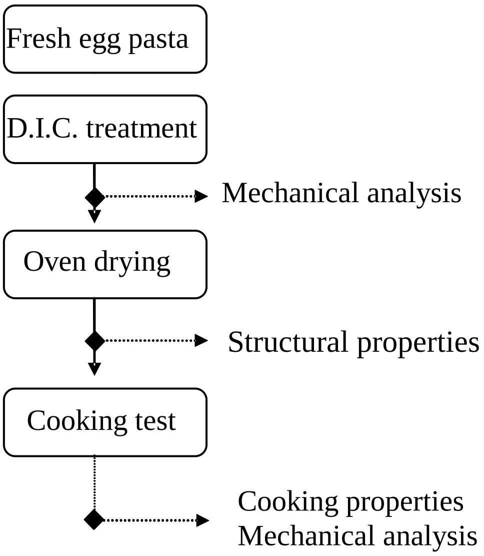
Fresh egg pasta
D.I.C. treatment
Mechanical analysis
Oven drying
Structural properties
Cooking test
Cooking properties
Mechanical analysis

Figure 2

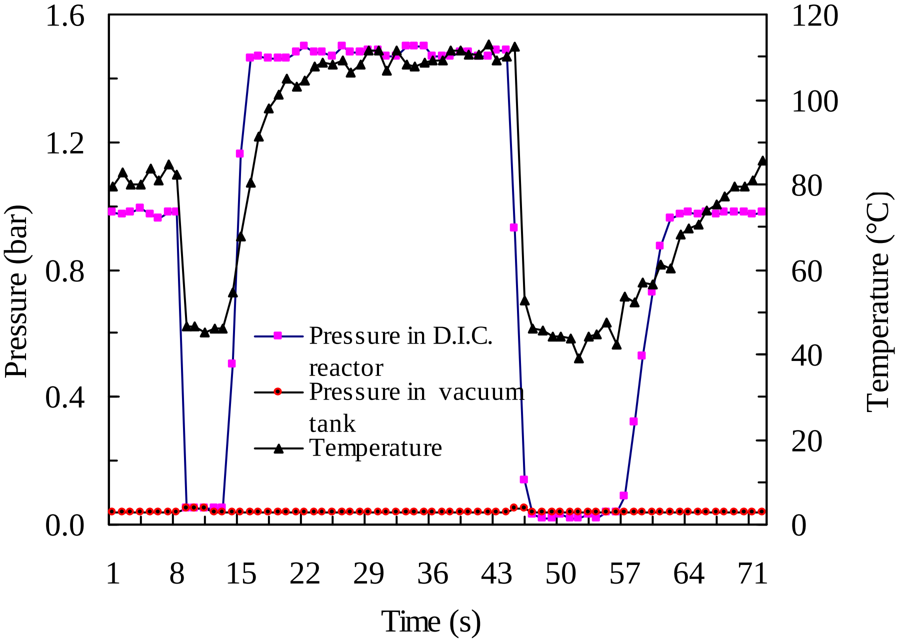
1.6
1.2
0.8
0.4
0.0
Pressure (bar)
120
100
80
60
40
20
0
Temperature (°C)
1
8
15
22
29
36
43
50
57
64
71
Time (s)
Pressure in D.I.C. reactor
Pressure in vacuum tank
Temperature

Figure 3

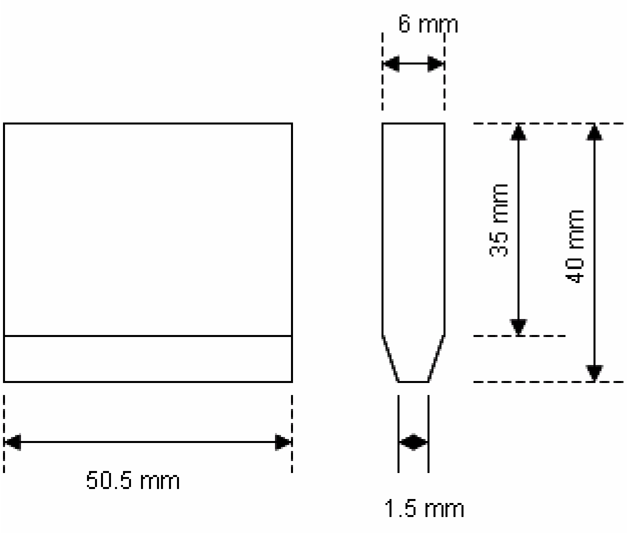

Figure 4

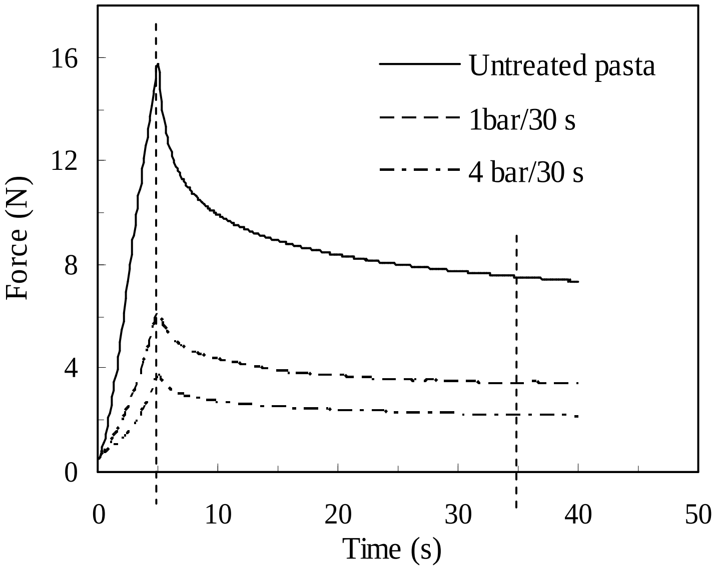
Untreated pasta
1bar/30 s
4 bar/30 s
Force (N)
16
12
8
4
0
0
10
20
30
40
50
Time (s)

Figure 5

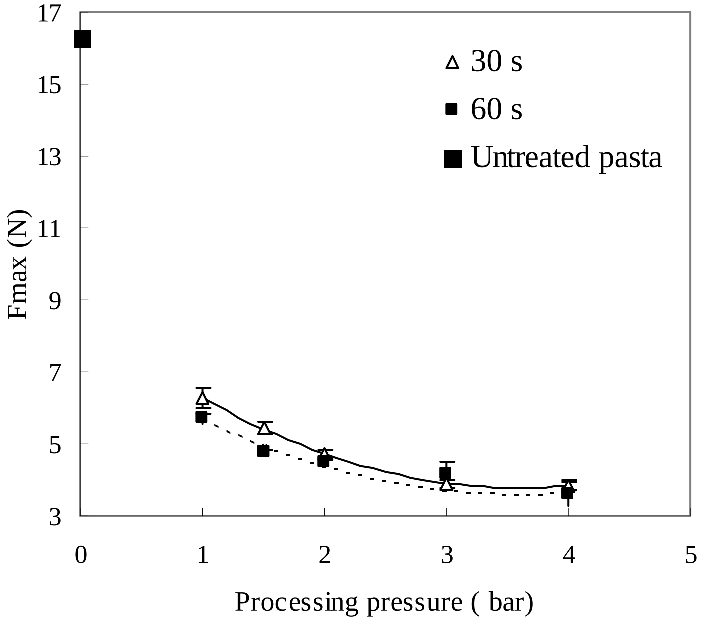
17
15
13
11
9
7
5
3
Fmax (N)
0
1
2
3
4
5
Processing pressure (bar)
△ 30 s
■ 60 s
■ Untreated pasta

Figure 6

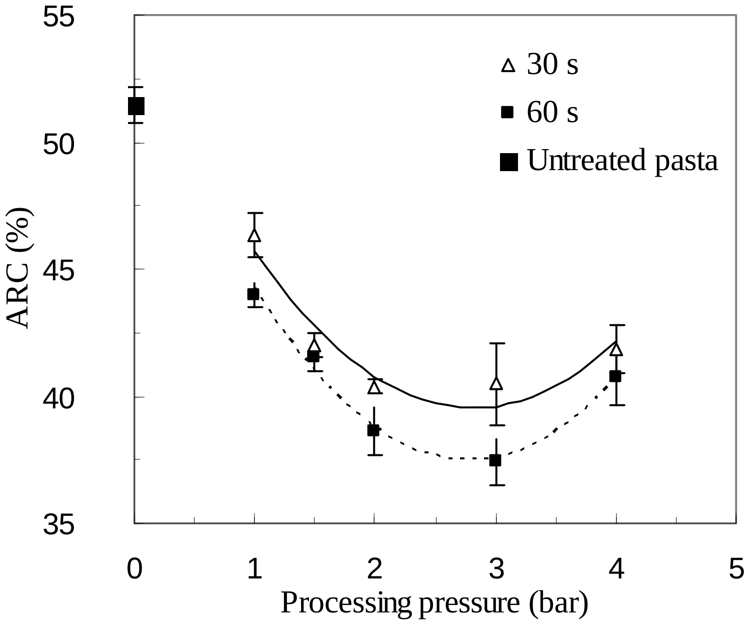
55
50
45
40
35
ARC (%)
0
1
2
3
4
5
Processing pressure (bar)
△ 30 s
■ 60 s
■ Untreated pasta

Figure 7

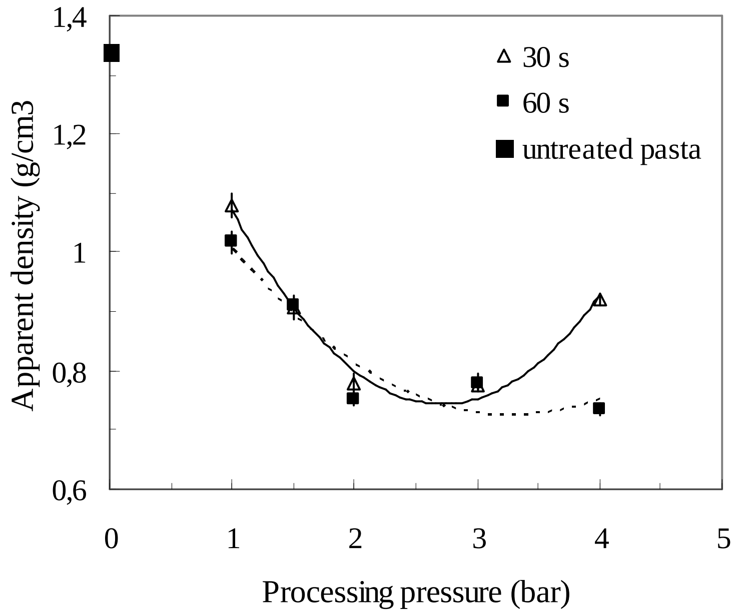
1,4
1,2
1
0,8
0,6
Apparent density (g/cm3
0
1
2
3
4
5
Processing pressure (bar)
30 s
60 s
untreated pasta

Figure 8

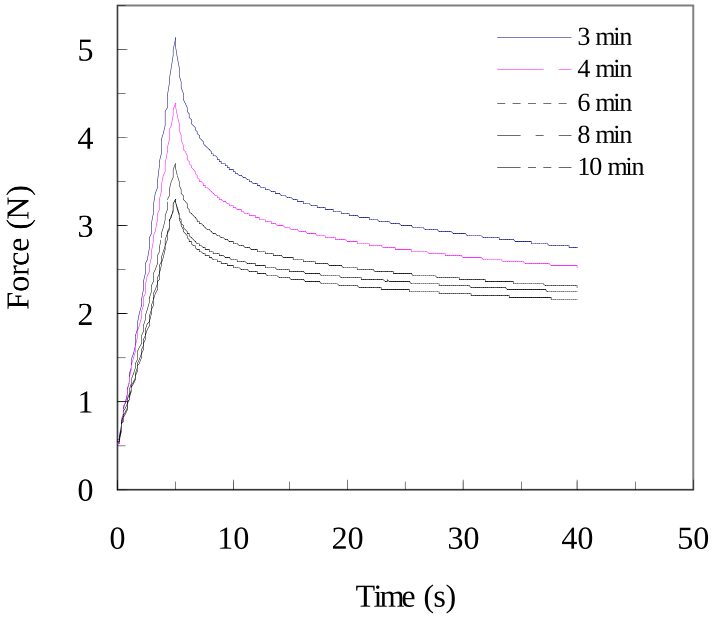

Table 1: Model parameters and regression coefficients of a second degree equation calculated to fit the experimental data in maximal force and apparent relaxation coefficient as a function of processing pressure. (Eq. (1))

Processing time (s)	Model parameters			R^2
	a	b	c	
F_{max}				
30	8.588	-2.671	0.371	99.96
60	7.546	-2.204	0.305	98.07
ARC				
30	54.367	-10.532	1.870	91.36
60	54.030	-11.911	2.143	98.33

F_{max} , maximal apparent force at 0.5 mm compression; ARC, Apparent Relaxation Coefficient.

Table 2. Cooking characteristics of D.I.C. treated pasta as function of processing conditions.

D.I.C. processing conditions			Rehydration characteristics at 5 min of cooking time				
Pressure (bar)	Time (s)	OCT (min)	W/W_0	SI (g water/g dry matter)	Solid loss (%)	Soluble loss (%)	TCL (%)
1	30	3.7	2.38	2.16	1.21	4.24	10.38
1.5		2.7	2.78	2.19	0.95	3.16	9.89
2		3.0	2.68	2.24	0.86	2.02	9.89
3		3.3	2.64	2.24	0.85	1.79	9.63
4		3.6	2.55	2.16	0.58	0.69	8.64
1	60	2.8	2.75	2.63	1.64	4.62	11.33
1.5		2.2	2.90	2.52	1.63	4.23	10.35
2		2.1	2.96	2.47	1.50	3.83	8.70
3		3.0	2.70	2.22	1.44	3.28	7.76
4		4.2	2.42	2.21	1.44	2.58	7.30
Untreated pasta		5.0	2.27	2.09	1.45	4.61	13.33
Mean absolute error*		0.1	0.08	0.07	0.06	0.14	0.41

OCT, optimal cooking time; W/W_o, mass ratio; SI, swelling index; TCL, total cooking losses;* mean absolute error calculated with 4 repetitions at 2 bar and 30 s.

Table 3. Mechanical properties as a function of cooking time of treated pasta at different pressures and at 60 s of treatment time.

	Mechanical properties of cooked pasta									
	Fmax (N)					Apparent relaxation coefficient (%)				
	Cooking time (min)					Cooking time (min)				
Processing pressure (bar)	3	4	6	8	10	3	4	6	8	10
1	4.03	2.82	2.77	2.53	2.54	42.51	39.10	33.12	31.27	29.19
1.5	3.98	3.48	2.90	3.14	2.83	34.80	34.20	30.66	30.63	29.68
2	4.36	3.25	3.53	2.83	2.62	34.63	35.38	32.86	34.98	31.68
3	4.42	3.94	3.33	3.22	3.05	34.88	33.54	31.96	35.76	34.82
Untreated pasta	5.13	4.39	3.71	3.29	3.19	44.94	41.17	36.80	33.60	31.62
Mean absolute error*	0.01	0.21	0.23	0.47	0.11	1.41	1.54	1.32	2.19	0.52

* mean absolute error calculated with 2 repetitions for untreated pasta