Influence of Extrusion Conditions on Extrusion Speed, Temperature, and Pressure in the Extruder and on Pasta Quality[1]

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ABSTRACT

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A fully instrumented pasta press was used to analyze the effects of experimental parameters (hydration, temperature, and shearing) on the pasta-making process and on quality characteristics of spaghetti. The rotational speed of the screw determined the flow rate of the extruder and influenced the extrusion speed, as well as the open surface of the die. The differential speed (ratio between the shortest and longest strands during the same extrusion time) was decreased by the presence of a *trefilette* at the end of the screw. From an energy viewpoint, the procedure was very susceptible to the variation of parameters. For instance, the average specific mechanical energy transferred to the product for pasta extrusion was about 70 kJ/kg, but it could vary in a 1:5 ratio according to the extruding conditions, especially dough hydration and dough temperature, which both determine dough viscosity. These two parameters also had a great effect on pressure in the barrel and at the die. The presence of a pre-die plate seemed to exert a greater influence on the running of the screw, especially the fill rate and pressure at the end of the screw, than did the extruding conditions at the die level. Production factors were found to have little influence on the color of pasta. They did, however, affect the cooking quality. Increasing the amount of hydration of the semolina and the rotational speed of the screw enhanced cooking quality. A large open surface of the die improved the surface condition of cooked products but decreased the viscoelastic properties. An excessive increase of pasta temperature during extrusion appeared to be the main factor in the degradation of cooking quality. Therefore, a control of pasta temperature at the die was proposed as the simplest method to guarantee the quality of finished products.

Pasta is made by hydrating semolina, mixing it, kneading it, extruding it through a die to obtain the desired shape, and then drying it. Production techniques and machinery have significantly changed the process of transforming semolina into pasta. The first important change was the advent of continuous presses just after the Second World War. This considerably increased production capacity and changed pasta production from an artisanal to an industrial process. The second major change occurred only recently with the introduction of high (Pavan 1979) and very high (Frances and Ollivier 1985) temperature drying techniques. These techniques significantly reduced drying time and further increased production capacity. The production potential of presses has yet to reach a maximum level (Baroni 1988). At present, their hourly output is no more than 2,500 kg/hr. There are a few very large (5,000 kg/hr) presses in use, but the cooking quality of the pasta they produce is disappointing. These presses were developed by simple extrapolation of existing materials to increase production capacity, and they have never been specifically investigated.

Other innovations in this field have improved the appearance of pasta: use of vacuum before extrusion to prevent air bubbles and avoid oxidation of carotenoid pigments, and the use of Teflon inserts to obtain a smoother product (Feillet 1986).

There has been little scientific research on pasta extrusion. Finzi and Finzi (1974) reported that the combined factors of mixing, kneading, pressure, and temperature result in major changes in the physical structure of pasta. Hot-processed pasta with a high water content had a better appearance than did cool-processed pasta (Renaudin 1951), but the hot-processed pasta was less firm after cooking (Walsh et al 1971). Menger (1977) stated that the extrusion temperature of pasta should not exceed 50° C, whereas Medvedev et al (1987) suggested that products of satisfactory quality could be obtained at temperatures up to 70° C. Moreover, it is generally accepted that pasta obtained by sheeting has a better cooking quality than do extruded products. Microscopic studies have shown that the organization of proteins in the extruded dough varies according to the production process. The gluten network should be more developed by sheeting than by extrusion (Matsuo et al 1978, Dexter et al 1979). Confirming these results, Pagani et al (1989) also observed that extrusion contributes to formation of a protein network with numerous discontinuities. They concluded that the extrusion process is not suited to pasta production when the raw material is of poor quality, such as soft wheat flour. Moreover, while the production of pasta modifies the solubility of proteins, no significant change was observed in the electrophoretic profiles of the different protein fractions obtained (Dexter and Matsuo 1977, Wasik 1978). These data, only partial and sometimes contradictory, do not give sufficient information concerning optimum pasta production. The lack of information on physicochemical phenomena occurring during extrusion justifies new and important systematic research on pasta

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formation.

The objective of this study was to investigate the influence of the main parameters of hydration, temperature, and shearing on pasta formation in the press, as well as mass flow properties and pasta quality. This new approach was based on experimental design techniques and on the use of an experimental press capable of capturing data online during the extrusion process.

MATERIAL AND METHODS

Instrumentation of a Pilot Press

The full instrumentation of an experimental press (Afrem, Lyon, France) was one of the most original parts of this program. Changes were made to the barrel, die, and motor to measure the pressure, temperature, and mechanical energy transferred to the pasta during extrusion. A diagram of the experimental press is shown in Figure 1.

The data transmitted by the sensors were relayed to a data acquisition system (AOIP SAM 80) capable of 60 acquisitions per second. Teleprogramming software was developed to accept the data in an IBM 8530-H21 computer. EXCEL software was used for data processing.

Experimental Design

Six main factors and their interactions were studied: open surface of the die, pre-die and filter plates, *trefilette*, screw rotational speed, temperature of circulating water in the barrel, and semolina hydration. Figure 2 shows the die, the pre-die and filter plates, and the trefilette. The open surface of the die was modified by closing some of the 112 holes of the die. Pre-die and filter plates are pierced stainless steel pieces that can be put before the die to regulate the differential speed between spaghetti strands. A trefilette is a removable end part of the screw with an helicoidal form used to break preferential flows created through the screw.

A series of preliminary tests were performed to assess the maximum values of the six factors. These limit values were determined as those that can be used simultaneously, in the same experience, to produce pasta with a regular shape and in the normal running conditions of the pilot press. Those values that determined the experimental area are given in Table I.

A two-level fractional factorial design (2^{6-2}) was built, and the effects of the various factors were evaluated by variance analysis (STAT-ITCF software). A few complementary tests were necessary to resolve some ambiguities (alias) where the effects of interactions were confounded (Box et al 1978). The validity of derived linear models obtained was evaluated by doing tests at the center point. Finally, additional processing of data was done by segmentation and stepwise progressive multiple regression to establish the relationship between variables.

Pasta Manufacture

Commercial durum semolina (6 kg) was used to make spaghetti (dry diameter = 1.5 mm). The production room was kept at 20°C and 70% rh. Semolina was hydrated to the value required by the level of this variable (44 or 48% db) and then mixed for 20 min at 120 rpm with deionized water. The temperature of the mixer was maintained at 30°C by water cooling. The product was then fed into the auger and extruded according to a predetermined level of the other variables (screw speed, temperature, screw profile, and shear characteristics) under partial vacuum (150 mm Hg). When extrusion conditions were stable, the spaghetti samples were kept and dried using a low-temperature drying cycle at 55°C for 17 hr.

Residence Time Distribution

The residence time distribution of the product in the barrel and die was measured according to Colonna et al (1983) with a colored tracer (Bleu 517-11 Givaudan, Cogilor). A pellet of tracer (0.5 g) was introduced at time zero ($t = 0$) into the extrusion screw filler opening. Pasta samples were then taken every 20 sec, and their color was immediately determined with a Labscan Hunterlab spectrocolorimeter. From the values obtained for the b^*

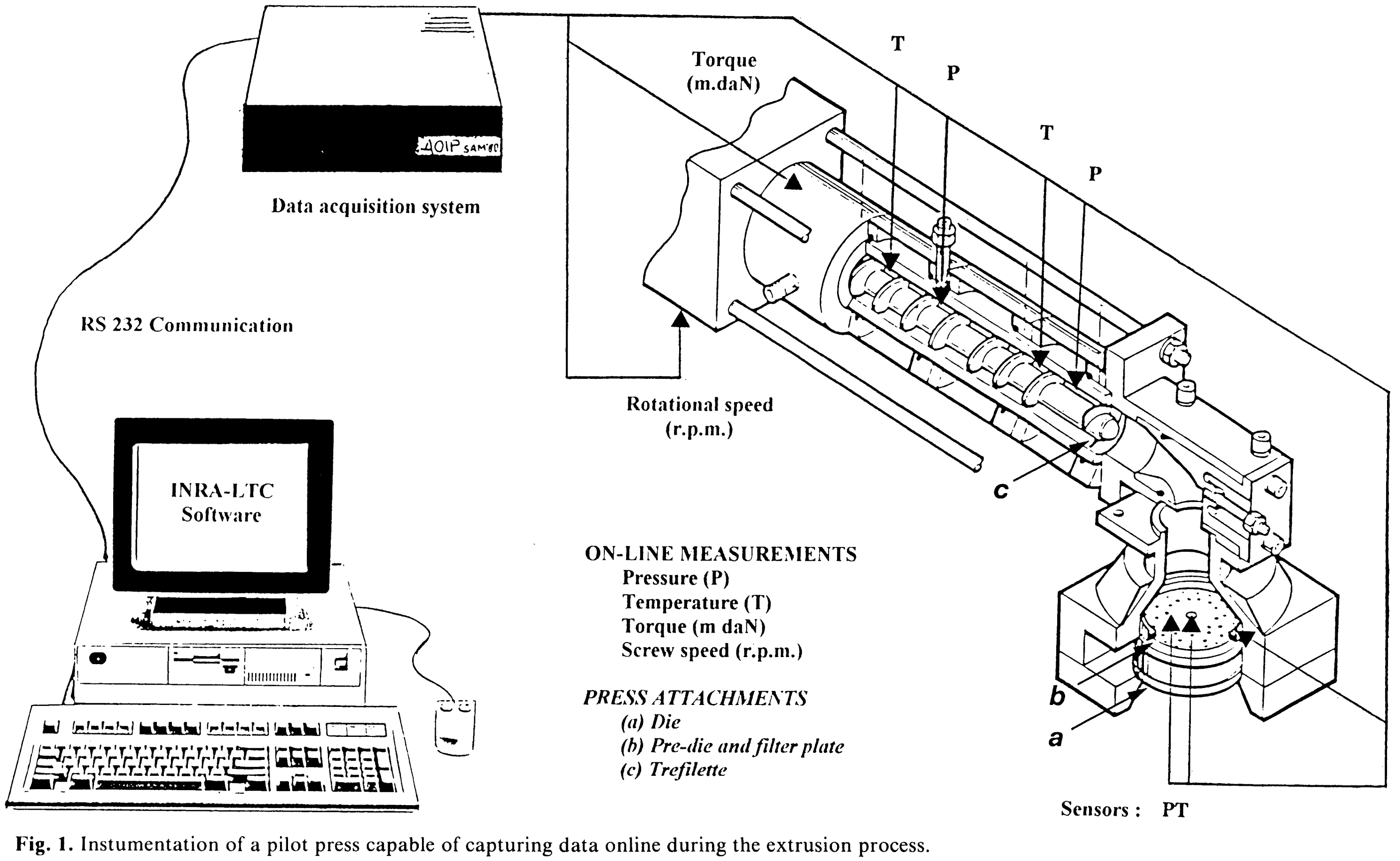

Fig. 1. Instumentation of a pilot press capable of capturing data online during the extrusion process.

indices, the minimum residence time (T_0) and average residence time (*Tm*) of the product in the extruder was determined. T_0 corresponds to the beginning of the passage of the coloring agent through the die, involving a decreasing of the b^* indices. *Tm* corresponds to the maximum intensity of blue coloring of the extruded product evaluated by the minimum value of the b^* indices.

Pasta Analyses

Color and cooking quality of pasta were measured as described by Abecassis et al (1989). For color, the international colorimetric indices L^*, a^*, and b^* were determined on spaghetti with the spectrocolorimeter. Brown index was expressed as $(100 - L^*)$; the red index as a^*, and the yellow index as b^*. Cooking quality was determined with 100 g of dry pasta broken into 20-cm strands that were placed in 3 L of boiling mineral water (ISO 1985) with NaCl at 7g/L. The minimum cooking time (T) is the minimum time necessary to gelatinize the starch. It was assessed by crushing cooked spaghetti between two glass plates and measuring the time for the starchy white core of the spaghetti to disappear. Cooking was continued until total cooking time equaled $T +$ 6 min.

Cooking losses (CL) are expressed as the total amount of soluble and insoluble pasta-derived matter left in the cooking water after draining. The cooking water was stirred, and 25 ml was taken and dried at 102°C for 15 hr in a ventilated oven. To account for the salt added to the cooking water, CL were calculated as:

$$\mathrm{CL} = (\mathrm{DM} - 0.175) \times \mathrm{V}/25 \times (100 - \mathrm{W}) \qquad (1)$$

where DM = weight of dry matter (g), V = final volume of cooking water (ml), W = water content of uncooked pasta (g). CL is therefore expressed as grams of DM per 100 g of DM uncooked pasta.

Weight after cooking is the mass (wet basis) of 100 g of dry pasta (water content 12%) after cooking and draining for 1 min. It corresponds to the amount of meal available to the consumer when cooking 100 g of raw pasta.

Surface condition relates to the disintegration of the spaghetti surface after cooking. It is assessed by comparison with a set of photographs (ISO 1985) and rated from 1 (highly disaggregated) to 9 (smooth surface).

Viscoelastic index of cooked pasta is measured with the Chopin-INRA Viscoelastograph (Feillet et al 1977) equipped with new acquisition and data processing software. Five strands of cooked spaghetti (4 or 5 cm long) were left for 1 hr in a petri dish under an atmosphere saturated with water and then cut to lengths of 2 cm. The initial thickness of cooked spaghetti (E), thickness after 40 sec under a load of 500 g (e_1) and thickness 20 sec after release of load (e_2) were measured. Average values (for five pieces of the same sample) of compressibility (C) and relative recovery (R) were calculated as:

$$\mathrm{C} = \mathrm{E} - \mathrm{e}_1/\mathrm{E} \qquad (2)$$

and

$$\mathrm{R} = \mathrm{e}_2 - \mathrm{e}_1/\mathrm{E} - \mathrm{e}_1 \qquad (3)$$

The viscoelastic index (VI) is calculated as:

$$\mathrm{VI} = \mathrm{R}/\mathrm{C} \times 10 \qquad (4)$$

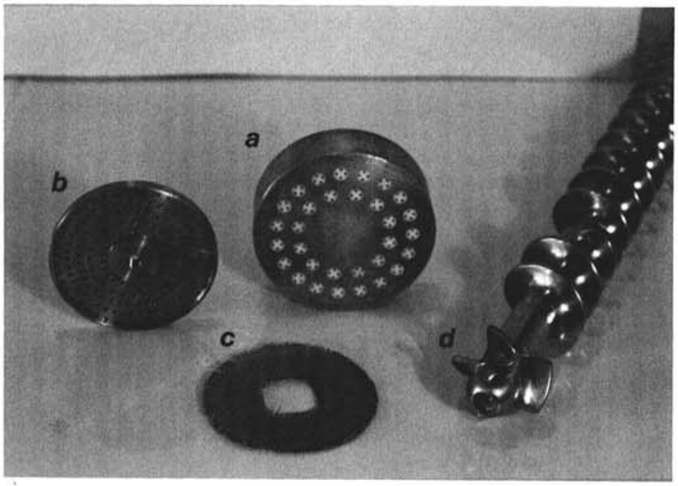

Fig. 2. Press attachments used with the pilot press: a, die; b, pre-die plate; c, filter plate; d, trefilette.

TABLE I
Range of Extrusion Parameters Tested

	Range
Open surface of die-hole, %[a]	54–100
Trefilette[b]	Absence–Presence
Pre-die and filter plates[c]	Absence–Presence
Screw rotational speed, rpm	15–30
Barrel temperature, °C	35–70
Semolina hydration, % (db)	44–48

[a] Percentage of the 112 die holes not closed.
[b] Additional end part of the extrusion screw.
[c] Stainless steel pierced piece placed just before the die.

RESULTS AND DISCUSSION

Variation of Physical Factors in the Extruder

The average, minimum, and maximum values for all experiments are given in Table II. A large variability of responses were obtained from the experimental area screened. For example, the pressure measured at the end of the screw varied between 2.9 and 17.6 MPa. The temperature of pasta at the extrusion die varied between 41 and 71°C, and the extrusion speed of spaghetti varied between 1.0 and 4.2 m/min.

The specific mechanical energy (SME) transferred to the product was calculated as the mechanical energy to extrude pasta (torque × angular screw speed) divided by the amount of the product processed. The mechanical energy required to operate the empty press was subtracted from the mechanical energy required to operate the press under load. Under these conditions, the average value of SME transferred to the product was about 70 kJ/kg, and it could reach 120 kJ/kg in drastic conditions. This value remains extremely low compared to that applied by a twin-screw extruder which, according to Della Valle et al (1989), is between 300 and 900 kJ/kg. This value remains, however, higher than that necessary for making bread dough, because the most vigorous kneading processes (e.g., Chorleywood method) uses an SME of ~40 kJ/kg (Axford et al 1963).

TABLE II
Summary of Responses During Pasta Extrusion

	Average	Minimum	Maximum
Flow rate, kg/hr	25.6	15.0	36.9
Extrusion speed, m/min	2.2	1.0	4.2
Differential speed[a]	1:1.5	1:1.1	1:3.0
Dough temperature, °C			
Start of screw	51	35	69
End of screw	53	36	74
Die	52	41	71
Pressure, MPa			
Start of screw	2.9	0.0	9.2
End of screw	8.2	2.9	17.6
Die	4.4	2.0	7.5
Torque, N·m	210	70	380
Specific mechanical energy, kJ/kg	66	27	122

[a] Ratio in length between shortest and longest strands during the same extrusion time.

TABLE III
Effects of Parameters Influencing Extrusion Functioning[a]

Parameters	Flow Rate	Extrusion Speed	Differential Speed	Dough Temperature			Pressure			Torque	S M E[b]
				Start Screw	End Screw	Die	Start Screw	End Screw	Die		
Die open surface increase (A)		−−							−−−		
Trefilette present (B)			−−								
Pre-die present (C)				++		+	+++	+++		+++	+++
Screw speed increase (D)	+++	++						++	++	++	
Temperature increase (E)				+++	+++	+++	−−	−−−	−−−	−−−	−−−
Hydration increase (F)				−	−−	−−		−−	−−	−−	−−
A×D		−			+	+					
A×E								−			
B×E			+								
B×F							+	+			
C×D								++		+	+
C×E							−−	−		−	−
C×F				−−							
D×E						−					
E×F										+	+

[a] +++ or −−− : very highly significant increase or decrease, respectively ($P < 0.001$); ++ or −− : highly significant increase or decrease, respectively ($P < 0.01$); + or − significant increase or decrease, respectively ($P < 0.05$).
[b] Specific mechanical energy.

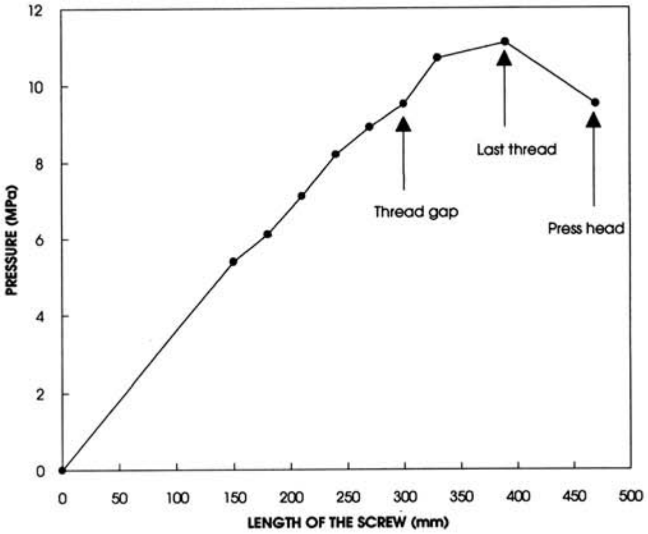

Fig. 3. Longitudinal pressure profile of the pilot press.

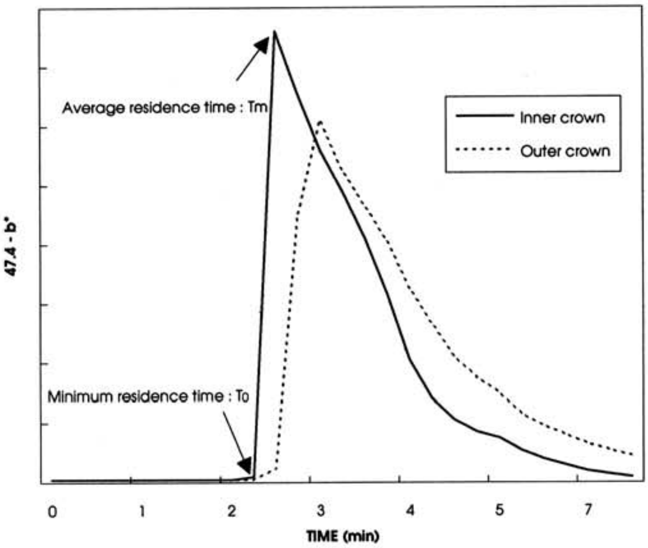

Fig. 4. Residence time distribution in the pilot press. Screw speed = 20 rpm; b^* value of the pasta without coloring = 47.4.

Factors influencing dough flow, temperature, and pressure are summarized in Table III. The rotational speed of the screw determines extruder mass flow rate, which, together with the open surface of the die, is responsible for the extrusion speed. The differential speed, measured as the ratio in length between the longest and shortest strands of pasta during the same extrusion period, is decreased by the presence of the trefilette at the end of the screw and by an increase in extrusion temperature. However, the test was not able to separate the effect of the pre-die plate on differential speed, which was intended to regulate the length of cutting. Even if the pre-die plate used in this study was regularly pierced with holes of the same diameter over its total surface, it is probable that the problems of scale-up would make the study of the extrusion pattern from such a pilot press difficult.

The temperature of pasta is mostly governed by the temperature of water circulating in the barrel jacket. An intense mechanical action (insertion of a pre-die plate, increase in screw speed at low temperature together with reduction of the open surface of the die) heats the product. An increase in semolina hydration tends to reduce the temperature.

The pressure (maximum value measured on the last thread of the screw) is the result of actions and interactions of numerous factors, such as pre-die plate, screw speed, temperature, and hydration. The influence of these factors can differ according to each zone of the extruder. The open surface of the die determines the die pressure, while the pre-die plate determines mainly the pressures measured on the barrel. The factors influencing the pressure at the end of the screw are, in general, the same as those that act on the torque motor and SME. As far as these two last parameters are concerned, the significant effect of interaction between temperature and hydration emphasizes the influence of the characteristics of the product (viscosity) on the extrusion process.

For each measured characteristic, a linear modeling equation can be derived (data not presented). The linear models were verified by producing pasta using parameters close to those of the center point. The mass flow rate, extrusion speed, torque, and pressure values were calculated using the model and are close to the values observed during processing; however, the temperature values appear slightly overestimated (by about 2°C).

Pressure along the length of the screw and the residence time are essential for establishing a mass flow model for the screw. The longitudinal profile of pressures was established by using production conditions close to those used in industrial presses. The longitudinal pressure profile of the pilot press is shown in Figure 3. The pressure increased very regularly from the beginning to the end of the screw, and then it decreased at the head of the die. The pressure measured on the barrel can vary greatly when operating conditions are changed. A sensor placed 150 mm from the start of the screw measured pressures that varied between

0 and 9.0 MPa. This shows that the fill rate of the extrusion screw with a compacted product varies greatly according to extrusion conditions. It can be concluded that the transformation of the semolina into dough can occur at different stages of extrusion. Regulation of extrusion conditions determines the variability of shearing rate before the product is formed. The pre-die plate factor mostly determines the fill rate of the screw.

Figure 4 shows the residence time distribution in the extruder for operating conditions close to the center point. The extrusion die consists of 112 holes mounted on 28 Teflon inserts situated on two concentric crowns (Fig. 2). The minimum residence time (T_0) of the product in the extruder is 2 min 15 sec in the inner crown, and 2 min 30 sec in the outer crown. The average residence times (Tm) are 2 min 30 sec and 3 min 0 sec, respectively. The residence time is actually different for each hole, even for those from the same Teflon insert. The differences observed between the residence times concur with the differential speed between strands of spaghetti. The main factor influencing the distribution of residence time is the screw speed. At 15 rpm, the average residence time is 4 min 20 sec; doubling the speed of rotation of the screw reduces residence time to 1 min 50 sec, all other factors being equal.

Influence of Production Conditions on Pasta Quality

Table IV summarizes the average and extreme values of pasta characteristics measured in this study. Generally speaking, the formation of pasta has only a limited effect on the color of the finished product, which depends more on the composition of raw material used (Abecassis 1991). By contrast, extrusion conditions greatly affect the cooking quality of the finished products and can result in cooking losses that vary between a minimum of 10% and a maximum of 50%. Similarly, considerable changes in viscoelastic properties and surface condition of cooked products were observed.

The effects of factors influencing the quality of pasta are summarized in Table V. The color of pasta appears to be little changed by the factors studied in this report. However, certain significant effects (at a confidence level of 95%) have been isolated. The increase of the open surface of the die increases the yellow index while decreasing the red index. It is probable that this effect is linked to the shearing speed, even when no direct effect of the screw rotational speed has been shown. The presence of the pre-die plate has a tendency to increase the brown index of dry pasta. In contrast with studies from Medvedev et al (1984), the beneficial effect of an increase in temperature on this characteristic was not found. Interactions between factors were revealed, in particular the interaction between the profile of the screw (trefilette) and screw speed, which influences the color indices (decrease in yellow and brown index).

Cooking quality is highly influenced by extrusion conditions. The most important of these factors is the temperature of the water circulating in the barrel. In the conditions used, the water temperature was raised from 35 to 70°C, resulting in an increase in cooking losses of about 250%, as well as a deterioration of surface condition and a decrease in the viscoelastic index. This result concurs with results obtained by Menger (1977), but it differs considerably from those presented by Medvedev et al (1984), who considered that, at temperatures up to 70°C, the quality of the products remains normal, despite a decrease of all the indices of cooking quality. Other factors that have an important effect on cooking quality are the increase in the amount of hydration of semolina and the rotational speed of the extrusion screw. These have a beneficial effect on all the characteristics of cooked products (increase of swelling, better surface condition and viscoelastic index, and decrease in cooking losses). The open surface of the die changes neither the swelling of cooked pasta nor the cooking losses. It does, however, affect both the surface condition and viscoelasticity. The increase of the open surface of the die leads to a slight improvement (significant at 5%) of the surface condition of pasta, but at the same time there is a decrease in viscoelastic properties (significant at 5%). Finally, the interaction between rotational speed of the screw and temperature exercises a highly significant effect (1%) on all parameters of cooking quality except viscoelasticity.

Linear modeling for surface condition and viscoelasticity is fairly good. However, the experimentally measured values are significantly higher for cooked weight, and lower for cooking losses when compared to those obtained using the model at the center point. This result thus indicates a nonlinear relationship between these two characteristics and the processing parameters.

TABLE IV
Summary of Analytical Data on Pasta

Analytical Data	Average	Minimum	Maximum
Color			
Yellow index (b^*)	47.4	42.9	52.0
Brown index ($100-L^*$)	35.4	33.1	37.7
Red index (a^*)	5.2	4.4	6.3
Cooking quality			
Weight after cooking (g/100g)	255	168	318
Cooking losses (% db)	21.7	9.6	51.5
Surface condition (0–9)	3.4	1.1	4.8
Viscoelastic index	2.6	0.6	5.6

Additional Data Analyses

While the effect of factors contributing to the quality of pasta has been clearly shown, data analysis was also performed using the method of analysis by segmentation to better understand the role and influence of some factors on cooking losses. Segmentation is a statistical method that aims to explain a population characteristic by successive dichotomies from a set of qualitative explanatory variables. It regroups the individuals in homogeneous groups while maximizing intergroup heterogeneity. It can thus separate those explanatory variables that best explain the phenomenon.

TABLE V
Effects of Parameters Influencing Pasta Quality[a]

	Color Index			Cooking Quality			
Parameters	Yellow	Brown	Red	Weight	Cooking Losses	Surface Condition	Viscoelasticity
Open surface of the die increase (A)	+		−			+	−
Trefilette present (B)							
Pre-die present (C)		+					
Screw speed increase (D)				++	−−	++	+
Temperature increase (E)				−−−	+++	−−−	−−−
Hydration increase (F)				++	−−	++	+
A×D				−			
A×E		−		−			
B×D	−	−					
B×F	+						
D×E				++	−−	++	

[a] +++ or −−− : very highly significant increase or decrease, respectively ($P < 0.001$); ++ or −− : highly significant increase or decrease, respectively ($P < 0.01$); + or − significant increase or decrease, respectively ($P < 0.05$).

Figure 5 shows the results of segmentation analysis of cooking losses. The first explanatory variable that can classify the samples is temperature. When temperature is low, pasta is classed in a homogeneous group (low standard deviation) for which the CL are low. At high extrusion temperature, the group formed can once again be divided into two classes according to the screw speed. A rapid speed has a beneficial effect by limiting CL. This further emphasizes the highly significant effect of interaction between the rotation of the screw and temperature on cooking quality.

The initial experimental design was split in two half fractions (at low and high temperature) to more accurately specify the influence of variables. With a high fractional factorial design (only eight experiments), it was not possible to study the effects of interactions. This is why only the principal effects were evaluated. According to the extrusion temperature, considerable differences were observed between the average values of the four parameters of cooking quality. As far as the cooking quality is concerned, the analysis of data revealed that, at low temperature, the amount of hydration of semolina is the factor that exercises the greatest effect, whereas at high temperature, the most important effect is that which concerns the rotational speed of the screw. A more detailed study shows that a faster extrusion screw rotational speed slightly changes the average temperature of the pasta: increase of 2°C at low temperature and decrease of 2°C at high temperature. This is not nearly as important as the reduction in the average residence time (*Tm*) in the barrel from 4 min 20 sec to 1 min 50 sec.

Equations for Cooking Quality

The effects of extrusion parameters need to be known to control production and help develop new materials. Nevertheless, in the production line, response data, such as pressure, are used more often than data on factors such as hydration rate. Multiple regression equations (stepwise regression) were derived to predict cooking quality from measured extrusion parameters. These were able to give some excellent estimations of CL values and good estimations of surface condition and viscoelasticity. These forecast equations are shown in Table VI. They use the temperature of the product at the time of extrusion, the mass flow rate (in relation to the screw speed), and the extrusion speed (in relation to the open surface of the die).

In some cases, the models obtained can be simplified. For CL, it is possible to use only the temperature of the dough at the die. Figure 6 illustrates the relationship between cooking loss and this temperature. The high correlation between these two parameters suggests that, in production, the online control of the temperature of the dough at the die could be a simple method of assuring the cooking quality of the finished product.

CONCLUSIONS

The objective of this study was to better understand how parameters of hydration, temperature, and shearing affect mass-flow properties and pasta quality. The use of an experimental press equipped with sensors, together with a detailed parametric study, have shown that the color of pasta is slightly changed by the extrusion process parameters. In addition, several factors affect cooking quality.

1. Temperature of extrusion is the main factor responsible for the degradation of cooking quality. The control of the temperature of pasta during extrusion seems to be the simplest method to guarantee a satisfactory finished product.
2. Increase in hydration of semolina has a beneficial effect on all the parameters of cooking quality by reducing the viscosity of dough.
3. At high extrusion temperature, the increase of screw rotational speed enhances the quality of the finished product by reducing the residence time of the product in the extruder.

TABLE VI
Predictive Equations of the Main Parmeters on the Cooking Quality of Pasta[a]

	R^2
Cooking losses = −27.1 + 1.7 die T −0.5 flow rate −1.0 start of screw P −0.4 start of screw T	0.95
Surface condition = 7.6 − 0.1 die T + 0.1 flow rate −0.3 extrusion speed	0.88
Viscoelastic index = 8.5 −0.1 end of screw T + 0.6 extrusion speed −1.1 differential speed	0.80

[a] Where: T = temperature (°C), flow rate = mass flow rate (kg/hr), P = pressure (MPa). Extrusion speed measured in m/min and differential speed is ratio between shortest and longest strands during the same extrusion time.

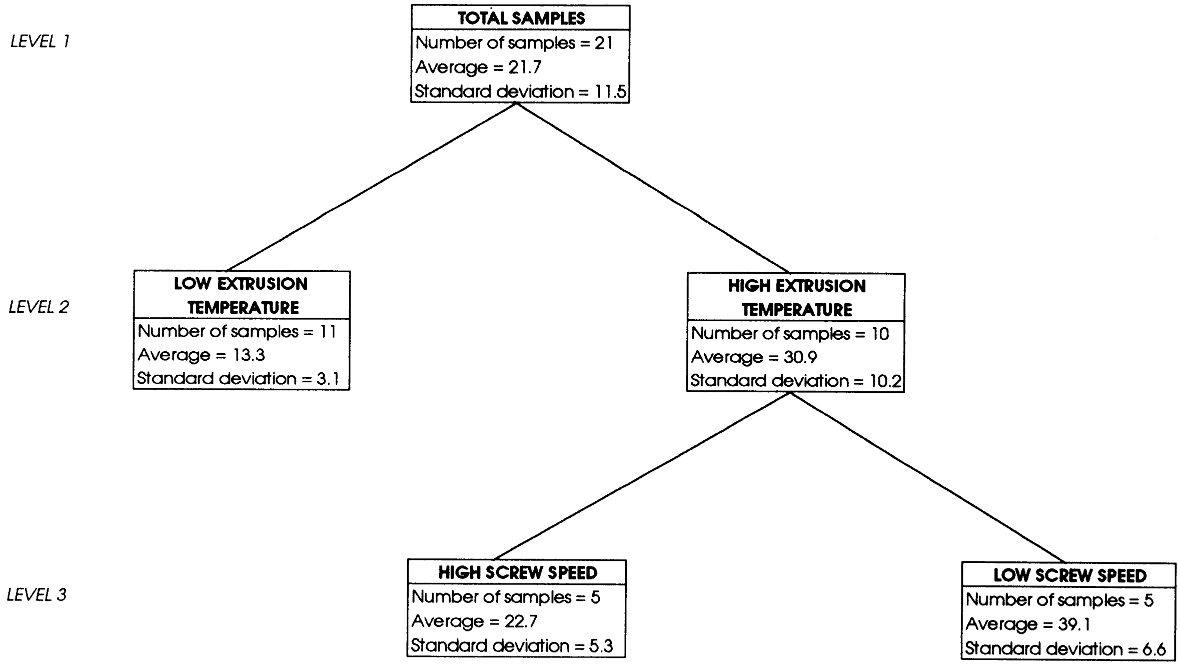

Fig. 5. Segmentation analysis of cooking losses.

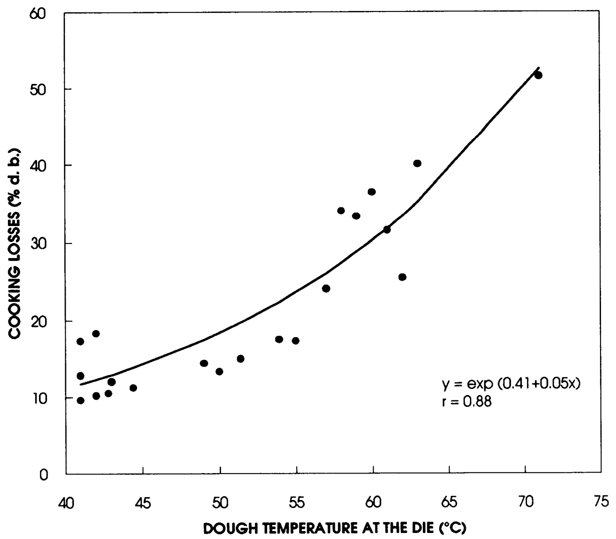

Fig. 6. Relationship between cooking losses and extrusion temperature of pasta.

4. A large open die surface improves the surface condition of the cooked product, but it decreases the viscoelastic properties. Apparently, the formation of dough in the die requires an equilibrium to give the pasta both extensibility during cooking so that it has a good surface and sufficient density to ensure firmness of the finished product.

The SME needed to make pasta is relatively low, and it is most important that the product should not be overheated. Three ways of avoiding this are:

1. Increase the hydration of semolina. However, a limit is quickly reached beyond which the products lose their shape, stick to each other, and experience difficulties at the drying step.

2. Decrease residence time in the extruder. The measurements from the experimental press showed that the average time to form pasta was about 2 min 30 sec, this could vary between 2 and 4 min. The results obtained during this study revealed that, according to the extrusion temperature used, this 2-min difference in processing can be disastrous to the quality of the finished product. Biochemical studies are in progress to explain these phenomena. They will be continued with the aim of characterizing the transformation of a hydrated semolina into pasta. This should result in a better understanding of pasta-forming mechanisms.

3. Reduce the number of pre-die and filter plates to achieve a better mass-flow control. Only minimal pressure is needed to create a back pressure that will generate a movement of the product inside the thread of the screw, resulting in the formation of pasta. Too high a pressure results in more recirculation of the dough and heating of the product.

A precise knowledge of rheological behavior of dough when hydration, temperature, and shearing rate are varied appears essential for optimizing dough-forming conditions for pasta extrusion. This research could also be useful in designing a better screw profile. It would be possible, therefore, to construct new higher performing pasta presses that would better control the mass flow of the product during extrusion through the die and would assure consumers the best quality of pasta.

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