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Procedia Food Science 1 (2011) 557 – 562

Procedia Food Science

11th International Congress on Engineering and Food (ICEF11)

Effect of die material on engineering properties of dried pasta

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Abstract

Extruding wheat semolina dough through a Teflon die allows to process pasta with a smooth and even surface, whereas bronze die can be used to obtain a product with a rough texture. Little is known about the impact of the die material on pasta properties other than surface characteristics. Knowledge of pasta properties would be relevant to better understand pasta digestibility. The aim of this work was to analyse the impact of the die material on engineering properties of dried pasta. Pasta were processed with fine semolina using a pasta extruder equipped with a 2.5 mm Teflon or bronze die. They were dried inside an environmental chamber under a controlled atmosphere at 40°C or 80°C for 20 hours. Pasta shrinkage, porosity and effective moisture diffusivity were measured. Scanning electron microscopy (SEM) was performed to characterize the external structure of pasta. Results showed that extrusion with a bronze die induces the production of more porous and less dense pasta, but does not have an impact on pasta shrinkage and volumetric percentage of water lost replaced by air during drying. Effective moisture diffusivity coefficients were higher for pasta extruded with a bronze die compared to a Teflon die for both drying temperatures studied, which indicates that the use of a bronze die could induce a diminution of the drying time. SEM observations at 50X and 500X clearly showed that pasta microstructure was affected by processing conditions. These results highlight the importance of food processing and their impact on the microstructure and characteristics of food matrices. Since pasta can be regarded as a good matrix for the incorporation of bioactive compounds beneficial to health and well-being, further studies are needed to better understand how processing would affect pasta digestibility and the release of bioactive compounds in terms of bioaccessibility into the gastro-intestinal tract.

Keywords: Pasta drying, porosity, shrinkage, effective moisture diffusivity, engineering properties, bronze die

1. Introduction

In order to produce cylindrically shaped pasta, dough is pressed through the die of an extruder to process it in the desired shape prior to the drying step. It is well known that the material of the die can

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doi:10.1016/j.profoo.2011.09.084

deeply impact the surface properties of pasta. Teflon die leads to pasta with smooth and even surface with a bright-yellow appearance, whereas bronze die can be used to obtain pasta with a rough texture. The die material can also influence physical properties of pasta other than surface characteristics, bronze die leading to the production of more porous pasta with lower breaking strength [1]. While some studies have been performed to characterize structural properties [2-4] and drying kinetics [5-9] of pasta extruded with a Teflon die, little is known about the impact of other die materials on pasta properties other than surface characteristics. Knowledge of pasta properties would be relevant to better understand pasta digestibility. Therefore, the aim of this work was to analyse the impact of the die material on engineering properties of dried pasta.

2. Materials & Methods

2.1. Raw Materials

Roller-milled durum wheat semolina was purchased from Horizon Milling (Montreal, QC, Canada). Total protein content of semolina (N x 5.7) was determined using an FP-428 LECO apparatus (LECO corp., Saint Joseph, MI, USA). The instrument was calibrated with EDTA as nitrogen standard. Fineness of semolina was determined by sieving and expressed according to ANSI/ASAE method S319.4.

2.2. Pasta Processing

To process pasta, durum wheat semolina was hydrated to 49.3 g-water 100g-dry matter-1 in a stand mixer (Model Professional 600, Kitchenaid, St. Joseph, MI, USA) under constant agitation with a flat beater for 15 min. The mixture was transferred to a pasta extruder (Dymasters Pasta Dies & Extruder, Port Coquitlam, BC, Canada) equipped with a metallic pre-die (1.9 mm-sieve openings) and a Teflon or Bronze die (2.5 mm). During extrusion, vacuum pressure was applied (about 78 kPa) to prevent air bubble formation and temperature was controlled at 50°C with water circulating in a double-jacket chamber. Drying was performed in an environmental chamber (Model RTH-16P-2, Burnsco Technologies Inc., Kanata, ON, Canada) with fresh pasta deposited on metallic rods. Air velocity inside the chamber was between 1 and 2 m s-1. Two 20 hours drying profiles were used; one at constant low temperature (40°C) and one at constant high temperature (80°C). Relative humidity was kept at 65% for both drying profiles. Two batches of 1.5 kg of pasta were processed for each die material (Teflon and Bronze) and drying temperature.

2.3. Fresh and dried pasta properties measurements

Initial and final moisture contents of pasta were determined according to AOAC Method 925.09 by drying samples overnight in a vacuum oven at 92°C. During drying, pasta weight was measured online every minute with a 5-kg load cell (National Scale Technology, Huntville, AL, USA) connected to a data acquisition system (Model TI 500E, Transcell Technology, Buffalo Grove, IL, USA). Effective moisture diffusivity (D_{eff}) was determined with R considered as pasta initial radius according to a method previously developed [9]. Fresh and dried pasta dimensions (length and diameter) were measured using a digital caliper (Model 62379-531, Control Co. Friendswood, TX, USA). Measurements were conducted on 10 strands of pasta. Apparent density was calculated from the measured dimensions and the mass of pasta under the hypothesis of cylindrically shaped pasta. The volumetric shrinkage that occurred between the initial and final stage of pasta drying, the porosity and the fraction of water lost during drying replaced by air (η) were calculated according to a method previously developed [10].

2.4. Scanning Electron Microscopy

Scanning electron microscopy was performed using an LEO surface scanning electron microscope (Model S-3000N, Hitachi High Technologies America, Inc., Pleasanton, CA, USA) under depressurised condition (10-4 Pa). A 20 kV potential was applied during visualisation. Samples to be analysed were mounted on aluminium stubs using double-sided adhesive tapes. They were coated with gold using a sputter coater (Model 108, Cressington Scientific Instruments Ltd, Watford, UK) until a thickness of about 15 nm was obtained, as measured by a thickness monitor (Model 10MTM, Cressington Scientific Instruments Ltd, Watford, UK).

2.5. Statistical Analysis

Analysis of variance was performed a priori on each parameter using SAS software (version 8.2, SAS Institute Inc. Cary, NC, USA). Multiple comparison procedures (Least Significant Difference, P = 0.05) were performed a posteriori to compare parameters whose variance was significantly different.

3. Results & Discussion

Protein content of semolina is 16.0 ± 0.2 g-protein 100 g-dry matter^{-1}. Semolina can be considered as fine since 99.9% of particles are smaller than 425 μm and 45.2% of particles, smaller than 250 μm. The geometric mean diameter of particles by mass is 282 μm with a geometric standard deviation of particle diameter by mass of 109 μm.

Fresh pasta properties are presented in Table 1. Pasta extruded with bronze die had higher water content and larger diameter than pasta extruded with Teflon die. Since 2.5 mm dies were used, bronze die pasta expanded more than Teflon die pasta after extrusion. These results indicate that die materials would lead to different matrix structures. Moreover, no significant difference was observed for apparent density and porosity of both die materials. After extrusion, pasta are not porous, void space being filled with water.

Table 1. Properties of fresh pasta extruded with a Teflon die or a bronze die at 50°C*

Parameters	Teflon die	Bronze die
Moisture (g-water 100g-dry matter^{-1})	45.7 ± 1.1b	47.9 ± 0.7a
Diameter (mm)	2.64 ± 0.02b	2.80 ± 0.20a
Apparent density (g cm^{-3})	1.305 ± 0.010a	1.228 ± 0.064a
Porosity (-)	0.00 ± 0.01a	0.05 ± 0.05a

* Values not sharing a common letter on the same line are significantly different (P < 0.05)

Dried pasta properties are presented in Table 2. Extruding dough with a bronze die induced the production of more porous pasta compared to a Teflon die, which is similar to the results previously reported [1]. The higher porosity is probably the consequence of the rough surface of the pasta, resulting in an increase in diameter and a decrease in apparent density. This could be explained by a higher volumetric fraction of air is present in the matrix of pasta extruded with a bronze die, which might explain the lower breaking strength that has been associated to these pasta [1], similarly to what is observed with fresh apples [11], potatoes [12] or extruded starch [13]. In term of temperature, drying at 80°C induced the production of denser pasta with smaller diameter and less porosity, similarly to what was reported in previous work [10].

The material of the die had little impact on pasta shrinkage compared to drying temperature. As previously observed [10], shrinkage was more important at high temperature, which might be because glass transition would occur at lower moisture content for higher drying temperature [14]. Taking the average of the four operating conditions, longitudinal shrinkage contributed to 32 ± 5 % of total volumetric pasta shrinkage. The volumetric fraction of water lost during drying replaced by air within the pasta matrix was between 0.06 and 0.28 for every operating conditions studied, indicating the presence of shrinkage ($\eta < 1$), but the absence of collapse ($\eta > 0$) in the structure of the matrix during the drying process.

The extrusion through a bronze die induced an increase in effective moisture diffusivity for both drying temperature compared to a Teflon die, while equilibrium moisture content was not affected. This might be the result of the higher porosity of pasta extruded with the bronze die. Indeed, porosity has been observed to be positively correlated to effective moisture diffusivity for the drying of cylindrically shaped pasta made from durum wheat semolina [8]. Thus, pasta extruded with a bronze die might need shorter drying time than pasta extruded with a Teflon die to reach target moisture content. For instance, from the measured effective moisture diffusivity and equilibrium moisture content and using the model derived from Fick's law and previously developed [5], the time required to dry a 2.5 mm pasta from 50.0 to 20.0 g-water 100g-dry matter^{-1} at 80°C would be 97 ± 2 min for a Teflon die extrusion and 71 ± 2 min for a bronze die extrusion. As previously observed [5; 9], drying at high temperature induced increase in effective moisture diffusivity and decrease in equilibrium moisture content.

Table 2. Properties of pasta extruded with Teflon die or bronze die and dried at 40°C or 80°C*

Parameters	**Teflon die**		**Bronze die**	
	40°C	**80°C**	**40°C**	**80°C**
D_{eff} (cm^2 s^{-1})	4.3 ± 0.1 x 10^{-7}d	7.2 ± 0.0 x 10^{-7}b	5.8 ± 0.2 x 10^{-7}c	7.7 ± 0.3 x 10^{-7}a
M_E (g-water 100g-dry matter^{-1})	14.8 ± 1.2a	8.5 ± 1.8c	13.0 ± 1.0ab	9.1 ± 0.8bc
Diameter (mm)	2.44 ± 0.01c	2.34 ± 0.01d	2.60 ± 0.01a	2.49 ± 0.02b
Apparent density (g cm^{-3})	1.275 ± 0.001a	1.366 ± 0.005a	1.176 ± 0.054b	1.324 ± 0.013a
Porosity (-)	0.108 ± 0.005b	0.056 ± 0.006b	0.175 ± 0.034a	0.082 ± 0.012b
η (-)	0.277 ± 0.035a	0.153 ± 0.007a	0.265 ± 0.064a	0.055 ± 0.177a
Shrinkage				
Radial (-)	0.083 ± 0.002b	0.111 ± 0.007a	0.070 ± 0.003b	0.111 ± 0.004a
Longitudinal (-)	0.108 ± 0.002b	0.056 ± 0.010b	0.175 ± 0.007a	0.082 ± 0.030b
Total (-)	0.208 ± 0.010b	0.279 ± 0.002a	0.197 ± 0.000b	0.290 ± 0.035a

Where *Deff* is the effective moisture diffusivity coefficient; M_E is the equilibrium moisture content and η is the volumetric fraction of water lost replaced by air.

* Values not sharing a common letter on the same line are significantly different ($P < 0.05$)

Scanning electron microscopy analyses were performed to visualise the impact of die material and drying temperature on pasta microstructure. Images showed that pasta microstructure, which is composed of starch embedded in a protein network, is indeed affected by the material of the die (Figure 1). The surface of pasta extruded with a bronze die seemed more loose and porous than the surface of pasta extruded with a Teflon die for both drying temperature, which is in accordance with the higher porosity and lower density measured. Much more cracks were visible at the surface of pasta extruded with a bronze die, which probably contributes to the lower breaking strength. Drying temperatures also seemed to impact pasta microstructure. The gluten network seemed more rigid and compact at high drying temperature, similarly to what was already observed [4]. High temperature might promote protein denaturation and cross-linking of the two gluten proteins, glutenin and gliadin, resulting in a denser network [4; 15].

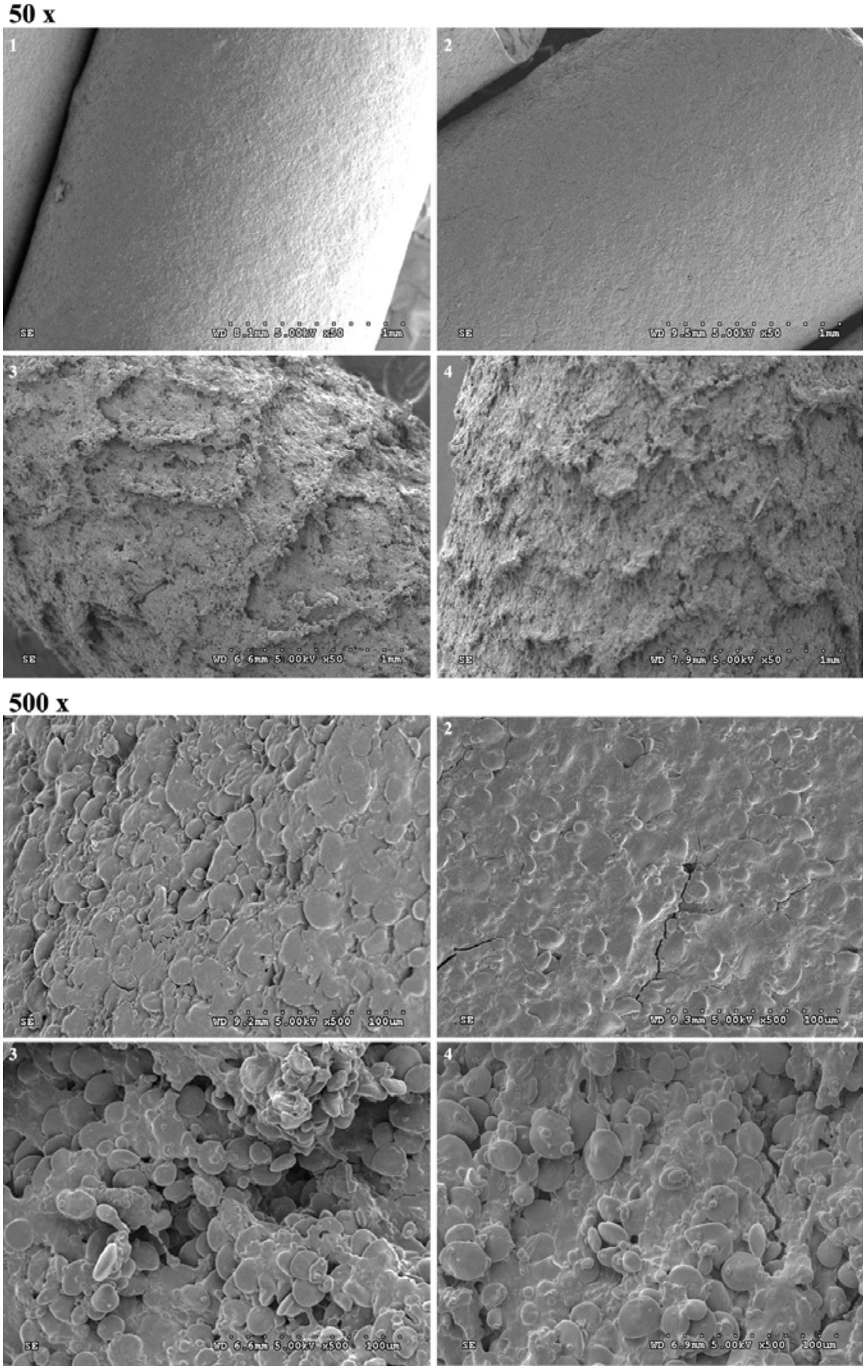

Fig. 1. Scanning electron microscopy at 50X and 500X of the surface of pasta extruded with a Teflon die and dried at 40°C (1) or 80°C (2) and, with a bronze die and dried at 40°C (3) or 80°C (4).

4. Conclusion

These results highlight the importance of food processing and their impact on the microstructure and characteristics of food matrices. Since pasta can be regarded as a good matrix for the incorporation of bioactive compounds beneficial to health and well-being, further studies are needed to better understand how processing would affect pasta digestibility and the release of bioactive compounds in terms of bioaccessibility into the gastro-intestinal tract.

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Presented at ICEF11 (May 22-26, 2011 – Athens, Greece) as paper EPF144.