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Evolution of porosity, shrinkage and density of pasta fortified with pea protein concentrate during drying

Samuel Mercier, Sébastien Villeneuve*, Martin Mondor, Louis-Philippe Des Marchais

Agriculture and Agri-Food Canada, Food Research and Development Centre, 3600 Casavant Blvd West, Saint-Hyacinthe, Quebec, Canada J2S 8E3

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ABSTRACT

The aim of this work was to study the impact of fortification with commercial pea protein concentrate on the evolution of the moisture content, density, shrinkage and porosity of pasta made from durum wheat semolina during drying. Pasta were processed from durum wheat semolina enriched with pea protein concentrate at 0, 5, 10 and 15 g 100-g-dry matter^{-1} and dried at low (40 °C) and high (80 °C) temperature. Moisture content, density, shrinkage and porosity and effective moisture diffusivity coefficients were linked through theoretical development. It enabled to study the behaviour of the properties as a function of drying time. The results showed that drying temperature has a greater effect on the studied properties than enrichment with pea protein concentrate. Drying at 80 °C increased radial and total shrinkage compared to drying at 40 °C, but no differences were observed for longitudinal shrinkage. Pasta dried at 80 °C were denser and overall less porous, but had greater internal porosity. The volumetric percentage of water lost during drying replaced by air within the pasta matrix was lower at 80 °C. Scanning electron microscopy analysis showed that the gluten network of pasta dried at 80 °C seems denser and more continuous. Effective moisture diffusivity coefficients of pasta dried at 80 °C were higher at 5 and 10 g 100-g-dry matter^{-1} enrichment level compared to the control.

1. Introduction

Over the last few years, many studies have been made on the production of protein-fortified pasta. Fortification compensates pasta deficiency in lysine and threonine, two essential amino acids (Abdel-Aal & Hucl, 2002; Kies & Fox, 1970). In most of these studies, pasta were produced from durum wheat semolina supplemented with protein-enriched flour (Bahnassey, Khan, & Harrold, 1986; Gallegos-Infante et al., 2010; Petitot, Boyer, Minier, & Micard, 2010; Sabanis, Makri, & Doxastakis, 2006; Shogren, Hareland, & Wu, 2006; Torres, Frias, Granito, Guerra, & Vidal-Valverde, 2007; Wood, 2009; Zhao, Manthey, Chang, Hou, & Yuan, 2005), concentrate (Nielsen, Sumner, & Whalley, 1980; Yanez-Farias, Bernal-Aguilar, Ramirez-Rodriguez, & Barron-Hoyos, 1999) or isolate (Alireza Sadeghi & Bhagya, 2008). It was observed that fortification affects pasta quality, namely in terms of texture (Nielsen et al., 1980), color (Gallegos-Infante et al., 2010), cooking quality (Zhao et al., 2005) and organoleptic properties (Alireza Sadeghi & Bhagya, 2008). However, only a few works were carried out to assess the impact of fortification on pasta making process. For example, Wood (2009) and Petitot et al. (2010) reported that high fortification level with chickpea, split pea and faba bean flour results in higher aggregation of particles, which renders the extrusion step difficult.

Drying plays the most critical role in pasta production. It deeply impacts the final characteristics of the product, mainly in terms of appearance and cooking behaviour (Owens, 2001). During drying, simultaneous heat and mass transfer occurs, causing the material to dehydrate. Those transport phenomena are highly linked to material properties like moisture content, density, shrinkage and porosity (Luikov, 1975; Martynenko, 2008). Thus, real-time evaluation of these properties is crucial to the design and optimisation of pasta drying.

Therefore, the aim of this work was to study the impact of fortification with commercial pea protein concentrate (CPPC) on the evolution of the moisture content, density, shrinkage and porosity of pasta made from durum wheat semolina during drying. CPPC was selected for this study because legumes and cereals complement each other amino acids deficiencies (Sánchez-Lozano & Martínez-Llorens, 2009). To achieve that, a system of equations linking the four aforementioned parameters was derived from Martynenko (2008).

* Corresponding author. Tel.: +1 450 768 3335; fax: +1 450 773 8461.
E-mail address: sebastien.villeneuve@agr.gc.ca (S. Villeneuve).

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Nomenclature

D_{eff}	pasta effective moisture diffusivity, $m^2\ s^{-1}$
m	mass, kg
L	pasta length, m
M	moisture content, kg H_20 kg dry matter^{-1}
P	pressure, Pa
r	radius coordinate, m
R	pasta radius, m
T	temperature, °C
t	drying time, s
V	volume, m^3
Greek symbols	
β_n	Bessel function characteristic roots of the first kind, (−)
ϵ	porosity, m^3 void m^{-3} total (−)
η	volumetric fraction of water lost replaced by air, (−)
ρ	density, kg m^{-3}
χ	shrinkage, $\Delta m^3\ m^{-3}$ initial or $\Delta m\ m^{-1}$initial (−)
τ	dry weight ratio of semolina to pea protein concentrate, (−)
Subscripts	
0	initial conditions
1	first
2	second
app	apparent
E	equilibrium
ext	external
int	internal
L	longitudinal
p	particle
PPC	pea protein concentrate
R	radial
sem	semolina
s	dry solid
T	total
w	water

2. Theoretical considerations

2.1. Moisture content as a function of drying time

Model proposed by Andrieu and Stamatopoulos (1986) and Villeneuve and Gélinas (2007) was used. The following assumptions were made: (1) as previous authors and for the needs of this study, pasta drying is described by a Fick's type law, although it may not be fully accurate due to non-Fickian behaviour near glass transition (2) pasta is modeled as an infinite cylinder; (3) mass transfer only occurs in the radial direction; (4) heat transfer is faster than mass transfer, thus allowing to consider drying as isothermal; (5) change in pasta radius during the process does not have a significant impact on mass transfer. Considering these assumptions, Fick's law can be used to express pasta water content during drying as follows:

$$\frac{\partial M}{\partial t} = D_{eff}\left(\frac{\partial^2 M}{\partial r^2} + \frac{1}{r}\frac{\partial M}{\partial r}\right) \quad (1)$$

The following boundary conditions were used:
at $t = 0$, $M = M_0$ for $0 < r < R$,
at $t > 0$, $M = M_E$ for $r = R$,
at $t > 0$, $\partial M/\partial t = 0$ for $r = 0$
The solution of Eq. (1) under these boundary conditions is:

$$\frac{M - M_E}{M_0 - M_E} = \sum_{n=1}^{\infty}\frac{4}{\beta_n^2}\exp\left(-\frac{\beta_n^2 D_{eff} t}{R^2}\right) \quad (2)$$

This solution enables to describe pasta moisture content as a function of drying time when knowing pasta effective moisture diffusivity, dimensions and equilibrium moisture content.

2.2. Shrinkage as a function of drying time

Volumetric shrinkage (χ_T) is here defined as the ratio of apparent volume lost to initial apparent volume:

$$\chi_T = \frac{V_{app0} - V_{app}}{V_{app0}} \quad (3)$$

As described by Khalloufi, Almeida-Rivera, and Bongers (2009), shrinkage occurs during drying when the water removed from the pasta is not totally replaced by air. The air present in the pasta matrix at the beginning of the drying process can also be reduced or disappear, leading to a collapse phenomenon (Fig. 1). Mathematically, these phenomena can be described introducing a dimensionless parameter defined as follow:

$$\eta = 1 - \frac{V_{app0} - V_{app}}{V_{w0} - V_w} \quad (\text{for } t > 0) \quad (4)$$

This parameter ultimately represents the volumetric fraction of water lost during drying that has been replaced by air within the pasta matrix and gives an indication of the occurring phenomena (value >1 indicates swelling; ≈ 1 indicates the absence of shrinkage; ≈ 0 indicates total shrinkage;<0 indicates collapse).

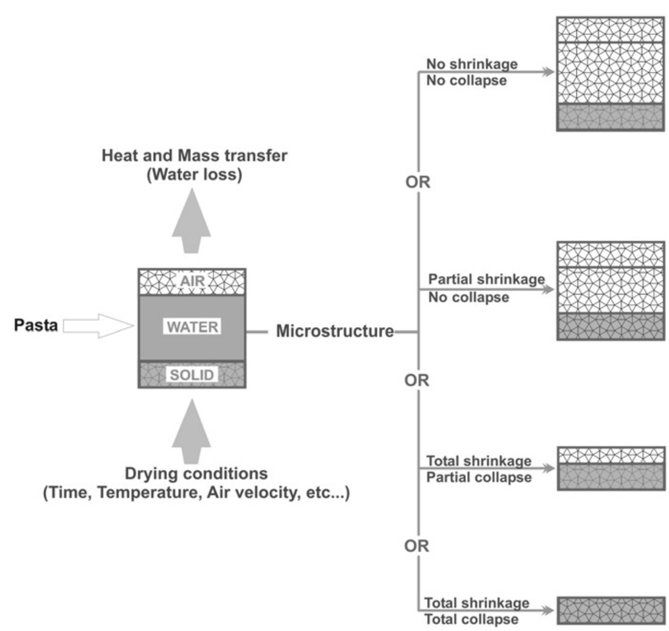

Fig. 1. Schematic representation of the shrinkage and collapse phenomena during pasta drying process.