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Effect of extrusion conditions on the structural properties of corn extrudates enriched with dehydrated vegetables

G.I. Bisharat [a], V.P. Oikonomopoulou [b,*], N.M. Panagiotou [b], M.K. Krokida [b], Z.B. Maroulis [b]

[a] Department of Chemical Engineering, Al-Hussein Bin Talal University, Maan, Jordan
[b] School of Chemical Engineering, National Technical University of Athens, Zografou Campus, 9 Iroon Polytechneiou, Athens 15780, Greece

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ABSTRACT

The present study examines the addition of dehydrated broccoli or olive paste to corn flour for the production of extrudates with increased value and superior quality. Extrudates were prepared using a twin-screw extruder, operated at different conditions, including screw speed (150 rpm, 200 rpm, 250 rpm) and extrusion temperature (140 °C, 160 °C, 180 °C). The moisture content of the raw mixture was regulated in three levels (14%, 16.5%, 19%), whereas the concentration of the added ingredient was adjusted to 4%, 7% and 10% for broccoli and to 4%, 6% and 8% for olive paste. Structural properties and rehydration were investigated with regard to process conditions and material characteristics. Mathematical models were also used to correlate structural properties with process parameters. Regression analysis showed that the increment of moisture content and broccoli or olive paste concentration, as well as the decrement of temperature and screw speed resulted in denser extrudates with lower porosity. Products with 14% moisture content and 4% material concentration that were extruded at the highest screw speeds (250 rpm) presented the highest degree of expansion. These conclusions were strengthened with the results obtained from mercury porosimetry and scanning electron microscopy. In addition, moisture diffusion coefficient was calculated from the rehydration kinetics and was correlated with process parameters. Diffusion coefficient decreased with moisture content and material concentration, while it increased with temperature and screw speed, indicating positive relationship with extrudates' porosity.

1. Introduction

The current way of life, which is characterized by limited free time and increased working hours, has turned consumers to the consumption of ready-to-eat products. In addition, children, worldwide, are attracted to several snack products which are particularly tasty and easy to be consumed. Therefore, food industries have increased the production of ready-to-eat products using several processes. Among these processes, extrusion is a high temperature-short time, well-established industrial technology, which is characterized by continuous cooking, mixing and forming processing and produces direct expanded materials with high quality (Ding, Ainsworth, Plunkett, Tucker, & Marson, 2006). Extrusion is flexible in the production of new products, such as cereal baby foods, breakfast cereals, snack foods, bakery products, pastas, etc. During extrusion food materials are thermo-mechanically cooked in a screw-barrel assembly by a combination of moisture, pressure and temperature in order to be mechanically sheared and shaped (Rodriguez-Miranda et al., 2011) and they undergo many chemical and structural transformations. Final products' quality depends on the process conditions, such as the extruder type, the feed moisture, the temperature profile in the barrel sections, the screw speed and the feed rate (Thymi, Krokida, Pappa, & Maroulis, 2005).

Additionally, nowadays, there is an increasing trend for the consumption of high-value food products. Consumers have increased interest to the Mediterranean diet and the consumption of fruits, vegetables and other functional foods. High consumption of fruits and vegetables is associated with reduced risks of cardiovascular disease and protection against many cancers (Kolonel et al., 2000; Satia, Kristal, Patterson, Neuhouser, & Trudeau, 2002; Steinmetz & Potter, 1996); therefore, it has been recommended by the dietary guidelines of many countries. Moreover, the low intake of fruits and vegetables has as a consequence the increment of childhood obesity (Olsen, Ritz, Kraaij, & Moller, 2012). As a result, many intervention studies have been designed in order to incorporate fruit and vegetable consumption in children's diet (Knai, Pomerleau, Lock, & McKee, 2006).

In order to combine the need for the production of ready-to-eat products with the need for the consumption of high-value products, beneficial ingredients are added to the extruded mixtures. These ingredients include legumes, beans, peas, tomato lycopene, apple pomace, herbs, cactus pear, grape seed, grape pomace etc. (Anton, Gary Fulcher, & Arntfield, 2009; Dehghan-Shoar, Hardacre, & Brennan, 2010; Grochowicz & Sobczak, 2007; Karkle, Alavi, & Dogan, 2012;

Abbreviations: SEM, scanning electron microscopy; CCD, central composite design.

* Corresponding author. Tel.: +30 2107723149.
E-mail addresses: Gibish@ahu.edu.jo (G.I. Bisharat), vasiaoik@central.ntua.gr (V.P. Oikonomopoulou), nickpan@central.ntua.gr (N.M. Panagiotou), mkrok@central.ntua.gr (M.K. Krokida), maroulis@mail.ntua.gr (Z.B. Maroulis).

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Khanal, Howard, & Prior, 2009; Pastor-Cavada et al., 2011; Sarkar, Setia, & Choudhury, 2011; Singh, Sekhon, & Singh, 2007).

The present study examines the production of corn extrudates enriched with olive paste and broccoli, two products that are part of the Mediterranean diet and have significant health benefits. Olive paste products are composed of lipids, fibers, proteins, carbohydrates, etc. and they have key pharmacological activities, such as antioxidant, cardioprotective, neuroprotective, anticancer, immune activities, obesity suppression, gastrointestinal diseases, liver disease activities, etc. (Hoefel et al., 2011; Zeb & Murkovic, 2011). Broccoli is one of the major agricultural products that contain many beneficial ingredients, such as proteins, fibers, fats, carbohydrates, high amounts of vitamins (C, E), phytochemicals (glucosinolates, phenolic compounds, carotenoids), metals and antioxidants. These substances have strong antioxidant and anticancerous properties, as well as they have been responsible for possessing protective properties against various chronic diseases (Radojcic Redovnikovic et al., 2012; Singh, Chaturvedi, Walia, Kaushik, & Thakur, 2011). Olive paste and broccoli must be initially dehydrated in order to be mixed with the flours. Among the drying methods that are used in food processing industries, freeze drying is considered one of the most advanced methods for drying high-value products sensitive to heat. Freeze drying produces materials with unchanged nutrition quality, superior taste, aroma, flavors and color, as well as good rehydration properties (Krokida, Karathanos, & Maroulis, 1998).

The consumer acceptability of the produced extrudates depends on many quality attributes, such as appearance, structure, texture, taste, color and flavor. Among them, structural properties are of major importance, since they characterize the texture and quality of expanded products by controlling their taste and appearance, as well as they are indexes of the extent of puffing (Hagenimana, Ding, & Fang, 2006). Porous formation in foods during processing affects a wide variety of other properties, such as physicochemical properties (specific surface area, pore size distribution, etc.) and transport properties (diffusion coefficient, mass diffusion, thermal conductivity, etc.) (Maroulis, Saravacos, Panagiotou, & Krokida, 2001; Rahman, 2001). The degree of expansion is another important parameter which describes product quality and is directly related to the degree of roasting. Expansion is desirable for successful product development and is also associated with other important properties, such as crispness, water absorption, etc. (Chen & Yeh, 2001; Chinnaswamy & Hanna, 1988; Jyothi, Sheriff, & Sajeev, 2009; Rodriguez-Miranda et al., 2011; Singh et al., 2007). High expansion index and low apparent density are the desirable properties of ready-to-eat extruded snacks, which depend on many parameters, such as feed moisture, feed rate, extrusion temperature, die diameter, and screw speed (Ali, Hanna, & Chinnaswamy, 1996).

The extrusion cooking is a widely studied process, however, the addition of highly nutrient ingredients on the extrudates, has not been extensively examined. In addition, the determination of the effect of process conditions on extruded snacks' properties is based on generalized models. As a result, the innovative aspect of the present study was the investigation of the effect of process conditions and material characteristics on structural properties and moisture diffusivity of extruded corn snacks enriched with either broccoli powder or olive paste powder. Simple mathematical models were also applied in order to predict structural properties from process parameters. Finally, moisture diffusion was correlated with porous structure.

2. Materials and methods

2.1. Material preparation

Corn flour was provided by Marra Bros Mills S.A. (Korinthos, Greece), olive paste was donated by Minerva S.A., while broccolis were purchased from the local market. Broccoli and olive paste were washed and frozen at −30 °C for 72 h. The materials were then dehydrated in a laboratory freeze dryer (Leybold-Heraeus GT 2A, Koln, Germany) for two days. The dried materials were ground to powder, sealed in polyethylene bags and stored at refrigerator until further use. Their moisture content was determined using the oven method at 70 °C under vacuum (AOAC, 1990), until constant weight. For mixtures' preparation, corn flour and broccoli powder were mixed in three different ratios, ranging from 4 to 10% (4%, 7% and 10% broccoli percentage), while corn flour and olive paste powder were mixed in ratios ranging from 4 to 8% (4%, 6% and 8% olive paste percentage). The moisture content of the samples was regulated in three different levels: 14%, 16.5% and 19%, by spraying with a calculated amount of distilled water. The moisture distribution was made uniform by continuously mixing the ingredients with a laboratory mixer. The mixtures were then stored in plastic bags for 24 h in order to equilibrate and then their moisture content was determined. If the determined moisture content was not the desired, certain amounts of either distilled water or materials were added for correction.

2.2. Extrusion cooking

Extrusion was performed in a co-rotating twin screw extruder (Prism Eurolab, model KX-16HC, Staffordshire, UK), consisting of five independent temperature control zones. The materials were fed into the extruder at a constant feed rate (3.5 kg/h) using a volumetric feeder. The screws had 40 cm length, 16 mm external diameter, 11 mm internal diameter and their maximum rotation speed was 500 rpm. The number of flights on either screw was 2. The die had a 3 mm diameter and 17.5 mm length. The barrel and screw die temperature, as well as the screw speed were displayed on the control panel. Extrudates were produced in three extrusion temperatures (140 °C, 160 °C and 180 °C) and three levels of screw speed (150 rpm, 200 rpm and 250 rpm). Table 1 presents in details the applied process parameters. The extrudates were cooled to room temperature and stored in laminated bags until required for analysis.

Table 1
Process conditions and material characteristics.

Material	Moisture content X (% w.b.)			Material concentration C (%)			Extrusion temperature T (°C)			Screw speed N (rpm)		
Corn/broccoli powder	14	16.5	19	4	7	10	140	160	180	150	200	250
Corn/olive paste powder	14	16.5	19	4	6	8	140	160	180	150	200	250

Material	Reference conditions					
	X_o (% w.b.)	C_o (%)	T_o (°C)	N_o (rpm)	ρ_o[a] (kg/m^3)[a]	Exp_o[a]
Corn/broccoli powder	16.5	7	160	200	183.200	2.584
Corn/olive paste powder	16.5	6	160	200	431.035	1.990

[a] Mean values of apparent density and expansion ratio.