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# Carrot pomace enhances the expansion and nutritional quality of corn starch extrudates

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A B S T R A C T

Corn starch was extruded with the inclusion of carrot pomace at levels of 5, 10, and 15 g/100 g at three different feed moisture levels of 15, 22.5 and 30 g/100 g. Corn starch without any added pomace was extruded as a control treatment. A thorough evaluation of the extrudate properties (expansion ratio, unit density, water solubility index, water absorption index, microstructure, and β-carotene content) was conducted to understand the role of the insoluble fiber in the carrot pomace on the extrusion process, specifically relating to expansion. The best expansion was observed in the extrudates with 5 g/100 g carrot pomace inclusion, and at 15 g/100 g feed moisture. The surface of this extrudate also improved, compared to the control and extrudates with higher levels of pomace inclusion. The extrudates with higher levels of carrot pomace showed a significant decrease in expansion. Overall, the results showed that the level of carrot pomace inclusion had significant impact on the extrudate quality.



## 1. Introduction

Carrot pomace is a byproduct obtained from carrot juice processing. The juice industry produces significant amounts of carrot pomace. It is estimated that in the United States (US) over 125,000 tons of pomace per year is produced (Sonja, Jasna, & Gordana, 2009). Carrot pomace is generally used as animal feed, which is a low value outlet for the pomace (Yoon, Cha, Shin, & Kim, 2005), even though it contains a high amount of beneficial nutrients, including bioactive compounds with antioxidant properties (Chantaro, Devahastin, & Chiewchan, 2008).

Dried carrot pomace has β-carotene and ascorbic acid in the range of 9.9–11.6 mg and 13.5–23.0 mg per 100 g, respectively (Dar, Sharma, & Kumar, 2014). Typical composition of partially dried carrot pomace is 9.1–10.8 g/100 g water, 1.4–7.7 g/100 g ash, 6.7–8.4 g/100 g protein, 1.1–2.1 g/100 g fat, 19.3–25.0 g/100 g total carbohydrates, and 55.7–63.5 g/100 g total dietary fiber (Chau, Chen, & Lee, 2004; Kohajdová, Karovičová, & Jurasová, 2012). A majority of the total dietary fiber is insoluble dietary fiber. Insoluble dietary fibers are reported to have a beneficial impact on human health, such as reducing the risk of coronary heart disease, colon cancer, obesity, high blood pressure and stroke (Chau et al., 2004). Insoluble fiber isolated from carrot pomace, has also been found to have very pronounced hypocholesterolemic and hypolipidemic effects (Hsu, Chien, Chen, & Chau, 2006).

Pomace, as a whole, has the potential to be used as a food ingredient because of its composition (Sonja et al., 2009). Dry pomace can be incorporated into various food products as a source of dietary fiber and other bioactive compounds. One alternative method for utilization of this byproduct into useful food products, is extrusion. Extrusion technology has become more popular due to its versatility, high productivity, and relative low cost. Extrusion can be used to produce direct-expanded snack foods, cereals, and pet foods. Extruded products are typically made by subjecting a raw material, often flour, to high temperatures while also creating a high shear and high pressure environment using rotating screws (Ganjyal, Hanna, & Jones, 2003).

Many types of starches are used in extrusion processing including corn (*Zea mays* L.), wheat (*Triticum aestivum* L.), and rice (*Oryza sativa* L.) (Dehghan-Shoar, Hardacre, & Brennan, 2010; Robin, Dubois, Curti, Schuchmann, & Palzer, 2011; Singkhornart, Edou-ondo, & Ryu, 2014). The starch in extrusion cooking is

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gelatinized and dextrinized using a combination of temperature, moisture, shear, and pressure before being pushed through a die. Upon exiting the die, the pressure and temperature of the product equilibrate with the surrounding environment, causing rapid structural expansion as the water in the product vaporizes (Alvarez-Martinez, Kondury, & Harper, 1988). Products are often dried further and may undergo other post-extrusion processing to create a crunchy snack or cereal product (Moscicki, 2011).

In the past few years, efforts have been made to incorporate more fiber into extruded food products by adding fiber directly to starch (Ganjyal, Reddy, Yang, & Hanna, 2004). Fiber typically reduces expansion by rupturing cell structure (Camire & King, 1991) and acts as a filler material in extruded products. More recent studies have shown that it is possible to incorporate fiber into extruded products at levels below 5 g/100 g with no significant effects on product eating quality. Fiber can also act as a nucleating agent and support cell growth (Bénézet, Stanojlovic-Davidovic, Bergeret, Ferry, & Crespy, 2012). Inclusion of fiber at low levels does not hinder structure development, but higher inclusion levels tend to result in fiber aggregation and rupture the cell walls (Ganjyal et al., 2004). The fiber has been thought to act as an inert material as it does not go through any physicochemical changes due to heat and mechanical energy inputs (Camire & King, 1991).

There have been many reported studies on the incorporation of pomace from fruit and vegetable into extruded products as summarized in Table 1 (Altan, McCarthy, & Maskan, 2008a, 2008b; Khanal, Howard, Brownmiller, & Prior, 2009; Selani et al., 2014; Upadhyay, Sharma, & Sarkar, 2010; White, Howard, & Prior, 2010). Beyond incorporation levels of 5–10 g/100 g, there are negative effects on the quality. Kumar, Sarkar, and Sharma (2010) reported the utilization of carrot pomace as a source of insoluble fiber in extruded rice flour products. They reported that carrot pomace proportion significantly influenced expansion ratio. The compromised optimum condition for product acceptability and maximum expansion obtained for the development of rice flour extrudates was at a level of 11.75 g/100 g carrot pomace.

In the making of direct expanded products with pomace, the physicochemical properties of both the starch and the pomace fiber play a significant role. Along with the physicochemical properties, physical and chemical interactions between the starch and pomace fiber may have impacts on the attributes of the extruded product. Our objective was evidence the existence (or not) of an active role for the fiber from carrot pomace in the extrusion expansion process. For that, carrot pomace was incorporated at different levels and with different hydration ratios into corn starch during extrusion and the physicochemical and micrographic properties of corn starch extrudates were examined.

## 2. Materials and methods

### 2.1. Materials

Native corn starch (23 g amylose/100 g dry starch) was obtained from Tate and Lyle Company (Decatur, IL, USA). Carrot pomace was from Bolthouse Farms Company (Bakersfield, CA, USA) and dried in a convection oven at 60 °C (Model # 414004-568, VWR International, LLC, PA, USA). The pomace was dried to a final moisture content of 3.15 ± 0.10 g/100 g (wet basis) while also having a protein content of 4.36 ± 0.15 g/100 g, a fat content of 0.58 ± 0.11 g/100 g, an ash content of 1.76 ± 0.19 g/100 g, a non-fiber carbohydrate content of 26.85 ± 0.55 g/100 g, and a total dietary fiber content of 63.30 ± 0.69 g/100 g. The dried carrot was ground using a Cyclone Mill (Model# 3010-060, UDY Corporation, Fort Collins, CO, USA) with 2 mm screen size. Carrot pomace powder was stored in sealed polythene bags in a dry area until further use.

### 2.2. Sample preparation

A calculated amount of corn starch was mixed with the dried carrot pomace powder at levels of 5, 10, and 15 g/100 g, following the experimental design shown in Table 2. Each sample of corn starch blended with carrot pomace powder was adjusted to moisture content of 15 (±0.5), 22.5 (±0.5) and 30 (±0.5) g/100 g to represent feed moisture. The required amount of water was added and the material was mixed for 5 min in a Hobart mixer (Model #A-200, Hobart, OH, USA). The hydrated blends were placed in sealed plastic jars and allowed to equilibrate overnight in a walk-in refrigerator (4 °C).

### 2.3. Extrusion

Extrusion was performed using a 20 mm co-rotating twin screw extruder (Model# TSE 20/40, 7.5 HP, CW Brabender, S. Hackensack, NJ, USA). The overall length of the extruder barrel was 400 mm and had a length to diameter (L/D) ratio of 20:1. The barrel had 4 individual heating zones and temperatures were set at 50, 100, 140, 140 °C for all the experiments. A rod-shaped die with a diameter of 4.0 mm was used. The screw profile used in the study is shown in Fig. 1. The equilibrated samples were fed into the extruder. Extrusion was carried out maintaining full feed, ensuring that the flights and feed port were full throughout the extrusion runs. The extruder screw-speed was varied at 100, 175 and 250 rpm for all treatments as per the design shown in Table 2. Extrudates were collected when system stabilized, with constant pressure at the die, constant torque, and constant output flow rate. The collected extrudates were dried in a convection oven (Model # 414004-568, VWR

**Table 1**
Brief summary of selected studies involving pomace incorporation in extrusion.

| Pomace type | Starch/flour type | Significant finding | Reference |
|---|---|---|---|
| Blueberry pomace | White sorghum flour | Extrusion processing can be used to increase procyanidin monomer and dimers in blueberry pomace. | (Khanal et al., 2009) |
| Carrot pomace | Rice flour | The study demonstrated that an acceptable extruded product can be prepared by 5 g/100 g carrot pomace incorporation. | (Upadhyay et al., 2010) |
| Cranberry pomace | Corn starch | Extrusion alters the polyphenolic distribution of cranberry pomace and has application in the nutraceutical industry as a means of improving the functionality of this product. | (White et al., 2010) |
| Grape pomace | Barley flour | Grape pomace inclusion at 4.47–6.57 g/100 g can be extruded with barley flour into an acceptable snack food. | (Altan et al., 2008b) |
| Pineapple pomace | Corn flour | Addition of 10.5 g/100 g of pineapple pomace did not negatively impact the properties of the extruded product. | (Selani et al., 2014) |
| Tomato pomace | Barley flour | Tomato pomace at 2 and 10 g/100 g levels can be extruded with barley flour into an acceptable and nutritional snack. | (Altan et al., 2008a) |