Contents lists available at ScienceDirect

Food and Bioproducts Processing

journal homepage: www.elsevier.com/locate/fbp

# Agro-food industry byproducts into value-added extruded foods

*Ilankovan Paraman*, Mian K. Sharif, Susmoko Supriyadi, Syed S.H. Rizvi*

*Department of Food Science, Cornell University, Stocking Hall, Ithaca, NY 14853, United States*

ARTICLE INFO

*Article history:*
Received 30 December 2014
Received in revised form 17 April 2015
Accepted 2 July 2015
Available online 10 July 2015

*Keywords:*
Extrusion
Value-added process
Co-products
Fruit pomace
Supercritical fluid extrusion
Cheese whey

ABSTRACT

Food industry co-products, fruit pomace and liquid whey, were converted into shelf-stable, puffed products by using low-shear, low-temperature supercritical fluid extrusion. Co-products were utilized as a source of dietary fiber, phytochemicals, and milk nutrients in extruded products. Liquid whey was concentrated and pumped directly into extruder barrel in lieu of water while processing cereal formulations fortified with finely ground fruit pomace. The resulting extruded products were very light in weight with 0.21–0.35 g/cm$^3$ density and contain14 g dietary fiber, 93 mg gallic acid equivalent polyphenols, and 652 mg vitamin C equivalent antioxidants in 100 g products. The natural fruit color is retained in the final product, indicating the preservation of color pigments and the associated bioactive compounds. About 84% of the total phenolics and 74% of the antioxidants of apple pomace were preserved in the final extrudates. The utilization of the agro-industry waste streams offers effective preservation and utilization of the nutritionally attractive byproducts as a source of functional ingredients in extruded products while adding value to the industrial waste streams.


## 1. Introduction

Fruit pomace is a byproduct that remains after juice extraction from fruits and constitutes about 20–25% of the fresh fruit weight. It is treated as an industrial waste with very little or no economic value and is often used either as animal feed or returned to farms for composting. Since pomace contains large amount of water (66.4–78.2%, wet basis) and fermentable sugars (3.6%, wb), its direct disposal into soil creates environmental concerns due to uncontrolled fermentation and high chemical oxygen demand (300 g COD/kg pomace) during its degradation. Similarly, cheese whey is another co-product of cheese manufacture, about 9 pounds of whey is generated for each pound of cheese production. Cheese whey is an important source for high quality proteins, health promoting factors, and minerals (Walzem et al., 2002; Madureira et al., 2010). A considerable research emphasis has been directed towards better transforming byproducts generated from agro-food processing plants into various value-added products.

As a part of fruit, pomace has the potential to be transformed into various ingredients for food applications (Mahawar et al., 2012; Yu and Ahmedna, 2013). For instance, apple pomace, which consists of peel, core, and pulp, can be converted into various food and industrial ingredients such as citric acid (Mahawar et al., 2012; Hang and Woodams, 1984), pectin (Schieber et al., 2003); alcohols (Madrera et al., 2013), enzymes (Dhillon et al., 2012), bio-adsorbents (Robinson et al., 2002) and biofuels (Vendruscolo et al., 2008). However, the economics of such undertakings is often found to be unattractive for commercialization of the developed processes. As a rich source of dietary fiber and phytochemicals, direct utilization of pomace in food applications offers an attractive opportunity to both processors and consumers. Although the direct use of fruit pomace in food applications has been studied for

* *Corresponding author*. Tel.: +1 314 659 3486.
E-mail address: iparaman@gmail.com (I. Paraman).
http://dx.doi.org/10.1016/j.fbp.2015.07.003

well over two decades (Wang and Thomas, 1989; Alavi et al., 2011), it has not reached commercialization due to its negative impacts on end-product sensory attributes.

Extrusion, as a continuous process with high versatility and productivity, offers a good avenue to incorporate fruit or vegetable pomace in ready-to-eat snacks and breakfast cereals. In addition to value addition to the byproducts, incorporating pomace can improve nutrient density of extruded products that are otherwise carbohydrate-rich, high glycemic products (Brennan et al., 2013). This will also help overcome nutrient shortfall in modern convenience food because fruit pomace is a good source of functional food compounds: dietary fibers (60 g/100 g apple pomace), polyphenols (350 mg/100 g apple pomace) and a rich source of antioxidants.

Extrusion based food production is a multibillion dollar market and is a good channel to incorporate fruit based dietary fiber and phytochemicals into a number of products. Recent studies have clearly indicated the potential of incorporating various fruit and vegetable-based pomace in extruded products like apple pomace (Alavi et al., 2011; Karkle et al., 2012), grape pomace (Altan et al., 2008; Kumar et al., 2010), cranberry pomace (White et al., 2010), blue berry pomace (Khanal et al., 2009), tomato pomace (Altan et al., 2008), and carrot pomace (Altan et al., 2008) into various product matrices. However, the effect of pomace addition on extruded end-product sensory and nutritional qualities was observed to be highly variable depending on extrusion conditions, pre and post-extrusion treatments, source of byproducts, etc. Conventional cooking extrusions used in previous studies are also based on high-temperature (130–200 °C) and high-shear (150–300 rpm) operations. Such high process requirements invariably lead to loss of sensory and nutritional qualities.

The present research utilizes supercritical fluid extrusion (SCFX), a modified process utilizing supercritical $CO_2$ (SC-$CO_2$) as an expansion agent instead of steam. The process produces highly expanded, low-density products at process temperatures below 100 °C and with low shear conditions (Rizvi and Mulvaney, 1992; Rizvi et al., 1995). Therefore, heat- and shear-sensitive nutrients and bioactives can be effectively incorporated to produce nutrient enriched products without much loss (Alavi and Rizvi, 2009; Paraman et al., 2012). Such mild operating requirements are very advantageous when processing fruits, vegetables, and their byproducts, along with whey as a replacement for water which is required during extrusion processing. The objectives of this study were to develop novel extrusion protocols to directly incorporating fruit/dairy byproducts into shelf-stable, puffed, extruded products and evaluate changes in their quality due to processing.

## 2. Materials and methods

### 2.1. *Apple pomace and cheese whey preparation*

Apple pomace was obtained from the New York State Agricultural Experiment Station fruit processing pilot plants (Geneva, NY). Moisture content of wet apple pomace was 71% and pH was 4.8. Pomace was dried in a hot air oven at 50 °C for about 48 h to a moisture content of 5–8% (Oven model LR-27, ST333, LR Technologies, Los Angeles, CA). The dried pomace was ground into fine powder with a hammer mill using a 0.031 inch screen. Cheese whey was collected from cheddar cheese manufacturing operation at Cornell University (Ithaca, NY). It contained 5.6% total solids and the pH was 4.6. The whey was concentrated to ~20% total solids using a vacuum evaporator (Anhydro Laboratory Vacuum Evaporator) at ~70 °C. The pH of the concentrated whey was 4.2.

**Table 1 – Feed formulations of apple pomace extrusion treatments.**

| Formulations | Ingredient composition (%, dry weight) |
|---|---|
| Starch extrudate | 98% Pre-gelatinized starch, 1% lecithin, and 1% distilled monoglycerides |
| Apple pomace extrudate | 22% Apple pomace, 76% pre-gelatinized starch, 1% lecithin, and 1% distilled monoglycerides |
| Apple pomace—cheese whey extrudate | Same as (ii) and with added cheese whey (5.6% dry wt.) |
| Protein fortified apple pomace puffs | 22% Apple pomace, 48% pre-gelatinized starch, 12% soy protein isolate, 7% dried yogurt powder, 7% brown Sugar, 1% lecithin, and 1% distilled monoglycerides, .8% vanilla extract, 0.5% apple flavor, 0.6% salt, 0.3% cinnamon, 0.4% citric acid, 0.2% nutmeg |

### 2.2. *Feed formulation*

Extrusion formulations consisting of fruit pomace and other required dry ingredients as shown in Table 1 were mixed for 9 min in a 0.14 $m^3$ ribbon blender (Littleford Day Inc., Florence, KY, USA) to ensure uniform mixing. Preliminary experiments were conducted to determine the appropriate amounts of apple pomace (22 and 28%). Pre-gelatinized corn starch obtained from Tate & Lyle Ingredients (Decatur, IL, USA). Lecithin and distilled mono-glyceride were provided by Danisco Ingredients (Kansas, MO).

### 2.3. *Supercritical fluid extrusion*

The dry-blended formulations were extruded in a pilot-scale Wenger TX-52 Magnum co-rotating twin screw extruder (Wenger Manufacturing, Sabetha, KS, USA) with a length to diameter ratio (L/D) of 28.5:1 (Rizvi et al., 1995). The extruder was operated at a feed rate of 35 kg/h and screw speed of 100–120 rpm. Barrel temperature in all 5 barrel zones were maintained at ~25 °C by circulating chilled brine (−10 °C) through barrel jackets. The concentrated whey was directly pumped into the extruder barrel while processing fruit pomace in extruder at a flow rate of 27.5–32.0% of the dry-feed flow rate, which yielded 21–24% moisture content and 5.6 wt.% whey solids in extrudate. A diagram of the screw profile along with extrusion parameters used is shown in Fig. 1. The extruder parameters and operating conditions are summarized in Tables 2 and 3.

A pilot scale supercritical fluid system was used to generate SC-$CO_2$ and inject at a constant flow rate ($7.6 \times 10^{-5}$ kg/s) into the barrel through four valves located at L/D of 24. The SC-$CO_2$ was injected at 1100 psi (7.58 MPa) to maintain a continuous flow of SC-$CO_2$ into the product melt (Rizvi et al., 1995). A flow restrictor was used to maintain the die pressure at ~10 MPa (1500 psi). The residence time inside the extruder is about 130 s for the screw speed (100 rpm) used in this study. The product melt was forced through one die insert of 4.2 mm diameter and cut by a 2-bladed knife rotating at 900 rpm to