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Properties of extruded expandable breadfruit products

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It is vital to process breadfruit in order to develop new value-added products with improved sensory and physicochemical characteristics. In this research, dried breadfruit was extruded with a twin screw extruder and effects of barrel temperature, moisture content, feeding rate and screw speed on product physicochemical properties and process energy consumption were studied. Quadratic models were obtained to predict the product quality under various processing conditions. The best range of crispness of the extrudate was from 2.0 to 3.5N/s, hardness from 60 to 75 N and bulk density from 0.3 to 0.38 g/cm^3. Corresponding operating conditions of feeding rate, temperature, screw speed and moisture content to obtain best results of crispness, hardness and bulk density were 16 kg/h, 130 °C, 160 rpm, 22 g/100 g; 22 kg/h, 150 °C, 160rpm, 22 g/kg; 19 kg/h, 140 °C, 115 rpm, 19 g/100 g; and 25 kg/h, 140 °C, 145 rpm, 19 g/100 g, respectively. The linear term of screw speed significantly effected all indexes ($p < 0.001$), especially water absorption and solubility indexes, sectional expansion ratio, bulk density, color and specific mechanical energy. The interaction term of feed rate and temperature, and square term of screw speed had no significant influences ($p \geq 0.1$). The findings were useful for developing and optimizing extruded or value-added co products of breadfruit.

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1. Introduction

Breadfruit (*Artocarpus altilis*) is a member of the Moraceae family and is normally consumed after cooking. Breadfruit is a rich source of carbohydrates, fiber, and vitamins and minerals, such as vitamin C and potassium (Graham & Negron de Bravo, 1981). The chemical compositions of breadfruit, especially starch, vary with the stage of its maturity (Wootton & Tumaalii, 1984).

Because of the limited use of fresh breadfruits, there is an increased research interest in developing new value-added products from the fruits. Extensive studies have focused on the functional, physical, chemical and sensory properties of breadfruits, and modified and unmodified starches to be used as food ingredients for various food products including bread and snacks (Adebowale, Olu Owolabi, Olawumi, & Lawal, 2005; Adewusi, Udio, & Osuntogun, 1995; Akubor, 1997, 2005; Akubor & Badifu, 2004; Ayodele & Oginni, 2002; Englberger et al., 2003; Golden & Williams, 2001; Huang, Titchenal, & Meilleur, 2000; Ijarotimi & Aroge, 2005; Loos, Hood, & Graham, 1981; McHugh & Huxsoll, 1999; Nnam & Nwokocha, 2003; Solomon, Layokun, Ibbowu, & Ilori, 1994). As the results, up to 10% of breadfruit flour was successfully used to replace wheat flours for producing breads. To take advantage of the high starch content in breadfruit, Nochera and Moore (2001) studied the properties of extruded products from breadfruit flour. They evaluated the chemical composition, texture and sensory qualities of extruded breadfruit products and concluded that the product was similar to typical crispy rice cereal. However, no detailed reports are available on the effect of extrusion processing parameters on the product quality characteristics of pure breadfruit based extruded products.

The ultimate objective of this study was to develop pure breadfruit based extruded product that can be used as a breakfast cereal or snacks. The specific objective was to investigate the effect of processing parameters on product quality. Four processing parameters studied in this research were moisture content (MC),

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screw speed, feed rate and barrel temperature. The measured product quality indicators were sectional expansion ratio, color, texture, bulk density, water absorption index (WAI) and water solubility index (WSI).

2. Materials and methods

2.1. Materials

Breadfruit (*A. altilis*, Tahitian variety) was harvested from a commercial orchard near Hilo, HI and the fruit were transported to the U.S. Pacific Basin Agricultural Research Center for pre-processing. The breadfruit was weighed, cut into quarters lengthwise, hand-peeled, and sliced in a Cuisart food processor (model DLC-XPP, Beverage Factory, San Diego, CA). Breadfruit slices were weighed, placed in a wire colander, and blanched for 3 min in hot (100 °C) water. The 3-min blanching inactivated peroxidases in the fruit. After blanching, the breadfruit slices were placed in a food dehydrator (Excaliber) at 60 °C until thoroughly dried (5-7 g of moisture content per 100 g dry weight). Dried breadfruit was shipped to the Western Regional Research Center in Albany, CA for extrusion processing. The dried breadfruit was then ground into flour using a hammer mill (screen size 1 mm). The dried breadfruit flour consisted of 85.38 g of total carbohydrate, 4.89 g of protein, 1.27 g of fat, 14.15 g of crude fiber, 2.56 g of ash and 5.91 g of moisture per 100 g dry weight according to analysis done using standard procedures at Anresco Labs, South San Francisco, California. Total calories were 352 J per 100 g (Anresco Labs, South San Francisco, California).

2.2. Experimental design and statistical analysis

A central composite experimental design was used to determine the effect of four independent variables on the extruded product quality (Table 1). These variables were feeding rate (13–25 kg/h), barrel temperature (120–160 °C), screw speed (115–175 rpm) and moisture content (13–25g/100 g dry weight). The eight dependent variables were sectional expansion ratio, bulk density, color difference, crispness, hardness, WAI, WSI, and specific energy consumption (SEC). A total of 36 experiments were conducted based on the design (Gardiner & Gettinby, 1998, pp. 335).

The regression model between a dependent variable (Y) and independent variables can be generally written as:

$$\begin{aligned} Y =& B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_{11}X_1^2 + B_{22}X_2^2 + B_{33}X_3^2 \\ &+ B_{44}X_4^2 + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{14}X_1X_4 + B_{23}X_2X_3 \\ &+ B_{24}X_2X_4 + B_{34}X_3X_4 \end{aligned} \quad (1)$$

The relationship between the dependent and independent variables was determined using nonlinear regression analysis with Stat-Ease software (Stat-Ease, Design-expert 7.0.2, Minneapolis, MN, USA). The effects of independent variables on dependent variables were statistically investigated. After removing the non-significant terms with the $p < 0.1$ level, the constant terms, coefficient of independent variables, and their p-value levels are presented in Table 2.

Response surface graphs were drawn using Sigma Plot (Version 2001, SPSS Science) to show the effect of two independent variables on dependent variables when the other two dependent variables were fixed at central level.

The relationships among the product quality parameters, such as sectional expansion ratio, bulk density, color, crispness, hardness, WAI and WSI, were also examined through regression analysis.

Table 1
Coded variable levels of central composite design.

Variables	Levels				
	−2	−1	0	1	2
Feeding rate (F, kg/h), X_1	13	16	19	22	25
Barrel temp. (T, °C), X_2	120	130	140	150	160
Screw speed (S, rpm), X_3	115	130	145	160	175
Moisture content (M, g/100g), X_4	13	16	19	22	25

2.3. Extrusion tests

A Hakke Microline 18 extruder (Thermo Scientific, Newington NH) was used in this study. The extruder was equipped with a co-rotating twin screw set, 2 mm diameter die of length 540 mm, K-tron volumetric feeder (K-tron America, Pitman NJ) and a Bran + Luebbe NP32 metering pump (Bran + Luebbe Inc., Delavan WI) for water feed. The screw diameter was 18 mm with the ratio of length and diameter as 30:1. The water pump was used to pump water directly into the extruder barrel so as to mix with the breadfruit flour to achieve desired moisture levels. All processing parameters and torque of extruder motor were automatically recorded on a HAAKE RC9000 DATA (V1.36) system.

The barrel consisted of five sections heated with electricity. The barrel temperature distribution was from low at the section next to the feeding to high at the section next to the die. The studied barrel temperatures were the temperatures of the section next to the die. The corresponding five different barrel temperature distributions in °C were 25-57-88-120-120, 25-60-95-130-130, 25-63-102-140-140, 25-67-108-150-150 and 25-70-115-160-160.

The extrudate was cut to approximately 30 cm long sections and dried to approximately 3.7 g of moisture per 100 g of material (wet base) at 50 °C using a hot air dryer. They were then stored in sealed polyethylene bags until additional quality measurements were carried out.

2.4. Product quality and energy consumption analysis

2.4.1. Texture measurement

To determine the textural quality of an extrudate, its texture profile was measured by compression using an Instron (Model 1122, Canton, MA, U.S.A.) to obtain the crispness and hardness. The force-time curve was recorded when a piece of 20 mm long extrudate was compressed at 1 mm/min of speed to rupture. The maximum force of F_{max} (N), i.e. the resistance of extrudate before rupture, represented the hardness (Bourne, 1978). The slope of the force-time curve before rupture was considered as crispness (Casas, Martinez, Guillen, Pin, & Salmeron, 2006; Ding, Ainsworth, Tucker & Marson, 2005). So, the crispness can be calculated using the following equation:

$$\text{Crispness} = F_{max}^2/(2A) \quad (N/s) \quad (2)$$

where, F_{max} is the maximum force (N) and A is the corresponding area under the curve. Eight measurements were conducted for each sample and the average maximum force and slope were reported as hardness and crispness, respectively.

2.4.2. Sectional expansion and bulk density

Sectional expansion was defined as the ratio of extrudate diameter to die diameter (Alvarez-Martinez, Kondury, & Harper, 1988; Fan, Mitchell, & Blanshard, 1996). The diameters were measured at five locations of an extrudate with a digital caliper and