Physicochemical Properties of Extrusion-Cooked Amaranth Under Alkaline Conditions

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ABSTRACT

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A Brabender extruder was used to study the effect of processing variables on the water absorption index (WAI), water solubility index (WSI), and masa hardness of alkaline-extruded amaranth flour. Extrusion variables studied were barrel temperature (50, 60, and 70°C), feed moisture content (20, 25, and 30%), and screw speed (30, 45, and 60 rpm). Regression analysis showed that changes in all response variables for amaranth flour were promoted by barrel temperature and feed moisture content. Screw speed in the evaluated range was significant for masa hardness. Polynomial equations obtained for each physicochemical property accounted for 86-93% of the total variation. In general, WAI values increased when the barrel temperature and feed moisture content were increased. WSI values decreased with increasing barrel temperature and feed moisture content. Higher masa hardness values were found at extreme values of barrel temperature and feed moisture content, whereas increasing moisture content and screw speed resulted in lower masa hardness values. Extrusion-cooked amaranth flour under alkaline conditions may be used for preparation of tortillas and tortilla-based products.

Studies on the effects of processing amaranth grain by extrusion cooking appear to be limited to research related to blends of amaranth with other grain products or whole grain amaranth for food product development such as snacks (Koeppe et al 1987) and flours to prepare drinks (Mendoza and Bressani 1987). No studies have been reported on the alkaline extrusion cooking of amaranth grain to prepare instant tortilla flour and similar products. Vargas-López et al (1990) prepared an alkaline-cooked amaranth flour by a traditional nixtamalization method and reported that this flour possesses the basic functional properties to be used for tortilla production. This preliminary study was carried out to assess the effects of temperature, feed moisture content, and screw speed on several of the physicochemical properties of alkaline-extruded amaranth flour.

MATERIALS AND METHODS

Grain Tempering

Amaranthus hypochondriacus, Mercado type, obtained from an experimental station of INIFAP, Chapingo, Mexico, was stored at 4°C until used. Samples of amaranth grain (500 g) were moistened by spraying distilled water containing 0.3% $Ca(OH)_2$ to a total water content of 20-30%. Tempered materials were placed in polyethylene bags, refrigerated 12 hr to allow the moisture to equilibrate, and brought to room temperature (22°C) before being extruded.

Extrusion

Extrusion was performed with a single-screw Brabender 20 DN extruder mounted to a Do-Corder DCE 330 (C. W. Brabender Instruments, South Hackensack, NJ) equipped with a three-temperature-zone barrel in which the temperature was maintained by electrical-resistance heating elements and regulated by air cooling. The extruder operation conditions were selected from factorial combinations of the following parameters: barrel temperature 50, 60, 70°C; feed moisture content 20, 25, 30%; screw speed 30, 45, 60 rpm. The extrusion parameters and levels in the design (Table I) were chosen on the basis of previous experimental work. An outline of the experimental plan is shown in Table II. The barrel and die were held at the same temperature; screw speeds were maintained by automatic control. The screw compression ratio (1:1) and round restriction die (3 mm) were the same in all experimental runs. The extruder was operated at steady state for each set of conditions. Attainment of steady state was judged by a constant torque required to turn the screw and by a steady extrusion rate.

Flour Preparation

The extruder was started, the three temperature zones were adjusted to the desired operating temperature, and the tempered sample was fed. Material was collected in aluminum trays; the extrudates subsequently were dried in an oven (Rios-Rocha, Mexico City) with forced air at 50°C for 12 hr. The moisture content of these samples ranged from 6.1 to 8.1%. Finally, the alkaline-extruded amaranth flour was prepared by milling of extrudates on a cyclone sample mill (Udy Corp., Boulder, CO) with a 1-mm mesh screen and stored at 4°C until used.

Determinations of Moisture, pH, and Water Absorption and Solubility Indexes

Moisture was determined by AACC Method 44-19 (AACC 1983). The pH was measured at 25°C after preparing a slurry with 10 g (db) of flour and 100 ml of boiled distilled water, which was agitated every 5 min for a total of 20 min; then the pH was read, according to AACC Method 02-52 (AACC 1983). Experimental flours were evaluated by measuring the water absorption index (WAI) and water solubility index (WSI) according to methods described by Anderson et al (1969); measurements were performed on four samples from each of the 15 treatments.

Masa Hardness Evaluation

A simple objective method to assess masa (dough) mechanical quality properties was performed using a Universal Testing Machine (Model 1130, Instron Engineering Corp., Canton, MA). Two polished stainless steel plates (6.9 cm in diameter) were used. The top movable plate was attached to a compression load cell (capacity, 50 kilogram force). The masas were prepared from samples of flour (100 g), which were mixed with distilled water (1:1) for 3 min in a Brabender farinograph and fitted with a stainless steel bowl (300-g capacity). The temperature of the farinograph was adjusted to 30°C. The masa was prepared and immediately divided into three equal parts by weight and allowed to rest for 10 min. The temperature of the masa sample was 27 ± 0.5°C. The masa was molded to a circular shape and flattened into a stainless steel container (30 mm in diameter, 6 mm in height). The resulting masa disk was carefully placed between

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TABLE I
Independent Variables and Levels in the Experimental Design

Variables	Levels −1	Levels 0	Levels 1	Code
Barrel temperature, °C	50	60	70	X_1
Feed moisture content, %	20	25	30	X_2
Screw speed, rpm	30	45	60	X_3

the two parallel plates and aligned in the center of the bottom stationary plate. The compression loading proceeded until the plates were 1.4 mm apart, which corresponds to a thickness of a tortilla sample. The force required for the compression test was recorded. Data were obtained in this way using a loading speed and a chart speed of 5 and 100 cm/min, respectively. Hardness was defined as the maximum stress and was reported in pascals. Each measurement was triplicated using fresh masa samples from each of the 15 treatments.

Statistical Analysis

In selecting the conditions for the extruder operations, independent variables including barrel temperature, feed moisture content, and screw speed were incorporated in a factorial experimental design according to the presentation of Henika (1972) for a systematic study. The design consisted of 15 treatments, which included triplication of the center point. Dependent variables included the flour physicochemical properties, WAI, WSI, and masa hardness. These variables were expressed individually as a function of the independent variables mentioned above. Ranges of the independent variables are shown in Table I. Our preliminary experimental work (Vargas-López et al 1990) showed that these variables had measurable effects on the masa and that the levels selected were reasonable. Polynomial regression analysis by means of least squares was used to determine the relationships between the process and functional variables. Response surface methodology was applied on the experimental region defined. Experimental data analysis and estimated response surfaces were performed with multiple regression analysis and surface plotting subroutines, respectively, by using the Statgraphics program (STSC 1986). Regression models with linear and quadratic terms were used to create three-dimensional response surfaces. In response surface methodology, independent variables are located along the X and Y axes, and the dependent or response variable is on the Z axis.

RESULTS AND DISCUSSION

The physicochemical properties of alkaline-extruded amaranth flour, which were evaluated under the different process variables, are presented in Table III. Some changes were observed in the dependent variables of the experimental flours. Analysis of variance for each response variable and for full regression were calculated. The signs of the regression coefficients within each model of Table IV show the direction of the effect of each independent variable, the quadratic terms, or the interactions.

pH

The pH measurements obtained for the alkaline-extruded amaranth flour suspensions indicated that pH increased from 6.7

TABLE II
Treatments Applied for the Alkaline Extrusion Cooking of Amaranth

	Treatments														
Variables	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
X_1	−1	1	−1	1	−1	1	−1	1	0	0	0	0	0	0	0
X_2	−1	−1	1	1	0	0	0	0	−1	1	−1	1	0	0	0
X_3	0	0	0	0	−1	−1	1	1	−1	−1	1	1	0	0	0

TABLE III
Independent Variables and Responses of Dependent Variables to the Alkaline Extrusion Cooking of Amaranth

	Independent Variables			Dependent Variables		
Treatment	**Barrel Temperature (°C) X_1**	**Feed Moisture Content (%) X_2**	**Screw Speed (rpm) X_3**	**Water Absorption Index[a] Y_1**	**Water Solubility Index[b] Y_2**	**Hardness[c] $\times 10^{-4}$ Y_3**
1	−1	−1	0	2.23 ± 0.00	15.87 ± 0.12	6.91 ± 0.03
2	1	−1	0	2.27 ± 0.04	12.70 ± 0.16	7.42 ± 0.06
3	−1	1	0	2.25 ± 0.06	14.80 ± 0.06	7.81 ± 0.00
4	1	1	0	2.25 ± 0.05	13.53 ± 0.15	5.31 ± 0.01
5	−1	0	−1	2.16 ± 0.00	15.10 ± 0.20	8.31 ± 0.00
6	1	0	−1	2.21 ± 0.02	12.47 ± 0.28	6.41 ± 0.02
7	−1	0	1	2.16 ± 0.01	11.37 ± 0.40	7.08 ± 0.00
8	1	0	1	2.24 ± 0.08	10.27 ± 0.11	6.90 ± 0.02
9	0	−1	−1	2.18 ± 0.01	15.33 ± 0.21	7.89 ± 0.00
10	0	1	−1	2.31 ± 0.06	15.53 ± 0.30	8.25 ± 0.02
11	0	−1	1	2.22 ± 0.00	15.17 ± 0.19	7.55 ± 0.00
12	0	1	1	2.26 ± 0.03	14.17 ± 0.16	5.51 ± 0.01
13	0	0	0	2.14 ± 0.05	13.85 ± 0.15	6.84 ± 0.00
14	0	0	0	2.17 ± 0.04	13.93 ± 0.25	5.82 ± 0.03
15	0	0	0	2.14 ± 0.03	13.77 ± 0.06	6.15 ± 0.01

[a] Weight of gel obtained per gram of dry flour sample.
[b] Amount of dry solids expressed as percentage in the flour sample.
[c] Values in the test masa were calculated in pascals.

TABLE IV
Regression Models for Response Variables

Response Variable	Regression Model[a]	R^2
Water absorption index	$Y_1 = 2.150 + 0.021X_1 + 0.021X_2 + 0.002X_3 + 0.025X_1^2 + 0.075X_2^2 + 0.022X_2X_3$	0.86**[b]
Water solubility index	$Y_2 = 13.850 - 1.021X_1 - 0.130X_2 - 0.931X_3 - 1.186X_1^2 + 1.561X_2^2 + 0.475X_1X_2$	0.93*
Hardness	$Y_3 = 6.272 - 0.509X_1 - 0.360X_2 - 0.476X_3 + 0.358X_2^2 + 0.668X_3^2 - 0.752X_1X_2 - 0.600X_2X_3$	0.90*

[a] X_1 = Barrel temperature, X_2 = feed moisture content, X_3 = screw speed. Any term (linear, quadratic, interaction) significant at $P < 0.25$ was incorporated in the model.
[b] ** = Significant at $P < 0.01$, * = significant at $P < 0.05$.

for the raw flour to 7.1 ± 0.2 for the extruded sample (data not shown). Previous studies (Vargas-Lopez et al 1990) show that the pH of nixtamalized amaranth flours by a traditional procedure varies from 6.9 to 7.5. Bedolla and Rooney (1984) reported that the pH values of nixtamalized maize flours from the commercial market ranged from 7.1 ± 0.2 to 7.4 ± 0.2. Based on sensory evaluation studies, they concluded that maize tortillas produced from flours at pH 7.1 have substantially better traditional alkaline flavor than those produced from flours at pH 7.4.

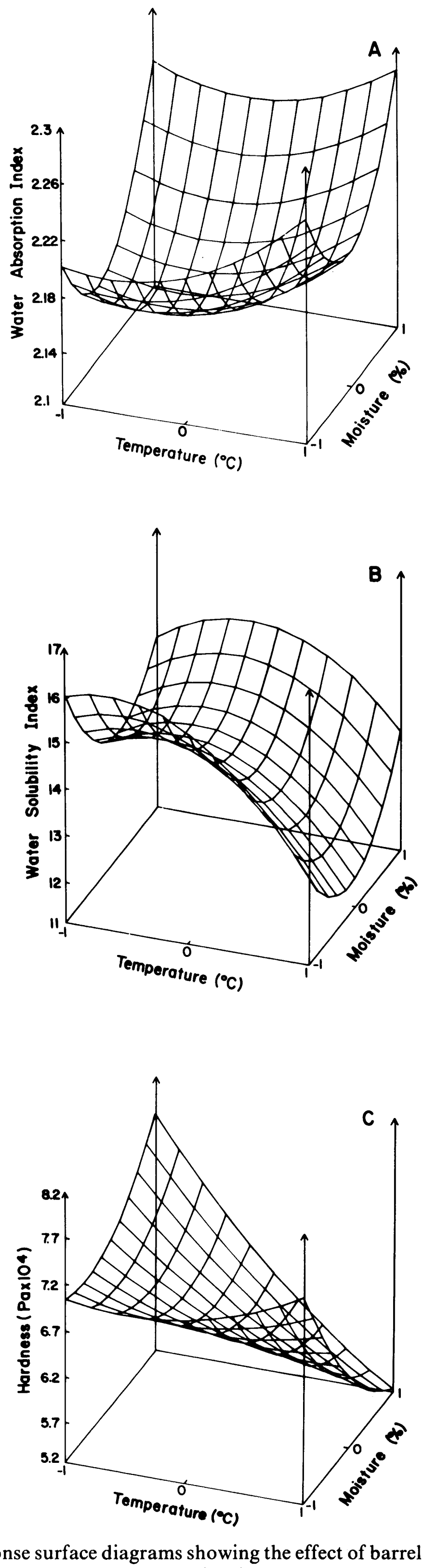

Fig. 1. Response surface diagrams showing the effect of barrel temperature and moisture on the water absorption index (**A**), water solubility index (**B**), and (**C**) masa hardness generated at constant screw speed (45 rpm).

WAI

The regression model for the WAI as a function of the independent variables is shown in Table IV. This model accounts for 86% of the total variation ($P < 0.01$) in the WAI values. Of the three independent variables, the linear effects of barrel temperature and feed moisture content were found to be significant ($P < 0.1$). The quadratic effect of feed moisture content was the next significant term ($P < 0.01$). The presentation of the relationship between the barrel temperature and feed moisture content on the WAI of the extruded flour showed that in general, with an increase of both variables simultaneously, the WAI also increased (Fig. 1A). WAI values ranged from 2.14 to 2.31 g of gel per gram of dry flour. Gomez et al (1987) reported that the WAI for five commercial nixtamalized maize flours varied from 2.9 to 3.8 g/g. A shorter shelf-life for tortillas would result from flours with high water uptake indexes. Bedolla and Rooney (1984) found that the WAI of tortillas flours depends on the pH, protein content, degree of enzyme susceptible starch, and particle size. A strong interaction of barrel temperature and feed moisture content on the characteristics of the extrudate was reported by Anderson et al (1969) and Owusu-Ansah et al (1983). Extruded corn and sorghum grits and corn starch exhibited maximum WAI at high barrel temperature and high moisture content. Gelatinization of starch increased the WAI values of these materials. In the present study, the low temperature levels used were deliberately chosen to ensure adequate functional behavior of amaranth flour obtained by the extrusion process. Perhaps the incomplete gelatinization of starch decreased the WAI of this flour.

WSI

Table IV shows the model for the WSI as a function of barrel temperature, feed moisture content, and screw speed. Regression analysis demonstrated that changes in the WSI response variable for alkaline-extruded amaranth flour were promoted by barrel temperature followed by feed moisture content. The linear term of temperature contributed significantly ($P < 0.01$) to the model. The quadratic terms for both variables were also significant ($P < 0.05$); screw speed was found to be insignificant within these significance levels. The regression model accounts for 93% of the total variation ($P < 0.05$) in the WSI values. Graphic presentation of the functional model (Fig. 1B) shows that the WSI decreased when barrel temperature increased; the WSI changed from 15.87 to 10.27% when barrel temperature was augmented from 50 to 70°C. In contrast, the effect of feed moisture on the WSI was relatively opposite that of barrel temperature. Increasing feed moisture content caused an increase in the WSI. Moisture levels and temperature very strongly influence the properties of extrusion-cooked starchy material; the WSI values for amaranth flour showed a trend similar to values obtained from roll-cooked wheat grits reported by Anderson (1982). The WSI may be used to estimate the suitability of using extruded starchy products in suspensions or solutions. Increases in the WSI for extruded samples might be related to the lower molecular weight of starch components released from the granules (Colonna et al 1989). However, this aspect requires further study.

Masa Hardness

Table IV shows the regression model for masa hardness as a function of barrel temperature, feed moisture content, and screw speed. Statistical analysis of data indicated that the linear effects of the three independent variables were found to be significant. Hardness was significantly affected by barrel temperature ($P < 0.01$), feed moisture content ($P < 0.1$), and screw speed ($P < 0.05$). Significant interaction of barrel temperature and feed moisture content was found ($P < 0.01$). The quadratic term of screw speed was significant ($P < 0.05$). The model had a high coefficient of determination ($R_2 = 0.90$, $P < 0.05$). The response surface for masa hardness as a function of barrel temperature and feed moisture content is presented in Fig. 1C. Higher values

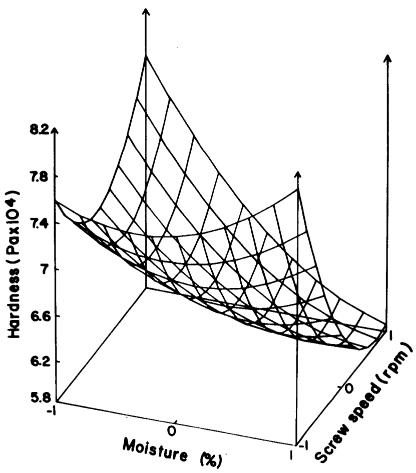

Fig. 2. Response surface diagram showing the effect of moisture and screw speed on masa hardness generated at constant barrel temperature (60°C).

of masa hardness were found at extreme values of the two independent variables (high barrel temperature and low feed moisture content and vice versa). The opposite occurred when barrel temperature and feed moisture content were both at higher levels of their ranges; lower values of hardness were then obtained. A likely explanation for this behavior might be related to the effect of the screw speed on masa hardness.

Figure 2 exhibits the response surface for masa hardness as a function of feed moisture content and screw speed. A saddle point surface was obtained. The observed effect of increasing screw speed and moisture content resulted in lower values of masa hardness. This pattern appears anomalous, but it can be explained as a result of decreasing the residence time of the material within the extruder; a decrease in residence time would cause a decrease in the degree of cooking. Bhattacharya and Hanna (1987) observed that corn starch granules were less susceptible to shearing action with increases in moisture content and screw speed. Chiang and Johnson (1977) reported that the variables affecting starch gelatinization during extrusion of wheat flour were barrel temperature, feed moisture content, and screw speed. They observed that the interaction of temperature and moisture significantly affected starch gelatinization. Increases of extrusion temperatures increased starch gelatinization; in contrast, increases of screw speed decreased starch gelatinization. The considerations mentioned above require further investigation.

CONCLUSIONS

The regression models allowed the calculation of the relative contribution of barrel temperature, feed moisture content, and screw speed for any combination of extrusion variables assessed in the experimental spectrum. Statistical analysis showed that changes in all response variables for alkaline-extruded amaranth flour were dependent on barrel temperature and feed moisture content, whereas those of screw speed in the evaluated region were only significant for masa hardness. The coefficients of multiple determination R^2 for each of the best-fitting model equations showed that they accounted for close to 86–93% of the variability in all dependent variables. In general, WAI values increased when the barrel temperature and feed moisture content also increased. WSI values decreased when the barrel temperature increased. Increasing feed moisture content caused an increase in WSI values. Increases in screw speed resulted a decrease in masa hardness, which suggests that this behavior may be attributed to the degree of cooking. Desired functional properties may be obtained through extrusion cooking by control of the operation variables; the processor can then use prediction models to selected conditions that will yield a nixtamalized amaranth flour with adequate functional behavior. Previous experiments in our laboratory suggest that alkaline-extruded amaranth flour may be used for preparation of tortillas with acceptable functional properties. However, physicochemical, functional, and sensory evaluation studies on extrusion-cooked amaranth flour for preparation of tortilla and tortilla-based products need to be performed.

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