SODIUM BICARBONATE AND THE MICROSTRUCTURE, EXPANSION AND COLOR OF EXTRUDED BLACK BEANS

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ABSTRACT

Seed microstructure provides complementary information to physicochemical determinations. Scanning electron micrographs of cross sections of black bean extrudates illustrated the increase in volume expansion, with an increase of sodium bicarbonate ($NaHCO_3$) in the extrudate. This increase in volume expansion is attributed to the increase in air cell size and corresponding decrease in air cell wall thickness with additional concentrations of $NaHCO_3$. The measured increase in diameter and expansion ratio of extrudates with $NaHCO_3$ addition may be explained by the increase in number of air cells within the extrudate and the increase in pores in the gelatinized starch matrix of air cell walls. Extrusion conditions, which involved the use of heat and moisture, provided the necessary conditions for the release of CO_2 from $NaHCO_3$ during processing. Expansion ratio increases between the control extrudate, and extrudate with 0.5% $NaHCO_3$ addition were twofold at the node and 1.8-fold at the area between the nodes. Statistical analysis of color data exhibited no significant change in L, hue or chroma across concentrations of $NaHCO_3$ for nonextruded flours. A simple linear regression adequately described changes in L* and hue for extruded flours. However, a curvilinear relationship was needed to explain changes in chroma versus $NaHCO_3$ for extruded flours, making changes in chroma measurements less easy to interpret. The color data in this study serve as primary information for future establishment of cut-off values of color for the development of an acceptable legume snack.*

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INTRODUCTION

Microstructural studies using scanning electron microscopy (SEM), transmission electron microscopy and light microscopy (LM) techniques have been applied to raw and processed legumes by several researchers (Hahn *et al.* 1977; Ben-Hdech *et al.* 1991; Garcia *et al.* 1993; Gujska *et al.* 1994; Berrios *et al.* 1998) to obtain structure–function information that can then be related to physicochemical determinations. Wood *et al.* (1998), using SEM and LM, observed that the initial raw states of starch and protein components in black bean purée were greatly modified in the final drum-dried product. Ingredients such as leavening agents used as food processing aids may induce changes in microstructure as well. Sodium bicarbonate ($NaHCO_3$) is a leavening agent commonly used in the bakery industry, and more recently it has been used in directly expanded extruded cereal products to enhance product physical properties and acceptability (Lai *et al.* 1989; Lajoie *et al.* 1996; Parson *et al.* 1996). More recently, $NaHCO_3$ was used to produce expanded snack-type products by twin-screw extrusion processing (Berrios *et al.* 2002).

Color is an important component of the visual appearance of foods and nonfood materials. Additionally, color may also be related to the wholesomeness of foods. Along with flavor and texture, color is often perceived as a valuable quality factor in the acceptability and marketability of food products. Color is perceived three dimensionally, based on responses of three different receptors (red, green and blue) in the human eye (Francis and Clydesdale 1975), yet all three dimensions may not be of practical importance (Francis 1995). The Judd–Hunter L, a, b and CIELAB L*, a*, b* are alternative color scales used to measure the degree of lightness (L*), redness or greenness (±a*) and yellowness or blueness (±b*), with the CIELAB scale being most commonly used for the evaluation of color in foods (CIE 1986). Conversion of a* and b* readings to hue and chroma values gives results more closely associated with human perception (Setser 1984). The purpose of this study was to evaluate the effect of adding selected concentrations of sodium bicarbonate to black bean flours on the structure, expansion and color characteristics of black bean extrudates.

MATERIALS AND METHODS

Commercial black beans (*Phaseolus vulgaris* L.) were blended in a paddle-type mixer (Marion Mixer, Rapid Machinery Co., Marion, IA) to a uniform lot and ground in a disc attrition mill (CE-Bouer, Springfield, OH) equipped with a Dayton AC inverter model no. 1XC98A (Dayton Electric Mfg. Co., IL) operated at 3600 rpm, using 8118 plates. Proximate analysis showed that the black bean flour used in this study contained 9.83% moisture, 24.68% crude protein, 2.25% crude fat, 4.30% ash and 58.94% total carbohydrates (calculated by difference). Certified A.C.S. $NaHCO_3$ (Fisher Scientific, Fair Lawn, NJ) was added to bean flours in selected proportions to yield flours containing 0.0, 0.1, 0.2, 0.3, 0.4, or 0.5% of $NaHCO_3$ and mixed in a Hobart mixer (Model A-200, The Hobart Mfg. Co., Troy, OH) for 5 min at speed 1 before the flour–$NaHCO_3$ mixtures were extruded.

Extruder and Processing Conditions

A Leistritz Micro-18-GL twin-screw extruder (American Leistritz Extruder Corporation., Sommerville, NJ) equipped with a 5 hp motor and corotating intermeshing screws containing three pairs of right-handed kneading blocks were used at a constant screw speed of 200 rpm. Additional extruder parameters were previously described by Berrios *et al.* (2002). The flour mixtures were fed into the extruder at a rate of 80 g/min and extruded at moisture content of 20% (wwb) by adjusting the amount of water in the extruder. Extruded bean rods were collected in stainless steel trays for 6 min, starting approximately 10 min after the operation conditions of torque and pressure reached steady state. Extruded bean rods were cooled to room temperature. The diameter of extrudate was measured and the extrudate packaged in zip-lock plastic bags. After bulk density determination, a set of bean extrudates was refrigerated for microscopic evaluation, and another set was ground for color measurement.

Scanning Electron Microscopy

Extruded bean flours in the form of rods were fractured with a razor blade and mounted onto aluminum specimen stubs using carbon conductive tabs and sputter coated with gold–palladium in a Denton Desk II sputter coating unit. The extrudates were observed and photographed in a Hitachi S-530 scanning electron microscope (SEM) or a Hitachi S-4700 Field Emission SEM (Hitachi Instruments Service Co., Ltd., Tokyo, Japan) at ambient temperature and 1 to 5 kV. Images were recorded by using Kodak T-Max 400 $4'' \times 5''$ sheet film and converted to digital files, or were recorded digitally.

Light Microscopy

Sections of the bean flour extrudates were prepared by fixing blocks of 2 mm^3 of the extrudate in a fixative containing 3% glutaraldehyde, 2% formaldehyde and ethanol–cacodylate buffer (50% ethanol and 0.05 M cacodylate), pH 6.9, overnight at 4C. Fixed extrudates were rinsed in ethanol–cacodylate buffer for 10 min. The rinse was repeated three times. The extrudates were dehydrated in an ethanol graded series (70%, 95% and 3 × 100%, 20 min each) and infiltrated with glycol methacrylate (GMA, Technovit 7100, Germany) and catalyst at 21C. The dehydrated extrudates were flat embedded and sectioned to a 2–4 μm thickness by using glass knives with a Sorvall Porter-Blum MT-2 ultramicrotome (Diversified Equipment Co., Inc., Lorton, VA).

Sections were stained for starch and proteins simultaneously by treating sections for 15 min in a Coplin staining jar containing 0.5% aqueous Safranin O. Following staining, slides were rinsed in running tap water, air dried and mounted in immersion oil. Sections were viewed and photographed by using a fluorescence filter set at a 450–490 nm excitation wavelength. Under these conditions, starch fluoresces yellow-green and proteins appear pink to red. As a second verification for proteins, sections were stained for 2 min in 0.01% acid fuchsin in 1.0% acetic acid, rinsed in running tap water, air dried and mounted in immersion oil (Fulcher and Wong 1980). Under this condition, proteins appear red when viewed under fluorescence illumination at a 546 nm excitation wavelength. For determination of starch granules and amylose, sections were stained with Iodine/potassium Iodide (I_2KI) (Clark 1991), rinsed briefly in running tap water and mounted in water. Ungelatinized starch granules were detected by mounting unstained sections in immersion oil and viewing the sections through crossed polarizing lenses.

Extrudate Diameter, Expansion Ratio and Bulk Density

Cross-section diameters of black bean extrudates were measured randomly with a digital caliper in millimeters at two different places, at the node and between the nodes. A total of 20 measurements were made per treatment, and the expansion ratio of the extrudates, in the form of rods, was calculated by dividing the cross-sectional area of the extrudates by the cross-sectional area of the 2 mm die orifice. Mean expansion ratios are reported. Bulk density was determined in triplicate with a sand displacement method as described by Edwards *et al.* (1994).

Color Evaluation

Nonextruded black beans and black bean extrudates were milled in a Udy mill (Udy Corporation, Fort Collins, CO) through a 0.5 mm screen before color evaluation. The colorimeter, a Minolta Chroma-Meter CR-200 (Minolta Corporation, Ramsey, NJ) equipped with a xenon lamp in the L*, a* and b* system, was calibrated with a white tile (L* = 94.4000; a* = 0.3134; b* = 0.3205). Color measurements were determined by holding the sensing head in direct contact with the surface of the flours. Triplicate measurements were determined at random surface locations on each flour. The L*, a* and b* readings obtained directly from the instrument provide measures of lightness, redness and yellowness, respectively. These readings were converted to the L*C*H* system by using a* and b* to calculate values of hue ($h°_{ab}$), a description of the color, and chroma ($C*_{ab}$), a measure of color saturation (vividness or dullness). Hue, the angle expressed in degrees from pure red at 0°, to yellow at 90°, green at 180° and blue at 270°, and chroma, the distance from the center of color space, were calculated as follows (X-Rite 1993):

$$\text{Hue is } h°_{ab} = \arctan(b^*/a^*) \text{ or } \tan^{-1}(b^*/a^*), \text{ whereas}$$

$$\text{Chroma is } C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$$

Statistical Analysis

For statistical analysis of color results, means of triplicate measurements of L*, hue and chroma at each concentration of $NaHCO_3$ for nonextruded and extruded bean flours were fit with a general linear model using the SAS GLM procedure (SAS 1989). The model was chosen to provide estimates and test statistics for the overall difference between extruded material and the nonextruded control (discrete effect for treatment), the change across concentrations of $NaHCO_3$ (regression – linear or curvilinear) and, perhaps most importantly, the difference between the regression for extruded and for nonextruded flour (interaction). For ease of interpretation, results are presented graphically with prediction lines and 95% confidence intervals. For this purpose, the SAS/GRAPH Software Version 6 (SAS 1990) was used.

RESULTS AND DISCUSSION

Microstructural Evaluation

Scanning electron microscopy observation of cross sections of black bean control extrudates exhibited the presence of small numbers of air cells of irregular size (Fig. 1a). Also, the control extrudate exhibited the smallest overall expansion when compared to extrudates with added $NaHCO_3$. Entire cross sections of extrudates are presented at equivalent magnifications of 1 mm to illustrate changes in air cell dimensions (Fig. 1a–f). Addition of $NaHCO_3$ decreased the mean air cell size and promoted air cell size uniformity. Moreover, the number of air cells increased and cell wall thickness decreased with an increase in $NaHCO_3$ concentration. The combined effect of these two development factors may result in the collapse of cell walls and the appearance of large void spaces within the extrudates. The collapse of cell walls and the appearance of large void spaces within the extrudates was observed as the expansion volume of the extradite increased with an increase in $NaHCO_3$ concentration (Fig. 1b–f). Similarly, Lai *et al.* (1989) reported that

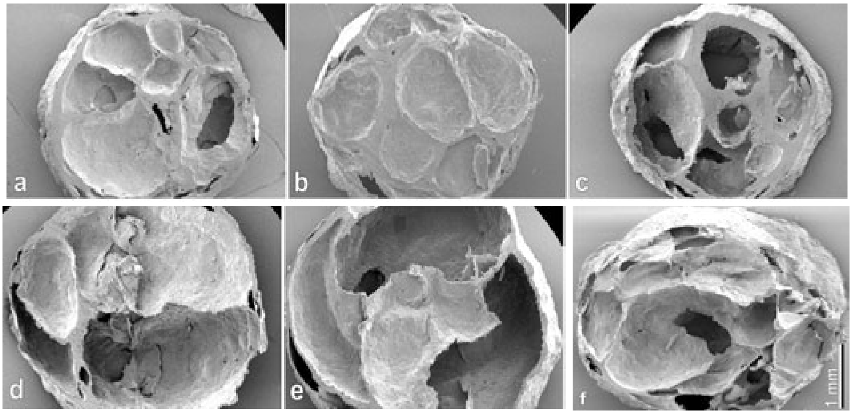

FIG. 1. SEM CROSS SECTIONS OF BLACK BEAN EXTRUDATES WITH $NAHCO_3$ AT CONCENTRATIONS:
(a) 0%; (b) 0.1%; (c) 0.2%; (d) 0.3%; (e) 0.4%; and (f) 0.5%. Magnification bar = 1 mm.

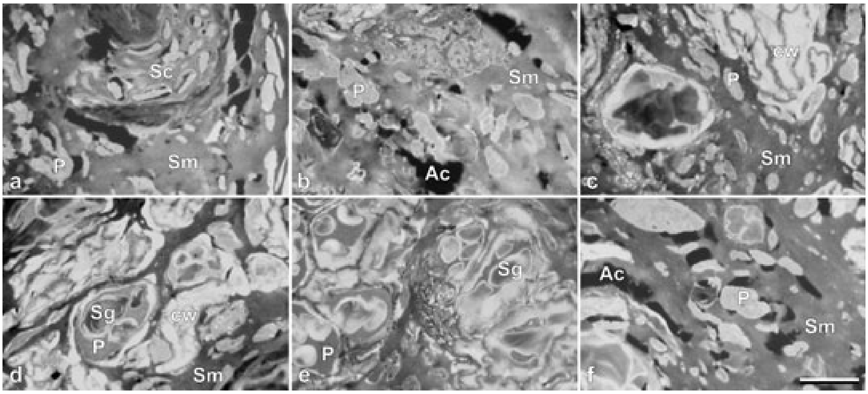

FIG. 2. FLUORESCENCE (450–490 NM) MICROGRAPHS OF EXTRUDED BLACK BEAN SECTIONS STAINED WITH SAFRANIN O
Extrudates contained concentrations of $NaHCO_3$: (a) 0%; (b) 0.1%; (c) 0.2%; (d) 0.3%; (e) 0.4%; and (f) 0.5%. Cellular components may be differentiated by color: cotyledon cell walls (cw) are bright yellow; proteins (P) are red (inside cells) to orange (in matrix); starch granules (Sg) occur inside intact cells and appear yellow (less gelatinized) to green (more gelatinized). Gelatinized starch makes up the matrix (Sm) of the extrudate; protein (P); air cells (Ac); seed coat (Sc); cell wall (cw). Magnification bar = 50 µm.

the addition of sodium bicarbonate or sodium carbonate to wheat starch improved expansion but weakened the structure of wheat starch extrudates.

The air cell walls of black bean extrudates are composed mainly of gelatinized starch matrices, cooked protein inclusions (Fig. 2), cotyledon bean

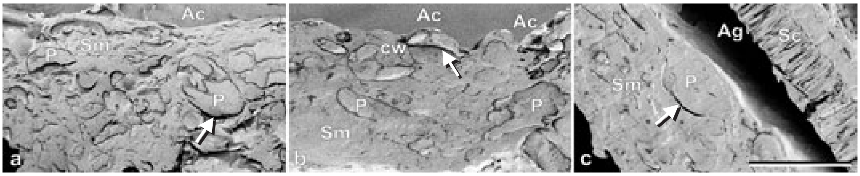

FIG. 3. SEM SECTIONS EXHIBITING AIR CELL WALLS OF BLACK BEAN EXTRUDATES WITH ADDED $NaHCO_3$ AT (a) 0%; (b) 0.4%; AND (c) 0.5%
Small air gaps (arrows) are evident between the cellular components (cell walls, cw; protein, P) and starch matrix (Sm). Large air gaps (Ag) appear between the cotyledon and seed coat (Sc) tissues. Magnification bar = 100 μm.

cell wall components (Fig. 2c), intact cells containing partly gelatinized starch granules and protein (Fig. 2d,e), and seed coat fragments (Figs. 2a and 3c). Most cellular components are readily identified in SEM micrographs by correlating the shapes to the stained components viewed by light microscopy. The starch matrices expand (Figs. 2a,f and 3), and protein networks become smoother and more elongated with increasing concentrations of $NaHCO_3$ (Fig. 2). Air cell walls containing heat-denatured proteins (Fig. 2b,f) and seed coat fragments embedded in the gelatinized starch matrix were observed (Figs. 2a and 4c,d). Seed coat fragments embedded in the gelatinized starch matrices were also observed in drum-dried black bean flakes by Wood *et al.* (1998), indicating that thermal processing did not destroy seed coat fragments.

Large air gaps occurred at the junctions of the seed coat and starch matrix constituents (Fig. 3c), and smaller air gaps were observed among proteins and starch matrices (Fig. 3). The numbers of small air cells and smaller pores (tiny air cells) increased with increasing concentrations of $NaHCO_3$. The relative amounts of space occupied by the starch matrices, as indicated by fewer protein inclusions in a field of view, also increased with increasing $NaHCO_3$ concentrations (Fig. 4). The tiny air cells were more evident in the gelatinized starch matrices at high magnification and also observed in the cooked protein inclusions (Fig. 5a,b,c,e). However, these tiny air cells were less abundant than those in the gelatinized starch matrices. Fractured protein inclusions containing pores with jagged edges were attributed to fracturing that occurred during preparation of extrudates for SEM. Protein bodies contain crystalline inclusions of phytic acid that were apparently retained in the protein associations after extrusion. The hard crystals of phytic acid may be responsible for the jagged edged pores in the protein associations (Fig. 5d).

$NaHCO_3$ and Diameter, Expansion Ratio and Bulk Density

Expansion of the extrudates was evident when the molten bean mixture was expelled under high pressure through the extruder restriction dies (2 mm

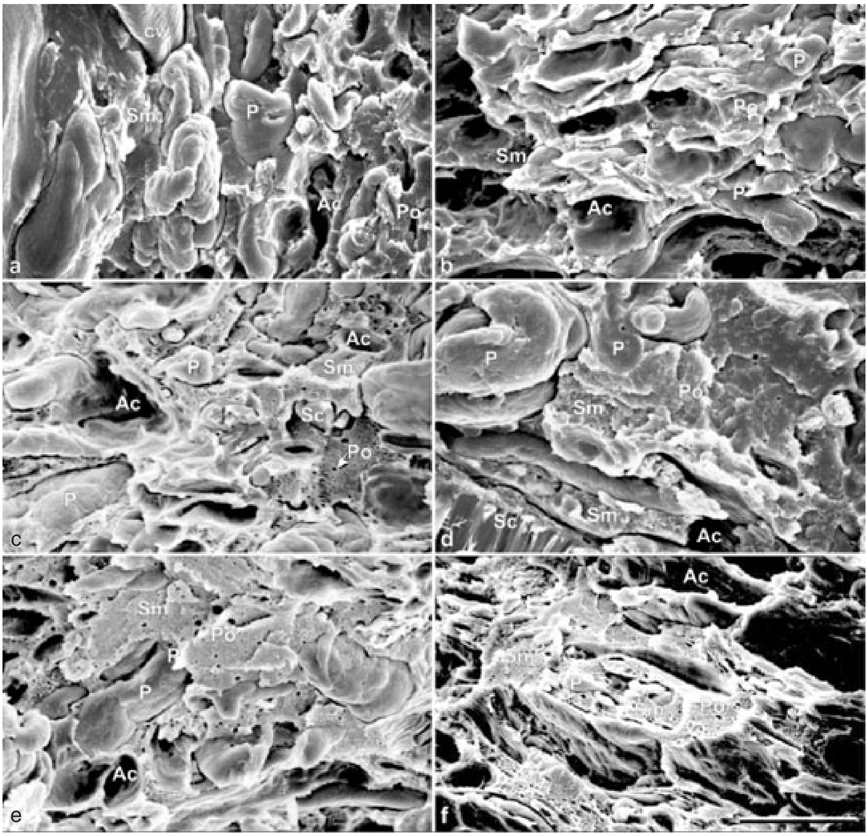

FIG. 4. SCANNING ELECTRON MICROGRAPHS EXHIBITING AIR CELL WALLS OF BLACK BEAN EXTRUDATES WITH ADDED $NaHCO_3$ AT (a) 0%, CONTROL; (b) 0.1%; (c) 0.2%; (d) 0.3%; (e) 0.4%; AND (f) 0.5%

The numbers of small air cells (Ac) and small pores (Po) increase with increasing concentrations of $NaHCO_3$. Other cellular components observed are: starch matrix (Sm), protein (P) and cell wall (cw). Magnification bar = 20 μm.

diameter) in the form of rods. The rapid reduction in pressure resulted in intensive flash-off of internal moisture and the subsequent expansion of the extrudate. Guy and Horne (1988) reported that the elastic character of the molten extrudate creates a die swell, which controls the overall expansion of the extrudate.

Temperature of the molten bean extrudate was determined at the dies before measurement of extrudate rod diameter. The extruded material close to the die was too hot and too soft for diameter measurement. Therefore, the

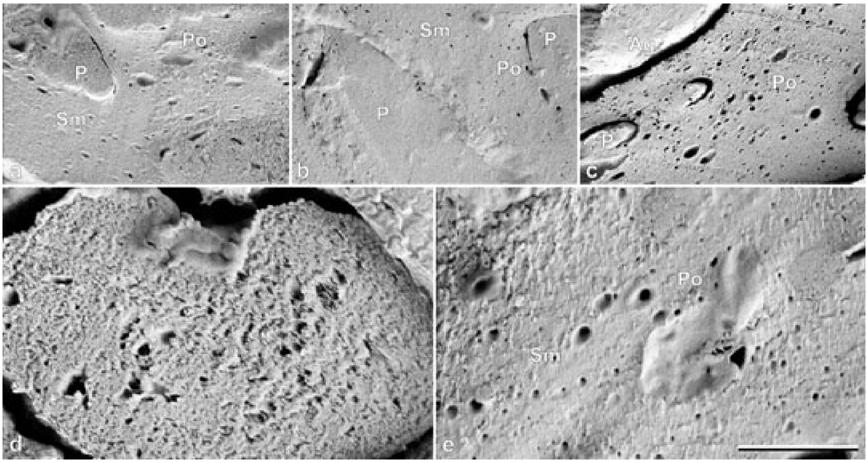

FIG. 5. SCANNING ELECTRON MICROGRAPHS EXHIBITING AIR CELL WALLS OF BLACK BEAN EXTRUDATES WITH ADDED $NaHCO_3$ AT (a) 0%; (b) 0.3%; (c) 0.4%; (d) 0.4%; AND (e) 0.5%.
Cellular components observed are: small pores (Po); protein (P); starch matrix (Sm); and air gap (Ag). Pores with jagged edges are also observed (e). Magnification bar = 5 μm.

extruded material was cooled to room temperature before the diameter was determined. The diameter of the extrudate decreased slightly upon cooling and setting of the extrudate structure. Mercier *et al.* (1989) also reported that as the temperature of the extruded melt decreased, the extrudate solidifies and retains its expanded shape. Carbon dioxide is produced during heating (Bennion 1980) or dissolving of $NaHCO_3$ in aqueous media (Anonymous 1983) according to the following reaction:

$$2\ NaHCO_3 \text{ ------ Heat + Water } \dashrightarrow Na_2CO_3 + CO_2 + H_2O.$$

The conversion is 100% at 100C. As the bean flour–$NaHCO_3$ mixtures were heated at 20% moisture during extrusion cooking, production of CO_2 and a subsequent increase in expansion of the extrudates was expected. The increase in number of air cells within the extrudate and the increase in number of pores (tiny air cells) in the gelatinized starch matrices of the air cell walls with an increase in concentrations of $NaHCO_3$ (Figs. 1 and 4) may be attributed to an increase in CO_2 released during extrusion processing. The increases in diameters and expansion ratios of the extrudates with an increase in $NaHCO_3$ concentrations (Table 1) additionally explain the increase in CO_2 released during extrusion processing. Therefore, expansion characteristics of black bean extrudates corroborate SEM observations.

TABLE 1.
DIAMETER, EXPANSION RATIO AND BULK DENSITY OF EXTRUDATES WITH INCREASED CONCENTRATIONS OF $NaHCO_3$

	Diameter (mm) at the nod	Diameter (mm) between the nod	Expansion ratio at the nod	Expansion ratio between the nod	Bulk density (g/cm^3)
Control	5.18 ± 0.13	4.77 ± 0.12	6.70 ± 0.33	5.68 ± 0.28	0.35 ± 0.00
0.1% $NaHCO_3$	6.64 ± 0.32	5.71 ± 0.27	11.03 ± 1.06	8.18 ± 0.78	0.32 ± 0.01
0.2% $NaHCO_3$	6.88 ± 0.31	5.61 ± 0.36	11.86 ± 1.08	7.90 ± 1.01	0.33 ± 0.00
0.3% $NaHCO_3$	6.90 ± 0.35	5.76 ± 0.27	11.92 ± 1.19	8.30 ± 0.79	0.28 ± 0.01
0.4% $NaHCO_3$	7.25 ± 0.30	6.03 ± 0.29	13.14 ± 1.09	9.10 ± 0.88	0.26 ± 0.00
0.5% $NaHCO_3$	7.34 ± 0.28	6.29 ± 0.26	13.48 ± 1.02	9.92 ± 0.82	0.24 ± 0.01

Diameter measurements taken at the node and at the area between the nodes demonstrated that the diameter of these two regions increased proportionally with increased $NaHCO_3$ concentration in the extrudates, and that there is a significant difference between the control extrudate and extrudates containing $NaHCO_3$ (Table 1). Also, the standard deviations of the control extrudate diameters and the diameters of the extrudates containing $NaHCO_3$ were large. However, the standard deviations around the mean diameter within the extrudates containing $NaHCO_3$ were small within the range of 0.28–0.35 at the node, and from 0.26 to 0.36 in the area between the nodes.

The increase in extrudate diameters is reflected in the expansion ratios. Expansion ratio is a measure of the cross-sectional area expansion of the extrudate. Expansion ratio increased 1.6-fold at the node and 1.4-fold in the area between the nodes for the control extrudate and the extrudate containing 0.1% $NaHCO_3$, respectively. The difference among expansion ratios increased to 2.0 and 1.8-fold for extrudates containing 0.5% $NaHCO_3$ at the designated cross-sectional areas. Differences in expansion distribution patterns of extrudates are important to consider in the fabrication of selected snack-type products.

Bulk density, expressed as g/cm^3, is also a measurement of expansion of the extrudate. Edwards *et al.* (1994) indicated that bulk density considers sample weight and the three dimensional changes of the extrudate resulting from expansion at the die. Bulk density is inversely related to expansion ratio, and bulk density decreased with an increase in $NaHCO_3$ addition from 0.35 to 0.24 g/cm^3 for control extrudate and extrudate with 0.5% $NaHCO_3$, respectively (Table 1). This suggests that the mass of the extrudate became lighter and expanded more with the addition of greater concentrations of $NaHCO_3$. Bulk densities were similar to those reported for small white bean extrudates processed with selected moisture contents, barrel temperatures and screw configurations in the range of 0.34–1.11 g/cm^3 (Edwards *et al.* 1994).

Color Evaluation

The colorimetric data for parameters of lightness (L*), hue angle ($h°_{ab}$) and chroma (C^*_{ab}) are presented in Fig. 6. Lightness (L*) data were well defined by a linear regression model across concentrations of $NaHCO_3$ for both extruded and nonextruded black beans. For the nonextruded bean flours, a small difference of 0.5 L* units between the control (0% $NaHCO_3$ addition) and bean flours with 0.5% $NaHCO_3$ addition was observed. However, this change was not statistically significant ($P = 0.11$), as demonstrated by comparing the computed slope to a slope of zero. After extrusion processing, a difference of more than 3 L* units existed between the control bean flours and bean flour extrudates containing 0.5% $NaHCO_3$. The importance of this change was confirmed by a highly significant ($P < 0.0001$) and negative slope. As a consequence of the stated differences, the slope of L* across concentrations of $NaHCO_3$ differed significantly ($P = 0.002$) for the nonextruded and extruded bean flours as tested with interaction in the model. Additionally, a large decrease of 14 L* units occurred between the control nonextruded and extruded bean flours, which increased to 17 L* units between the control and black bean flours containing 0.5% $NaHCO_3$.

Three important conclusions (Fig. 6) are confirmed by the statistical tests. First, the addition of $NaHCO_3$ in the selected concentrations did not significantly affect the lightness of nonextruded bean flours as exhibited by the lack of significance ($P = 0.11$) of the computed slope. Second, the black bean flours became darker after extrusion processing as exhibited by a large (14 L* units) and highly significant ($P < 0.0001$) decrease in lightness between the control nonextruded and extruded bean flours. Third, extruded bean flours darkened more with increasing concentrations of $NaHCO_3$ as exhibited by the negative and highly significant ($P < 0.0001$) slope. The L* values obtained for extruded bean flours were higher (lighter) than the L* values reported for cereal snack products reported in the range of 45–55 L* value (Wolk 1999). Cereal snack products generally contain reducing sugars that promote nonenzymatic browning, the Millard reaction, which promotes darkening of the cereal snack products.

Hue values (type of color) led to conclusions similar to those observed for L* values. The slope of hue relative to $NaHCO_3$ was not significantly different from zero ($P > 0.5$) for the nonextruded flours. Also, this slope was highly significant ($P < 0.0001$) for the extruded flours, but the slope was positive for hue, indicating an increase in hue angle values (increasing yellow) with addition of greater concentrations of $NaHCO_3$. As with L*, a

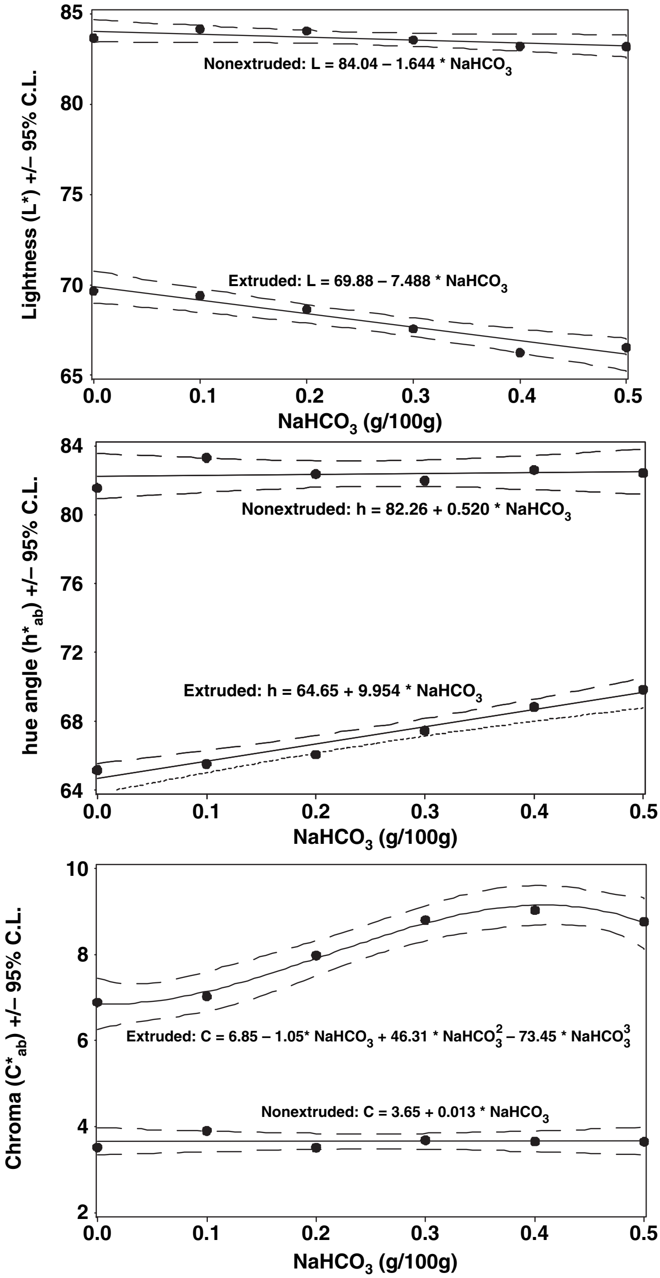

FIG. 6. COLORIMETRIC PARAMETERS FOR LIGHTNESS (L*)
Hue [$h°_{ab}$ = arctan (b*/a*)] and Chroma [$C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$].

large decrease of approximately 17° occurred between the control nonextruded and extruded bean flours. The differences decreased to about 13° with the addition of the greatest concentration of $NaHCO_3$, indicating that while extruded black bean flours are more reddish-brownish than nonextruded black bean flours, the hue becomes closer to the hue of nonextruded flours after the addition of $NaHCO_3$. Berrios *et al.* (2002) reported that the pH of extruded bean flours increases with an increase in $NaHCO_3$, and the differences in pH variability were larger than pH variability of nonextruded flours. They attributed the larger increase in pH values of the extruded flours to more effective alkaline reactions of $NaHCO_3$ resulting from the combined effect of multiple extrusion processing operations such as mixing, kneading, shearing, cutting and cooking. Therefore, we conclude that the darker color of the extruded black bean flours was a result of nonenzymatic browning influenced by the pH and heating conditions of the bean flours during extrusion.

Chroma values (vividness of color) for nonextruded flours, as with L* and hue, were not influenced by concentrations of $NaHCO_3$ in the selected range as exhibited by a nonsignificant slope (Fig. 6). For extruded black bean flours, values of chroma did change with the concentration of $NaHCO_3$; however, a cubic polynomial was necessary to describe the trend as opposed to the linear regression which adequately explained changes in L* and hue values. Chroma values for extruded bean flour remained small, about 7 units through 0.1% addition of $NaHCO_3$, increased to a maximum of about 9 units in the range of 0.3 to 0.5% of added $NaHCO_3$ where chroma values leveled off, or started to decline at 0.5% concentration of $NaHCO_3$. The controls containing no added $NaHCO_3$ exhibited nearly a twofold increase in chroma between the nonextruded and extruded bean flours, which increased to approximately a 2.5 difference at the highest concentration of added $NaHCO_3$.

Color determination using L* values and hue angles supports previous visual evaluation of flour extrudates that led to the conclusion that addition of $NaHCO_3$ at concentrations greater than 0.4% were detrimental for extruded bean flours and considered unacceptable for the production of snack-type products (Berrios *et al.* 2002). It is more difficult to interpret chroma information because the data are not linear. Therefore, chroma may be of less practical use than L* and hue for the evaluation of extruded bean flours.

Because of the lack of extruded legume snacks on the market, there are neither discrete references nor established threshold or cut-off values for color development of an acceptable legume snacks. Therefore, the color data in this study serve as primary information in this regard.

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