EFFECT OF EXTRUSION ON ESSENTIAL AMINO ACIDS PROFILE AND COLOR OF WHOLE-GRAIN FLOURS OF QUALITY PROTEIN MAIZE (QPM) AND NORMAL MAIZE CULTIVARS

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ABSTRACT - Whole-grain flours of Quality Protein Maize (QPM) and normal maize were extruded under controlled conditions in order to evaluate the effect of extrusion on the essential amino acids profile and color of the raw material used in the production of maize based extrudates. Flours were conditioned to 150g/kg moisture and processed in a single screw extruder at a screw compression ratio of 3:1, screw speed of 80 rpm, and die head temperature of 130^{0}C, using two different die nozzle diameters (3 and 5 mm). Extrusion caused a diminishment in the contents of the essential amino acids isoleucine, leucine, lysine, threonine and valine when compared to their original flours ($P<0.05$). But, the contents of histidine, methionine, phenylalanine and tryptophan were not different for flours and extrudates of the same source ($P>0.05$). QPM samples, either raw or extruded, were significantly higher in lysine, methionine and tryptophan compared to samples of normal maize ($P<0.05$). Extrudates produced with yellow QPM flours were lighter than their correspondent raw material ($P<0.05$), different from that of yellow normal maize. This trend was also observed for redness (*a* values) in extrudates. On the other hand, white and yellow extrudates presented higher *b* values (yellowness) than their correspond raw flour. Despite the adverse effect of extrusion in the amino acid retention, the use of QPM flours in replacement of normal maize flours can provide maize extrudates with superior protein quality.

Key words: maize, quality protein maize, extrusion, essential amino acids, color.

EFEITO DA EXTRUSÃO NO PERFIL DE AMINOÁCIDOS ESSENCIAIS E COR DE FARINHAS INTEGRAIS DE CULTIVARES DE MILHO NORMAL E DE ALTA QUALIDADE PROTÉICA (QPM)

RESUMO - Farinhas integrais de milhos de alta qualidade protéica (QPM) e normal foram extrusadas sob condições controladas, com o objetivo de se avaliar o efeito da extrusão no perfil de aminoácidos essenciais e cor da matéria-prima utilizada na fabricação de extrusados de milho. As farinhas foram acondicionadas a 150g/kg de umidade e extrusadas em um extrusor de rosca simples com razão de compressão da rosca de 3:1, velocidade de rotação da rosca de 80 rpm e temperatura na cabeça da matriz de 130^{o}C, utilizando-se duas matrizes com diâmetros de abertura distintos (3 e 5 mm). A extrusão promoveu redução no conteúdo dos aminoácidos essenciais isoleucina, leucina, lisina, treonina e valina das farinhas de milho ($P<0.05$), entretanto, os conteúdos de histidina, metionina, fenilalanina, e triptofano não diferiram para as amostras de farinhas e extrusados de mesma origem ($P>0.05$). As farinhas e os extrusados de milho QPM apresentaram teores de lisina, metionina e triptofano superiores àqueles de milho normal ($P<0.05$). Os extrusados produzidos com farinhas de milho QPM amarelas apresentaram-se mais claros do que as farinhas que lhes deram origem ($P<0.05$), diferentemente das amostras de milho normal. Resultado semelhante foi observado para o índice de cor vermelha (valores *a*) para os extrusados. No entanto, extrusados brancos ou amarelos apresentaram maiores valores *b* (amarelo) do que as farinhas correspondentes. Apesar do efeito adverso da extrusão sobre a retenção de alguns aminoácidos essenciais, o uso de farinhas de milho QPM em substituição à farinha de milho normal pode conferir melhor qualidade protéica a extrusados de milho.

Palavras-chaves: milho, alta qualidade protéica, extrusão, aminoácidos essenciais, cor.

QPM (Quality Protein Maize), a specialty maize with increased levels of the essential amino acids lysine and tryptophan (Paes & Bicudo, 1995), has been produced in developing countries as a strategy to improve protein quality of maize-based products and help reduce protein-energy malnutrition. Among different processing techniques used to process shelf-stable and desirable maize products, extrusion is of major importance. Ready–to-eat breakfast cereals, snack foods, dry pet food, pre-gelatinized flours and instant maize flours are examples of maize based products manufactured through extrusion (Riaz, 1997). However, studies previously carried out to evaluate the effect of this technique on nutritive value of foods have shown that extrusion can adversely affect the retention of amino acids, therefore, reducing protein quality (Dahlin, 1991). Noguchi *et al.* (1982) registered losses varying from 0 to 40% of reactive lysine in extruded soy protein-enriched starch biscuits. Also, Bjorck and coworkers (1993) observed significant reduction of lysine content when a mixture of wheat/maize (130g/kg moisture) was extruded at 170°C and 80 RPM. Similar to these findings, Martinez *et al.* (1996) reported decrease in lysine content in maize grits due to extrusion. Reduction in lysine upon extrusion has been attributed to nonenzymatic browning or the Maillard reaction, which involves free amino groups of protein, peptides or amino acids, mainly that of lysine and a reducing sugar (Maga, 1989). The reaction results in the formation of colorful compounds, which confer either desirable or undesirable color properties to foods (Friedman, 1996). The rate of the reaction is highly dependent on reducing sugar content, free amino groups, and also on temperature and water activity (Harper, 1989). Low moisture content, high temperatures and high shear during extrusion have been shown to promote starch degradation with sugar production that may favor the Maillard reaction (Gomez & Aguilera, 1983; Gomez & Aguilera, 1984). Despite the importance of extrusion on protein quality of raw materials, there is a lack of information in the extrusion effect on essential amino acids present in Quality Protein Maize (QPM). Therefore, this research aimed: 1) to assess the effect of extrusion on amino acid content of whole-grain flours of QPM and normal maize extruded at the same processing conditions, and 2) to compare the essential amino acid contents and color of extruded QPM and normal maize whole-grain flours.

Materials and Methods

Sample identification

Kernels of the two Brazilian open-pollinated semi-flint QPM maize cultivars, the white BR 451 and the yellow BR 473, and the QPM semi-flint maize hybrid, the yellow BR 2121, were obtained from the Brazilian Agricultural Research Corporation, Embrapa Maize and Sorghum, Sete Lagoas, Minas Gerais State, Brazil. Grains were produced during the 1996 growing season on experimental plots located in Sete Lagoas, MG, Brazil. The yellow dent normal maize, Pioneer 3779, was provided by the Colorado State University Soil and Crop Sciences Department. Whole grain flours were produced through milling of the whole kernels using a Thomas-Willey Laboratory Mill, model 4 (Arthur M. Thomas Co., Philadelphia, PA) coupled with a 2mm-mesh screen.

Proximate composition

Unprocessed maize flours were analyzed for moisture, crude fat, ash, protein (N x 6.25) and total dietary fiber using standard procedures described by AACC (1995). Total carbohydrate was calculated by difference. Results were expressed on a dry basis.

Sample preparation for extrusion

Following initial proximate analysis, two 1,000 g replicates of each maize flour were adjusted to 150g/kg moisture by adding the appropriate calculated volume of distilled water at 20°C. Uniformity was obtained by mixing the material thoroughly for 15 minutes. Samples were allowed to equilibrate for 24 hours at 10°C in sealed plastic bags. Moisture content was determined prior to processing to ensure adequate moisture content.

Amino acid determination

Whole flours of various maize genotypes and their extrudates were analyzed for the amino acids histidine, leucine, isoleucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine, tyrosine and tryptophan using a reverse phase high performance liquid chromatograph Pico •TAG® amino acid analysis system (Waters Corporation, Milford, MA). Prior to the analyses samples of raw and extruded samples were ground through a 0.5mm mesh screen by using a UDY cyclone laboratory mill (UDY Corp., Fort Collins, CO. Tryptophan content was determined after protein hydrolysis with 4.2N NaOH followed by separation in the Pico•TAG® system with detection at 280nm according to the procedure described by Allred and MacDonald (1988). Methionine was determined according to MacDonald *et al.* (1985) through performic acid oxidation and acid hydrolysis. The modified Pico •TAG® method (Cohen *et al.* 1989) was used to analyze the content of the additional amino acids. Samples were hydrolyzed with 6N HCl for 24 hr under nitrogen atmosphere at 110°C followed by derivatization with methanol, triethylamine and phenylisothiocyanate (PITC). Resulting phenylthiocarbamate (PTC) amino acids were vacuum-dried and re-suspended with Pico •TAG® diluent. Aliquots (20µl) of the diluted samples were injected in the system. Detection was done at 254nm. The standard sample used for calibration and analysis was treated the same as the samples, except that only 8µl was injected. The mobile phase was Pico •TAG® eluents A and B added to $(Na)_2EDTA$. The column was set at 35°C.

Extrusion conditions

A Brabender Plasticorder single-screw extruder, Model PL-V500 (C.W. Brabender Instruments, Inc., South Hackensack, NJ) with a 19.05mm barrel diameter, a 20:1 length to diameter ratio and eight 0.79x 3.18mm longitudinal grooves was used for processing. A screw compression ratio of 3:1 along with die nozzles diameters of 3mm and 5mm, were also applied. Runs were performed at 130°C die head temperature, while keeping the screw speed at 80 rpm. Temperature was maintained with electrically heated, compressed air-cooled collars around the barrel. The extruder was fed full and the order of processing was chosen at random. Each extrusion run was brought to steady state as indicated by constant torque before sampling and data collection. Resulting extrudates were dried for 48 hours at room temperature (~20-21^{0}c and 30% relative humidity) before being evaluated for amino acids and color.

Color

Color was determined using a Chroma Meter model CR 310 (Minolta) set on the Hunter L, a, b values scale. The equipment was standardized with a white square, which had standards of L = 97.67, a = +0.03 and b = +1.63. For raw material samples, twenty grams of flour were placed into a 0.5cm diameter translucent plastic petri dish that was covered and coupled to the equipment in such a way that no external light was allowed. For extrudates, color was determined by using small dry pieces of each sample placed into the whole internal surface of a plastic petri dish. Three readings were taken for each replicate sample by rotating the petri dish and the average used for means comparisons.

Experimental design and data analysis

The experimental design was a completely randomized design with treatments organized as a two by two factorial. The two factors consisted of four levels for maize cultivars (BR 451, BR 473, BR 2121 and Pioneer 3779) and two levels for die diameter (3 and 5mm). The experimental unit was the extrusion at fixed moisture, die head temperature and screw speed. Dependent variables consisted of essential amino acids and *L*, *a* and *b* Hunter values. Data were analyzed applying ANOVA, using the Statistical Analysis System (SAS) 6.12 (SAS Institute, Cary, NC). Actual means separation was performed using the Least Significant Differences (LSD) test.

Results and Discussion

Proximate composition

The proximate composition for whole-grain flours is presented in Table 1. Moisture content ranged from 91.5 to 118.8 g/Kg, with Pioneer 3779 and BR 451 flours having the highest and lowest values, respectively. Carbohydrate content was significantly lower for BR 2121 (736.4 g/Kg) compared to the other QPM samples and the normal maize flours. In other QPM samples, carbohydrate content was significantly different from that for normal maize flour and ranged from 756.5 to 787.9 g/Kg. Pioneer 3779 flour had the lowest protein concentration (69.9 g/Kg). BR 451 (92.0 g/Kg) and BR 2121 (90.6 g/Kg) did not differ in protein content, but they were significantly higher compared to BR 473 (86.6 g/Kg) and Pioneer 3779. Similar to protein content, percent crude fat was significantly higher for the QPM flours than for Pioneer 3779 flour. Significant differences for crude fat were not observed between BR 451 (46.3 g/Kg) and BR 2121 (52.9 g/Kg) flours, where values were lower than that obtained for the flour of BR 473 (61.6g/Kg). The whole-grain maize flours did not differ in ash composition. However, dietary fiber concentration was significantly different among samples, respectively, 83.2 g/Kg, 91.6 g/Kg, 98.5g/Kg and 106.1g/Kg for BR 473, BR 451, Pioneer 3779, and BR 2121 flours. Although QPM cultivars were semi-flint maize types, their chemical composition most closely resembled the data previously published for normal dent maize (Watson, 1987).

Extrusion effect on essential amino acids

Extrusion conditions significantly affected the essential amino acid content of the whole-grain maize flours. However, the interaction of treatment (raw/extrusion through 3mm die/extrusion through 5mm die) with cultivar had no significance in amino acid content (P>0.05), which implies that essential amino acid content of the whole-grain flours of various cultivars was affected by extrusion through different dies in a similar way. Essential amino acids least square means for combined raw maize flours and their extrudates are shown in Table 2. Extrusion

TABLE 1. Proximate composition of raw whole-grain flours of normal and QPM maize cultivars (g/Kg).

Cultivars	Moisture	Carbohydrate[1]	Protein (Nx6.25)	Crude fat	Ash	Dietary fiber
		g/kg db				
Pioneer 3779	118.8[a]	787.9[a]	69.9[c]	32.4[c]	11.4[a]	98.5[b]
BR 451 QPM	91.5[c]	757.2[b]	92.0[a]	46.3[b]	12.9[a]	91.6[c]
BR 473 QPM	97.7[b]	756.5[b]	86.6[b]	61.6[a]	12.2[a]	83.2[d]
BR2121 QPM	96.8[b]	736.4[c]	90.6[a]	52.9[b]	14.1[a]	106.1[a]
CV	0.52	0.44	1.15	5.93	8.84	0.07
LSD	0.146	0.937	0.270	0.795	0.310	0.018

*db= dry basis; ** Values are the average of two replicates; *** Means with same superscripts in a column within the same group are not significantly different (P<0.05).
[1]calculated by difference.

TABLE 2. Essential amino acid content (mg/g protein) in raw whole-grain flours and their extrudates combined for maize cultivars.

Essential amino acids	Raw	Extruded	
	mg aa/g protein*	3mm die	5mm die
		mg aa/g protein (%loss)	
Isoleucine	36.8[a]	33.5[b] (8.9)	33.8[b] (8.2)
Leucine	133.5[a]	120.9[c] (9.4)	122.8[b] (8.0)
Lysine	30.1[a]	26.8[b] (10.1)	27.0[b] (10.2)
Methionine	20.6[a]	18.8[a]	18.8[a]
Phenylalanine	53.0[a]	48.5[a]	49.0[a]
Threonine	37.8[a]	34.5[b] (8.7)	34.8[b] (8.0)
Tryptophan	10.4[a]	9.5[a]	9.3[a]
Valine	48.1[a]	43.2[b] (10.2)	43.5[b] (9.6)
Histidine	27.4[a]	25.0[a]	25.5[a]

*Means followed by the same superscript in a row are not significantly different (P<0.05).

adversely affected the contents of the amino acids isoleucine, leucine, lysine, threonine and valine in maize flours (P<0.05), but it did not cause any alteration in the contents of methionine, phenylalanine, tryptophan and histidine (P>0.05). When the effect of die diameter on essential amino acid content was evaluated, only leucine was significantly affected. Its content was lower in extrudates obtained with a 3mm die (120.9 mg aa/g protein) compared to the 5mm die (122.8 mg aa/g protein) (P<0.05). It is possible that the low shear rate and low residence time resulting from the usage of a 5mm die played a protective role in leucine destruction. The extrusion effect on amino acid retention found in this study is in agreement with other findings reported for potato flakes (Maga and Sizer, 1979), extruded wheat flour (Bjorck *et al.*, 1984) and extruded maize meal (Beaufrand *et al.*, 1978). Among essential amino acids which presented losses, lysine was the most affected. Moreover, valine also underwent a high percent loss. Lysine loss was in accordance with results reported by other authors for different cereal-based products. Bjorck *et al.* (1984) reported a lysine loss of 25 and 37g/Kg for wheat flour extruded respectively at 150 and 200 rpm, applying 171°C and 15g/Kg moisture in a twin screw-extruder. Also, Bjorck *et al*. (1985) observed a 13g/Kg lysine loss when a maize starch biscuit dough was extruded in a twin-screw extruder at 170°C/13g/Kg moisture/80rpm. In agreement with the previous results, Lasekan *et al*. (1996) described a 10g/Kg lysine loss in whole-grain maize flour extruded in a twin-screw extruder at 45g/Kg feed moisture/135°C temperature. All authors have attributed the Maillard reaction as the main cause for lysine reduction. Perhaps, extrusion at low moisture and high temperature led to starch degradation, thus providing reducing sugars (Pham and Del Rosario, 1984) at the same time that it modifies protein structure, exposing reactive sites, which favors browning reactions (Mauron, 1990). Since the lysine ε-amino group has been referred to as a major reactant in the Maillard reaction (Mauron, 1990), it might explain the extrusion effect on this particular amino acid. Considering the higher *a* and *b* values observed for the extrudates as compared to raw flours (Tables 5 and 6), it might be possible that nonenzymatic browning reactions occurred during the extrusion of whole-grain maize flours, affecting the retention of lysine in the extrudates. Lorenz *et al.* (1974) reported a correlation between color measurements and lysine content in extruded triticale.

Cultivar was a statistically significant factor influencing essential amino acid composition of maize ($P<0.01$), even though the interaction treatment versus cultivar had no significance ($P>0.05$). Therefore, means of raw and extruded whole-grain maize flours (small and 5mm die) for each amino acid were pooled and the resulting means were compared among cultivars. The results are shown in Table 3. Isoleucine, leucine, phenylalanine and valine contents were not statistically different among cultivars ($P>0.05$). However, all QPM exhibited higher lysine and tryptophan contents compared to the normal maize, regardless of the extrusion effect on these essential amino acids. Lysine, the first reported limiting amino acid in normal maize (Paes and Bicudo, 1995), was significantly lower in BR 473 compared to BR

TABLE 3. Essential amino acids in QPM and normal maize combined raw whole flours and extruded materials.

Essential amino acids	Pioneer 3779	QPM		
		BR 451	BR 473	BR 2121
	mg aa/g protein*			
Isoleucine	37.3 a	33.0 a	34.7 a	33.7 a
Leucine	128.7 a	121.5 a	124.0 a	128.7 a
Lysine	24.3 c	28.7 ab	27.8 b	31.0 a
Methionine	16.3 c	18.7 bc	20.7 ab	21.8 a
Phenylalanine	50.7 a	47.0 a	52 a	51.0 a
Threonine	37.3 a	37.7 a	34.7 b	33.0 b
Tryptophan	7.7 c	9.3 b	10.3 b	11.5 a
Valine	45.7 a	43.2 a	44.0 a	47.0 a
Histidine	26.5 ab	25.3 bc	23.7 c	28.3 a

* Values are means of combined raw and extruded samples, which were the average of two replicates.
** Means followed by same letter in a row are not statistically different ($P<0.05$).

2121, whose content of this amino acid did not differ from BR 451. However, tryptophan, the second reported limiting amino acid in normal maize, was significantly higher in BR 2121 than in the other two QPM cultivars. Histidine was higher in Pioneer 3779 and BR 2121 compared to BR 473. But, the BR 451 and BR 473 did not statistically differ in this amino acid. BR 473 and BR 2121 presented more methionine compared to Pioneer 3779, which content did not differ from that of BR 451. Threonine was greater in Pioneer 3779 and BR 451 compared to BR 473 and BR 2121.

Color

L (Lightness)

The term lightness or brightness refers to the relationship between reflected and absorbed light, regardless of specific wavelength. The values range from 0 (black) to 100 (white), (Pomeranz and Meloan, 1994). Extrusion processing adversely affected L values of QPM and normal maize whole-grain flours, but die size was not a significant factor for this color property for all studied samples (P>0.05). Due to this fact, the pooled means for L values were obtained, and statistically analyzed. The resulting least square means of each cultivar is presented in Table 4, as well as the *L* value means obtained from the raw whole-grain maize flours. Extruded QPM samples were lighter in color compared to their raw flours (P<0.05), whereas the normal maize extrudate was darker than its correspondent raw flour (P<0.05). Yellow QPM extrudates of BR 2121 and BR 473 were significantly lighter than the normal yellow maize extrudates (P<0.05). The results were reversed for the raw materials (Table 4). Similar fading of color was observed on Hopi blue maize whole-grain flour extruded under temperatures above 120°C, when feed moisture content was 150 g/Kg (Maga and Liu, 1993). The fading was attributed to the partial destruction of pigments upon processing, resulting in extrudates with higher *L* values. Perhaps, the expansion of the dough upon exit the die has contributed to increase in the surface area and favored light dispersion, giving a lighter appearance to the puffed products.

a (Redness)

The *a* value or redness in a Hunter scale determines green, gray and red color of a product. Positive *a* value refers to red, negative to green, and values near zero indicate gray (Pomeranz and Meloan, 1994). Both raw whole-grain maize flours and their correspondent extrudates had positive *a* values (Table 5). However, extrusion under 15g/Kg moisture/130°C die head temperature, for any die

TABLE 4. Hunter L value (lightness) in different raw whole-grain flours of various maize cultivars and their extrudates.

Source of flour	L value*	
	Raw flours	Extruded samples**
BR 2121 QPM	$63.7^{c\,B}$	$73.5^{a\,A}$
BR 451 QPM	$68.9^{b\,B}$	$72.9^{a\,A}$
BR 473 QPM	$62.5^{d\,B}$	$71.5^{a\,A}$
Pioneer 3779	$69.7^{a\,A}$	$61.6^{b\,B}$

*Values are the average of two replicates and represent the extrusion condition 150g/Kg moisture/130°C
** Pooled least square means of 3mm and 5mm die diameters.
*** Means followed by the same lower case superscript in a column within a group are not significantly different P<0.05
**** Means followed by the same capital superscript in a row are not significantly different P<0.05.

diameters, caused reduction in the redness values of the yellow QPM whole-grain flours (P<0.01). Conversely, the processing did not significantly alter the *a* value of the BR 451 white flour. A low *a* value might be caused by temperature and shear effect on pigments present in yellow maize, since *a* value of the white color BR 451 flour was not affected by extrusion (P>0.05). Maga (1989) mentioned that heat applied in the raw material during extrusion might damage anthocyanins, the pigments naturally present in maize kernels. Also, Marty and Berset (1986) demonstrated that extrusion cooking severely affected beta-carotene, the major carotene in maize. Moreover, die diameter significantly affected BR 2121 QPM extrudate redness. For the extruded samples obtained with a 3mm die, the average *a* value was significantly higher (2.26) than that observed (1.33) for extrudates resulting of a 5mm die (P<0.05) (Table 5). It is possible that extrusion of BR 2121 flour through a 3mm die opening, which is related to high shear, high dough temperature and longer residence time (Miller, 1990), promoted formation of compounds, such as those originated by the Maillard reaction (Friedman, 1996), which might have produced red color in the extrudate, despite of possible destruction of the BR 2121 flour natural pigments. In contrast, extrusion of the BR 2121 flour through a 5mm die have protected against the increases in *a* value due to the possible shorter residence time, less shear, and lower pressure associated with faster dough flow of a larger outlet die. Low shear results in less energy dissipation and thus less heat generated within the barrel. Besides, reduced residence time implies less exposure to heating (Miller, 1990), thus reducing the chances for Maillard reaction to occur.

b (Yellowness)

Extrusion significantly altered the yellowness of the maize flours (P<0.05) (Table 6). For all cultivars, the *b* values were significantly higher for the extrudates (P<0.05) than for the raw maize flours, which indicates more yellow products (Table 6). Die diameter was not a cause of variation in the yellowness (P>0.05) of same QPM flour. Extruded yellow QPM flours, BR 473 and BR 2121, within the 3mm die group, were not significantly different with regard to *b* value compared to the normal maize (Pioneer 3779) extrudate (P>0.05). In contrast, the BR 451 extrudate had a significantly lower *b* value than the other three materials in the same die group. This result was expected since BR 451 QPM flour was white. Extrudates of QPM yellow cultivars obtained through a larger die diameter had higher *b* values as compared to those of the normal maize extrudates (P<0.05), which also had a higher *b* value (P<0.05) than BR 451.

TABLE 5. Hunter *a* value (redness) of raw whole-grain maize flours of various cultivars and their extrudates.

Source of flour	a values*		
	Raw flours	[1]Extruded samples	
		3mm die	5mm die
BR 2121 QPM	$2.87^{b\,A}$	$2.26^{b\,B}$	$1.33^{b\,C}$
BR 451 QPM	$0.27^{d\,A}$	$0.64^{c\,A}$	$0.15^{c\,A}$
BR 473 QPM	$3.85^{a\,A}$	$2.03^{b\,B}$	$1.73^{b\,B}$
Pioneer 3779	$1.60^{c\,C}$	[2]$5.20^{a\,A}$	$2.37^{a\,B}$

* Values are the average of two replicates
** Means followed by same superscript in the column within a group are not significant different P<0.05
*** Means followed by the same capital superscript in a row are not significant different P<0.01
[1] 150g/Kg moisture/130°C extrusion temperature, except as indicated.

TABLE 6. Hunter *b* value (yellowness) of raw whole-grain maize flours of various cultivars and their extrudates.

Source of flour	b value*		
	Raw flours	[1]Extruded samples	
		3mm die	5mm die
BR 2121 QPM	25.95$^{b\ B}$	42.43$^{a\ A}$	41.28$^{a\ A}$
BR 451 QPM	13.39$^{d\ B}$	23.62$^{b\ A}$	20.88$^{c\ A}$
BR 473 QPM	26.17$^{a\ B}$	43.28$^{a\ A}$	42.45$^{a\ A}$
Pioneer 3779	20.16$^{c\ C}$	[2]42.42$^{a\ A}$	34.41$^{b\ B}$

* Values are the average of two replicates
** Means followed by same lower case superscript in a column within a group are not significantly different P<0.05
*** Means followed by the same capital superscript within a row are not significantly different P<0.05.
[1] Values represent the extrusion conditions 150g/Kg moisture/130°C temperature.

Conclusion

Extrusion adversely affected the contents of essential amino acid present in QPM and normal maize whole-grain flours, although the improved essential amino acid profile of QPM is maintained even after processing. Therefore, the use of whole-grain QPM flours in replacement of normal maize flours can provide extrudates with superior protein quality. But, attention shall be given to color modification of yellow maize flours processed through extrusion since the process affects lightness, redness and yellowness.

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