

Nonenzymatic Browning During Storage of Infant Cereals

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ABSTRACT

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The browning indicators furosine and color were determined in infant cereals and infant cereals containing powdered milk to evaluate the utility of these parameters for monitoring storage. Studies were made on seven infant cereal samples including both gluten and gluten-free products. Samples were stored under laboratory conditions at 28°C for four or 16 weeks; or under modified water activity conditions at 25°C or 55°C for one, two, three, or four weeks; or under industrial conditions in air or nitrogen atmospheres at 32°C or 55°C for one, three, six, or 12 months. Furosine levels increased during the storage of infant cereals containing

powdered milk under all time, temperature, and water activity (a_w) conditions assayed, except drastic conditions (55°C, $a_w = 0.65$). Color values increased in infant cereals with gluten (7-cereal and 8-cereal samples), regardless of milk content, when they were stored under drastic conditions (55°C or 25°C with normal or modified water activity). However, the gluten-free infant cereals (rice-corn and rice-corn-soy samples) that have a characteristic yellow color showed no increase in color during storage. The extent of the Maillard reaction was greatest in the infant cereals that included milk in their formulation.

Infant cereals are the first complementary foods given to babies because they provide a major source of energy and can be easily assimilated. In Mediterranean countries, they form the basis of weaning-feeding from the age of four to six months and were recently recommended as a means to prevent intolerance to foods (Molina Font and Maldonado 2000).

Commercial infant cereals are mostly composed of cereal flours (either with gluten or gluten-free) and additional legume flours such as soy. Other ingredients included in these cereals are sucrose, glucose, or fructose syrup, honey, powdered fruit, biscuits, minerals, vitamins, and flavors. These products can be commercialized with or without powdered infant milk formula and the consumer must reconstitute them with the addition of water or liquid infant milk formula before use.

Industrial production of infant cereals involves toasting and/or boiling, hydrolysis, and dry steps designed to improve sensory qualities, digestibility, safety, and shelf-life. Browning reactions (Maillard reaction and caramelization) occur during this process (Fernández-Artigas et al 1999; Guerra-Hernández et al 1999). These products have a long shelf-life and can usually be consumed for up to two years after manufacture. The length and conditions of storage and the specific composition of the cereals can all influence the progress of nonenzymatic reactions.

The early stages of the Maillard reaction can be evaluated by determination of furosine (ϵ -*N*-(furoylmethyl)-L-lysine) amino acid formed during acid hydrolysis of the Amadori compounds fructosyl-lysine, lactulosyl-lysine, and maltulosyl-lysine that are produced by the reaction of ϵ -amino groups of lysine with glucose, lactose, and maltose (Erbersdobler and Hupe 1991). Furosine determination has been used in cereals to control the processing of pasta (Resmini and Pellegrino 1994), bakery products (Henle et al 1995; Ramirez-Jimenez et al 2001), and infant cereals (Guerra Hernández et al 1999).

Brown pigments are formed in the advanced stages of browning reactions and can be measured by color determination. Color measurement provides a useful index to evaluate the intensity of browning reactions and has been used to monitor the processing of infant cereals (Fernandez-Artigas et al 1999) and bread (Ramírez-Jiménez et al 2000; Ramírez-Jiménez et al 2001). Studies have been published on the effects of processing infant cereals on browning reactions but not, to our best knowledge, on the impact of long storage periods.

With this background, we used furosine and color determinations to assess the effects of normal and adverse storage conditions (temperature, time, atmosphere, and humidity) on the browning of infant cereals. The study evaluated the utility of furosine and color as damage indicators in the storage of these food products and assessed the influence of the addition of powdered milk.

MATERIALS AND METHODS

Samples

Infant cereal samples with and without powdered infant milk were obtained from a dietetic products company. The seven samples were 7-cereal (brand containing wheat, rice, barley, corn, rye, oat, millet, and soy flours); 7-cereal+milk (including powdered milk); 8-cereal (brand containing wheat, rice, barley, corn, rye, oat, millet, sorghum, and soy flours); 8-cereal+milk; rice-corn (brand containing rice and corn flours); rice-corn+milk; and rice-corn-soy+milk (containing rice, corn, and soy flours). According to the label information, the milk-free cereals all contained 80% flour as well as sucrose, caramel, vitamins, minerals, and flavors. The infant cereals with milk contained $\approx 40\%$ powdered infant milk (follow-up formula). The samples with rice and corn were described as being gluten-free.

The samples were stored under industrial or laboratory conditions. Industrial conditions consisted of storage at 32 or 55°C for one, three, six, or 12 months in air or nitrogen atmospheres. The industry uses a nitrogen atmosphere to preserve the commercial product and 32 and 55°C to security and stability studies. Laboratory conditions consisted of storage at 25 or 55°C for one, two, three, or four weeks in air atmosphere with controlled water activity ($a_w = 0.65$), or at 28°C for one and four months. This water activity level was maintained using the procedure of Salmarch and Labuza (1980): placing samples in a Petri plate on the upper shelf of a desiccator containing sodium nitrite saturate solution. Samples were analyzed before storage and again after storage at different conditions. Samples were kept at -50°C until analysis.

Furosine Determination

Furosine was determined using the method described by Guerra and Corzo (1996). Briefly, 150 mg of the sample, weighed with analytical accuracy, was hydrolyzed with 4.5 mL of 7.95M HCl at 110°C for 24 hr in a Pyrex screw-cap vial with PTFE-faced septa. High-purity N_2 gas was bubbled through the solution for 2 min. The hydrolysate was filtered with a medium-grade paper filter. A 0.5-mL portion of filtrate was applied to a Sep-pak C_{18} cartridge (Millipore) prewetted with 5 mL of methanol and 10 mL of deionized water and then eluted with 3 mL of 3M HCl and evaporated under vacuum (Resmini et al 1990). The dried sample was dissolved in 3 mL of a mixture of water, acetonitrile, and formic

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acid (95:5:0.2); 50 μL of the resulting solution was introduced into a liquid chromatograph (model 250, Perkin-Elmer, Norwalk, CT) with an autosampler (Waters 717 Plus, Milford, MD) and a diode array detector (Perkin-Elmer model 235). Data were collected with a 1020 software data system (Perkin-Elmer). The furosine was separated using a Spherisorb ODS2 5 μm (250 mm \times 4.6 mm i.d.) (Phenomenex, Torrance, CA). The mobile phase consisted of a solution of 5 mM sodium heptane sulfonate with 20% acetonitrile and 0.2% formic acid (Delgado et al 1992). The elution was isocratic and the flow rate was 1.2 mL/min. The UV detector was set at 280 nm. Duplicate samples were analyzed. The external standard method was used for quantification. A standard stock solution containing 1.2 mg/mL of furosine (Neosystem Laboratoires, Strasbourg, France) was used for the working standard solution. The calibration was performed by adding increasing quantities of furosine standard, within the expected concentration range, to a previously hydrolyzed wheat flour sample. The curve was constructed by plotting the measured absorbance expressed in units of area against micrograms of added furosine. The equations for the curves were $Y = 9756878.61 \times -36197.418$ (range 0.0383–0.3830 μg) $r^2 = 0.9999$, and $Y = 9584643.42 \times +15901.2$ (range 0.0193–0.0958 μg) $r^2 = 0.9999$.

Color Determination

The color of cereal samples was measured using the CIE $L^*a^*b^*$ color system, where L^* is lightness, a^* is redness, and b^* is yellowness. The instrument used was a reflectance spectrophotometer (Elrepho 2000, Data-color S.A., Spain). The colorimetric parameters L^* , a^* , and b^* were referred to illuminant D_{65} , and the instrument was calibrated using a BaSO_4 standard.

The results are also expressed as the color difference (ΔE) between the sample before storage ($t = 0$) and the sample after different storage periods, using the equation proposed by Francis and Clydesdale (1975): $\Delta E = (\Delta L^2 + \Delta b^2 + \Delta a^2)^{1/2}$, where ΔL = brightness difference, Δa = redness difference, and Δb = yellowness difference. Analyses were performed on triplicate samples.

Additional Determinations

Protein was determined using the Kjeldahl method (AOAC 1990) and reducing sugars were determined using Schoorl's method (Snell and Ettore 1971).

Statistical analysis used analysis of variance (ANOVA). The Student's t test was used to compare means; 95% was regarded as the level of significance.

Preliminary Studies

Furosine determination. The precision, reproducibility, recovery, and limit detection of furosine in infant cereals were previously studied (Guerra and Corzo 1996). The precision, expressed as relative standard deviation (RSD), was 3.73%; mean recovery was 94.7%, and detection limit was 5×10^{-1} $\mu\text{g/g}$ of sample.

Color determination. The reproducibility of the color method was studied in 8-cereal and 8-cereal+milk samples. The coefficients of variation (CV%) for 8-cereal were 0.93 and 0.10 for the values b^* and L^* , respectively. The 8-cereal+milk sample showed coefficients of variation of 0.39 and 0.49 for b^* and L^* , respectively. No variability was detected for a^* . The color was also assayed in six samples each of 7-cereal and 7-cereal+milk, taken from different packets of the same batch to determine possible color variability within batches. The coefficients of variation were 2.98, 0.69, and 0.04 for a^* , b^* , and L^* , respectively, in 7-cereal, and 5.00, 1.51, and 0.13 in 7-cereal+milk. These precision levels permit the evaluation of color variations during infant cereal storage. The color parameters considered in the present storage study were b^* and ΔE .

Storage of Infant Cereals

The prestorage furosine content of the infant cereals was 337–508 mg/100 g of protein (Table I), similar to values obtained in previous studies of these types of sample (Guerra-Hernández et al 1999). The 8-cereal sample showed the highest furosine content and also the highest reducing sugar (6.54%) and protein (10.4%) contents. The reducing sugar content of 7-cereal and rice-corn samples were 4.77 and 3.93%, respectively. The protein content was 9.48% in 7-cereal and 5.77% in rice-corn samples. The infant cereals that contained milk had a higher furosine content (450–612 mg/100 g of protein) and also a higher protein content (12.7–14.5%) compared with the milk-free samples. Infant formulas dried by spray-drying and produced by the same infant cereal manufacturer show furosine values of 701 mg/100 g of protein (Guerra-Hernández et al 2002).

Storage Under Laboratory Conditions

Storage at room temperature. All the infant cereals showed increased furosine content after 16 weeks of storage at room temperature (28°C) (Table I). In rice-corn samples, there was no increase in furosine content at four weeks of storage and a slight

TABLE I
Furosine Content (mg/100 g of protein, $n = 2$) in Infant Cereals Stored Under Laboratory Conditions

Time (weeks)	Cereals			Cereals with Milk			
	Rice-Corn ^a	7-Cereal ^b	8-Cereal ^c	Rice-Corn	Rice-Corn-Soy	7-Cereal	8-Cereal
Initial value ^d							
0	337 \pm 2.9	429 \pm 3.9	508 \pm 2.5	560 \pm 9.6	450 \pm 7.0	612 \pm 2.0	609 \pm 3.1
25°C (a_w 0.65)							
1	359 \pm 3.0	404 \pm 8.0	536 \pm 2.4	642 \pm 2.9	723 \pm 1.4	639 \pm 9.6	625 \pm 0.3
2	355 \pm 1.2	396 \pm 0.1	500 \pm 5.8	849 \pm 2.0	857 \pm 7.1	736 \pm 1.6	806 \pm 2.2
3	360 \pm 1.7	416 \pm 3.3	499 \pm 1.5	1,006 \pm 7.0	895 \pm 8.3	876 \pm 11.6	865 \pm 3.9
4	358 \pm 0.2	464 \pm 1.0	497 \pm 2.2	1,185 \pm 3.0	1,120 \pm 3.0	1,011 \pm 4.0	1,076 \pm 7.0
55°C (a_w 0.65)							
1	1,276 \pm 4.0	1,307 \pm 4.0	2,227 \pm 8.0	2,952 \pm 1.0	3,116 \pm 1.0	2,845 \pm 3.0	2,281 \pm 11.0
2	1,365 \pm 7.0	1,396 \pm 2.0	2,269 \pm 7.0	2,736 \pm 5.0	2,399 \pm 12.0	2,880 \pm 3.0	2,407 \pm 7.0
3	1,245 \pm 5.0	1,589 \pm 11.0	2,140 \pm 6.0	2,458 \pm 6.0	2,479 \pm 9.0	2,554 \pm 4.0	2,189 \pm 3.0
4	1,176 \pm 2.0	1,581 \pm 11.0	1,712 \pm 6.0	2,476 \pm 3.0	2,644 \pm 3.0	2,547 \pm 2.0	1,645 \pm 2.0
28°C							
4	323 \pm 3.9	468 \pm 5.5	564 \pm 0.8	595 \pm 5.5	706 \pm 4.0	668 \pm 8.4	674 \pm 4.4
16	411 \pm 7.5	470 \pm 1.9	616 \pm 9.2	778 \pm 3.2	892 \pm 4.8	833 \pm 4.6	811 \pm 0.7

^a Reducing sugars 3.93%; protein 5.77%.

^b Reducing sugars 4.77%; protein 9.48%.

^c Reducing sugars 6.54%; protein 10.4%.

^d Commercial samples (before storage).

increase at 16 weeks (74 mg/100 g of protein). In the 7-cereal sample, the furosine content increased at four weeks (39 mg/100 g of protein) but remained constant at 16 weeks. In the 8-cereal sample, the furosine content was greater at four weeks (56 mg/100 g of protein) and 16 weeks (108 mg/100 g of protein) of storage. These results are consistent with the higher reducing sugar and protein content of the 8-cereal sample compared with the 7-cereal or rice-corn samples. The increase in furosine was higher in samples that contained milk and was observed at four weeks (35–256 mg/100 g of protein) and 16 weeks (200–450 mg/100 g of protein) of storage in all cases (Table I). Infant cereals with milk have a higher protein and lysine content because of the presence of milk proteins. Powder infant formula similar to that added to these cereals was stored at 20°C for 15, 30, and 90 days and showed an increase of 305 mg of furosine/100 g of protein after 30 days (Guerra-Hernández et al 2002).

With respect to the color parameter, the b^* values of the infant cereals before storage were 12.4, 12.6, and 13.1 for rice-corn, 8-cereal, and 7-cereal samples, respectively (Table II). After four weeks of storage, the b^* value was significantly increased (0.9) in the 8-cereal sample, whereas the increase did not reach significance in the other samples (<0.4). Before storage, the samples containing milk showed b^* values of 12.4–14.2 (Table II), and after four weeks of storage at 28°C, the b^* value was increased by 1.5–2.4 and the ΔE value by 1.97–2.89. Storage for 16 weeks produced a slight decrease in both parameters, especially for the rice-corn samples. This phenomenon has also been observed in powder infant formula samples stored at 20°C for 12 weeks (Guerra-Hernández et al 2002). The inclusion of milk produces a greater browning that can be subjectively visually assessed because differences of one ΔE unit are detectable by the human eye.

According to the present study, furosine is useful for monitoring the Maillard reaction during storage at room temperature of infant cereals with milk, which have a high lysine content, and of 8-cereal samples, which contain no milk but have a high reducing sugar content.

Storage at room temperature with modified a_w Modified a_w (0.65) and room temperature conditions (25°C) were assayed to determine the influence of a high-humidity environment during short storage periods (1, 2, 3 or 4 weeks). There was little effect on furosine values in infant cereals without milk (Table I). However, the samples with milk presented a significant furosine increase ($P < 0.01$) for each storage period. After four weeks, there was an increase of ≈ 650 mg/100 g of protein in the gluten-free infant cereals (rice-corn+milk and rice-corn-soy+milk) and an increase

of ≈ 425 mg/100 g of protein in the wheat-based cereals (7-cereal and 8-cereal). The protein content of 8-cereals+milk and rice-corn+milk samples was 12.4 and 14.5%, respectively. Moreover, a previous study demonstrated that rice-corn infant cereals have a higher lysine content than the 8-cereal types (Ramirez-Jimenez 2001).

In the infant cereals without milk, the color parameter behaved differently from the furosine content. The 7-cereal and 8-cereal samples showed an increase of ≈ 2 in b^* value and an ΔE value of 2.5. However, the rice-corn sample showed a decrease of 0.4 in b^* value. The color increased in cereals with milk, as found for the furosine content, with an increase in b^* value ranging from 2.3 for 8-cereals+milk to 3.3 for rice-corn-soy+milk.

In infant cereals with milk, furosine was a more useful indicator than color under these storage conditions. For gluten infant cereals without milk (7-cereal and 8-cereal), color was more useful than furosine. The color parameter increased during the storage of infant cereals without milk, except in rice-corn, in which the b^* value decreased from 12.4 at baseline to 12.0 at four weeks.

Storage at 55°C with modified water activity. Drastic temperature (55°C) and water activity (a_w 0.65) conditions were also assayed (Table I). Furosine values in infant cereals without milk increased after one week of storage to 1,276–2,227 mg/100 g of protein. After two weeks of storage, furosine values showed a further slight increase (40–90 mg/100 g of protein). After three weeks, furosine values decreased in the rice-corn and 8-cereal samples (there was a greater degradation than formation of furosine). The behavior of the color parameter was similar, with a marked increase in the b^* value of ≈ 7 after one week of storage (Table II). The highest increase was observed in the 8-cereal sample, which had the highest reducing sugar content. The color increased during all storage periods, reaching a mean b^* value of 9.3 and ΔE of 16.1 after four weeks.

The infant cereals with milk presented higher furosine and color values compared with the infant cereals without milk. The furosine contents of the cereals with milk were 3.7–6.9-fold prestorage values after one week. The gluten-free samples showed the highest values at 55°C and a_w 0.65. The rice-based samples showed a decrease in furosine values after two weeks and the wheat-based samples after three weeks. The color increased during each week of storage in all samples. The increase in b^* after four weeks was 13.4 in the 7-cereal+milk sample and ≈ 18 in the gluten-free and 8-cereal samples with milk.

Color proved useful for monitoring nonenzymatic browning during the storage of infant cereals with and without milk under drastic conditions.

TABLE II
Color Changes^a ($n = 3$) During Storage of Infant Cereals Under Laboratory Conditions

Time (weeks)	Rice-Corn		7-Cereal		8-Cereal		Rice-Corn+Milk		Rice-Corn-Soy +Milk		7-Cereal+Milk		8-Cereal+Milk	
	b^*	ΔE	b^*	ΔE	b^*	ΔE	b^*	ΔE	b^*	ΔE	b^*	ΔE	b^*	ΔE
Initial value ^b														
0	12.4	...	13.1	...	12.6	...	13.6	...	14.2	...	12.5	...	12.4	...
25°C (a_w 0.65)														
1	12.5	0.43 ± 0.03	13.9	0.97 ± 0.02	14.5	2.11 ± 0.17	15.7	2.22 ± 0.03	16.0	1.84 ± 0.12	14.9	2.36 ± 0.05	14.1	1.89 ± 0.11
2	12.2	0.52 ± 0.01	14.6	1.57 ± 0.04	14.6	2.24 ± 0.20	15.9	2.43 ± 0.12	16.5	2.29 ± 0.05	15.0	2.62 ± 0.03	14.8	2.66 ± 0.13
3	12.1	0.45 ± 0.01	14.9	2.03 ± 0.06	14.9	2.59 ± 0.29	16.3	2.91 ± 0.01	16.8	2.59 ± 0.16	15.3	3.08 ± 0.00	14.7	2.51 ± 0.01
4	12.0	0.56 ± 0.01	15.2	2.45 ± 0.01	14.8	2.45 ± 0.24	16.5	3.00 ± 0.06	17.5	3.36 ± 0.00	15.7	3.69 ± 0.06	14.7	2.40 ± 0.06
55°C (a_w 0.65)														
1	18.8	8.12 ± 0.01	18.3	6.47 ± 0.06	21.8	11.8 ± 0.08	28.1	17.8 ± 0.09	27.5	17.0 ± 0.09	22.6	11.6 ± 0.08	23.8	14.0 ± 0.06
2	19.1	8.57 ± 0.05	18.9	7.52 ± 0.05	23.2	13.2 ± 0.04	29.8	20.3 ± 0.08	29.8	20.3 ± 0.01	23.9	13.6 ± 0.07	26.6	18.1 ± 0.06
3	20.8	10.6 ± 0.02	19.1	8.54 ± 0.02	24.3	14.3 ± 0.02	31.5	23.7 ± 0.05	31.3	22.3 ± 0.04	25.4	15.6 ± 0.01	27.8	19.8 ± 0.06
4	20.9	10.5 ± 0.08	20.3	10.1 ± 0.10	25.7	17.6 ± 0.07	32.6	24.7 ± 0.06	31.7	23.2 ± 0.05	25.9	16.4 ± 0.06	30.4	24.7 ± 0.03
28°C														
4	12.7	0.44 ± 0.09	13.5	0.66 ± 0.10	13.5	1.05 ± 0.05	16.0	2.89 ± 0.04	16.2	2.34 ± 0.23	14.0	1.97 ± 0.17	14.1	2.03 ± 0.08
16	12.3	0.21 ± 0.00	13.8	0.86 ± 0.20	13.4	0.87 ± 0.09	15.5	2.27 ± 0.03	15.6	1.70 ± 0.01	14.0	1.85 ± 0.16	13.8	1.64 ± 0.2

^a b^* , yellowness; ΔE , color difference.

^b Commercial samples (before storage).

TABLE III
Furosine Content (mg/100 g of protein, $n = 2$) and Color Measurement^a ($n = 3$) in Infant Cereal Samples
Stored Under Industrial Conditions in Nitrogen Atmosphere at 32 or 55°C

Time (months)	8-Cereal			Rice-Corn-Soy+Milk		
	Furosine	Color		Furosine	Color	
		b^*	ΔE		b^*	ΔE
32°C						
0 ^b	508 ± 2.5	12.6		985 ± 5.9	14.1	
1	470 ± 8.8	12.5	0.25 ± 0.07	1,349 ± 6	14.0	0.77 ± 0.05
3	503 ± 10.6	12.7	0.18 ± 0.04	1,416 ± 9	14.2	0.67 ± 0.00
6	471 ± 1.2	12.8	0.25 ± 0.04	1,438 ± 2	14.2	0.70 ± 0.01
12	607 ± 9.4	13.5	0.92 ± 0.06	1,591 ± 10	14.5	0.67 ± 0.03
55°C						
0 ^b	508 ± 2.5	12.6		985 ± 5.9	14.1	
1	627 ± 6.0	12.8	0.21 ± 0.00	2,405 ± 11	14.5	0.65 ± 0.03
3	620 ± 5.1	13.1	0.46 ± 0.03	3,125 ± 8	15.8	1.70 ± 0.10
6	620 ± 9.8	14.0	1.42 ± 0.06	3,654 ± 7	16.8	2.73 ± 0.00
12	408 ± 5.6	14.9	2.28 ± 0.05	5,111 ± 8	19.2	5.34 ± 0.05

^a b^* , yellowness; ΔE , color difference.

^b Commercial samples (before storage).

TABLE IV
Changes in b^* (yellowness) Value Color ($n = 3$) in Infant Cereal Samples During Storage
at 32°C Under Industrial Conditions

Time (months)	Rice-Corn		7-Cereal		8-Cereal	
	Air	Nitrogen	Air	Nitrogen	Air	Nitrogen
	0 ^a	12.5	12.5	12.6	12.6	12.6
1	12.5	12.6	12.9	12.9	12.7	12.5
3	12.5	12.3	13.0	12.9	12.9	12.7
6	11.8	12.6	13.1	13.2	13.0	12.8
12	11.0	11.7	13.3	13.2	13.2	13.5

^a Commercial samples (before storage).

Storage Under Industrial Conditions

A wheat-based infant cereal without milk (8-cereal) and a rice-based infant cereal with milk (rice-corn-soy+milk) were stored at 32 and 55°C during prolonged periods (1, 3, 6, and 12 months). Samples of each type were taken from different packages of the same batch. Table III shows the furosine levels and color parameters. At 32°C, the samples without milk (8-cereal) showed an increased furosine content only after 12 months of storage, whereas the samples with milk (rice-corn-soy+milk) showed an increase for each storage period. There was a statistically significant increase in color only after 12 months of storage, especially in the 8-cereal samples, although the increase in the rice-corn-soy+milk samples was lower than expected. At 55°C, the samples without milk showed an increase in furosine content of 508–627 mg/100 g of protein after one month and a decrease after 12 months. The browning was detected with an increase in b^* value for each storage period from 12.6 before storage to 14.9 after 12 months. As expected, the browning was more evident in the sample with milk, and both furosine and color parameters increased for each storage period (Table III). Furosine proved to be a useful indicator of the Maillard reaction during storage of infant cereals with milk under industrial conditions. Color was a useful indicator when the storage conditions were drastic (55°C).

To study the behavior of color (b^* parameter) of wheat-based infant cereals (7-cereal and 8-cereal) and rice-based (rice-corn), the samples were stored for 12 months at 32°C in air or nitrogen atmospheres (Table IV).

During storage in air, the b^* parameter increased with time in 7-cereal and 8-cereal samples but decreased in the rice-corn samples. The samples with corn have a characteristic yellow color, and the corn pigments are probably degraded during storage so that the increase in the b^* parameter is less than could be expected from the browning reaction. The rice-corn samples showed a greater increase in the b^* value during storage in nitrogen because the residual oxygen content is lower than during storage in air. The

rice-corn sample was stored under industrial conditions at 55°C to confirm the above findings. After six months of storage, the b^* value decreased by 1.3 units in air atmosphere, whereas no change was detected in nitrogen atmosphere.

CONCLUSIONS

Furosine is a useful indicator for monitoring browning in infant cereals with milk under normal and adverse storage conditions. The b^* value is useful for monitoring the browning reaction in infant cereals with or without milk under adverse storage conditions, except in samples with corn that do not include milk. The extent of Maillard reaction was greatest in infant cereals that included milk in their formulation.

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