Principal Factor Analysis of Extruded Sorghum and Peanut Bar Changes During Accelerated Shelf-life Studies

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ABSTRACT

A prototype meal bar of extruded sorghum-peanut wafer with filling and enrobing was subjected to accelerated shelf-life testing at 60 °C for 4 wks Samples were withdrawn each week for analyses including slurry pH, Kramer shear texture measures, CIE L*a*b* color, water activity, peroxide values, malonaldehyde content, available lysine, and proximate composition. Principal factor analysis with varimax rotation was used to assess associations of related factors. Six factors accounted for 77.5% of variance. Significant changes occurred with respect to the control over 4 wk storage, particularly in a sharp reduction of pH, and increased pigmentation. Other measures were minimally changed.

Key Words: common factors, stressed storage, meal bar, CIE color

INTRODUCTION

IMPROVED FOOD/PACKAGING SYSTEMS HAVE ENABLED FOOD OF high nutrition content to be maintained in severe environments for long durations (Narayan et al., 1997). New food products must be sufficiently stable and able to occasionally endure high temperatures. The packaging system must be economical and protect the product against oxygen and water vapor transmissions (Duxbury, 1989). Physicochemical assessments of quality characteristics of extruded barley preparations have been reported by Shin and Gray (1983) under varied storage conditions. Falcone and Phillips (1988) reported assessments of physical and rheological properties of formulations composed of 33% cowpea and 67% sorghum under varying conditions of extrusion processing. Researchers (Phillips and Falcone, 1988) compared sorghum alone or with 15% replacement of peanut meal in extruded forms with variable process temperatures and moisture additions.

Extruded products of a peanut/sorghum flour mixture could to be utilized in different ways, such as a wafer subassembly of a snack bar or a meal bar. Food fillers, such as processed cheese, chocolate, peanut butter paste, or fruit combinations, could be added to enhance the nutritional quality and consumer appeal. Because of its fiber, protein, carbohydrates, and lipids, the peanut is a very nutritious and energy-rich food. High quality sorghum (*Sorghum bicolor* (*L.*) *moench*)) flour (yellow to white in color and low in tannin) is more suited for human consumption than common grain sorghum used for cattle feed. Sorghum, with high starch content could, with peanuts, provide a combination product high in nutritive quality.

We studied a bar-type food utilizing a sorghum/peanut extruded subassembly that was filled and enrobed to form a product developed as a prototype operational ration component. Our general goal was to determine the stability of the product during environmental storage conditions of 60 °C for up to 4 wk.

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Principle factor analysis (PFA) techniques with varimax rotation (VR) presentations have been used in differentiating legume composition (Barrado et al., 1994) and for development of an instrument for frequency recall evaluation of dietary intake (Gallagher et al., 1993). PFA with VR has also been used to evaluate the relationships of winter wheat cultivars in multiple international environments of production testing (Peterson and Pfeiffer, 1989) and forest growth patterns with varying environmental and fertility conditions (Gomoryova and Gomory, 1995). PFA applied to measures of quality associated with accelerated shelf-life testing of complex food items can provide effective methods to explain the bases for deterioration. Our objective was to apply PFA with VR to study relationships among the changes in chemical and physical factors in a peanut sorghum meal bar during accelerated storage.

MATERIALS & METHODS

Materials

Shelled peanuts (*Arachis hypogaea* (*L.*) var. Virginia) obtained from Peanut Processors, Inc. (Dublin, N.C.) were dry roasted at approximately 150 °C, employing an Aeroglide (Raleigh, N.C., U.S.A.) two-zone conveyor drier/roaster for about 40 min. The roasted nuts were processed on a Bauermeister model SNB2 splitnut blancher, removing the testa and heart, and splitting the nuts.

A low-tannin hybrid sorghum seed (*Sorghum bicolor* (*L.*) *moench* var. DK77) obtained from Dekalb Plant Genetics (Lubbock, Tex., U.S.A.) was planted at the Winfred Thomas Agricultural Experiment Station (Hazel Green, Ala., U.S.A.). The grain was harvested, cleaned, bagged, and stored at 10 °C. The sorghum grain was decorticated to an 80% extraction level using a Nutana dehuller (Saskatoon, Sask., Canada) to reduce the portion of seed coat.

Experimental design

Four batches of blanched peanut and decorticated sorghum grains were combined in a 13:87 (w/w) peanut-to-sorghum ratio with process and formulation based upon studies reported by Surjawan (1995). The combinations of sorghum grain and blanched peanut splits were held for 2 d or longer at 10 °C prior to milling to minimize any "oiling-off" effect from heating during milling (which tended to blind the mill screen). Each batch was milled with a JT Homoloid mill (Fitzpatrick Co., Elmhurst, Ill., U.S.A.) to produce flour. The resultant flours were mixed for 30 min to produce composite blends. The flours were each transferred to the feed hopper of a single-screw extruder (model AE303, Appropriate Engineering, Riverside, Calif., U.S.A.) equipped with a 1000 mm (L) × 70 mm (dia.) × 60 mm root (dia) screw within splined barrel sections (shell i.d. = 77 mm and spline i.d. = 72 mm). An adjustable slit die (set to a 1.8 mm opening) designed at Alabama A&M University was fitted to the barrel end. The screw speed was set to 45% of full-scale, flour was metered at 12% full-scale, and water was metered at 100 mL/min initially and then reduced to 40 to 60 mL/min to accommodate transition to a continuous extrudate production. The extrudate was cut into approximately 100-mm strips and oven dried (Aeroglide drier) prior to assembly into wa-

Table 1—Varimax rotated factors

	Factors						
	1	2	3	4	5	6	Communality[a]
CIE a*	**0.988**	–0.029	0.132	0.005	0.070	–0.022	0.999
Hue	**0.972**	–0.080	0.128	–0.038	0.133	0.072	0.992
WEEK (Time)	**0.961**	–0.069	–0.006	–0.036	–0.009	–0.153	0.954
Chroma	**0.829**	–0.089	–0.152	0.259	0.123	0.440	0.994
CIE b*	**0.780**	–0.101	–0.185	0.277	0.130	0.498	0.995
a_w	**0.481**	–0.284	–0.204	–0.097	0.446	0.058	0.566
POV	**–0.613**	0.182	0.167	–0.047	–0.394	–0.256	0.660
CIE L*	**–0.915**	0.131	–0.218	0.036	–0.181	–0.090	0.944
pH	**–0.930**	0.129	–0.030	0.040	0.078	0.243	0.949
Shear work	–0.132	**0.957**	0.035	0.126	–0.125	–0.095	0.975
Peak shear	–0.223	**0.918**	0.102	0.104	–0.146	–0.180	0.968
Shear sample wt	–0.022	**0.841**	–0.226	0.196	–0.301	0.028	0.888
Replications	0.039	0.055	**0.864**	0.021	–0.002	0.062	0.756
Protein (db)	0.124	–0.212	**0.400**	–0.019	0.302	0.188	0.347
Fat (db)	–0.174	0.139	–0.095	**0.676**	0.042	–0.117	0.531
Available Lysine	–0.303	–0.185	–0.161	**–0.614**	0.133	–0.001	0.547
Moisture (db)	0.076	–0.302	0.138	–0.021	**0.612**	–0.053	0.493
TBARS	0.060	0.138	–0.232	0.200	0.024	**–0.520**	0.388
Variance explained[b]	6.665	2.855	1.287	1.101	1.061	0.975	13.945[b]

[a]Communality and variance explained values are sums of squares of the values in the preceding entries of the rows and the columns, respectively. Together they both sum to the value in the lower right corner.
[b]Estimate of variances explained in experiment is specified by the ratio of the final communality estimate total by the number of variables considered. i.e., 13.945/18 = 77.5%.

fer sandwiches. Each of the 4 replicates of the composite flour were prepared, identified and passed through the extrusion process.

A 20-g portion of filling consisting of peanut butter, dextrose, salt, and stabilizer (from Earth Grains Bakery, Ft. Payne, Ala., U.S.A.) was spread to a thickness of about 3 mm between 2 wafer strips. Smaller half-bars (about 50 mm × 50 mm) were made to fit the Kramer shear press cell for texture studies. The filled bars were chilled at 10 °C for 10 min prior to enrobing (approximately 1 mm thick) with a white confectionery compound (supplied by Ambrosia Chocolate Co., Milwaukee, Wis., U.S.A.). The enrobing material consisted of sugar, partially hydrogenated soybean and cottonseed oils, nonfat dry milk, distilled monoglycerides, sorbitan monosaturate, soy lecithin (added as an emulsifier), artificial flavoring, and salt. The completed products were chilled at 10 °C for an additional 10 min, transferred (1 100-mm or 2 50-mm items) to each Flex Can II ration package and vacuum sealed. The packages were stored in a 60 °C environmental chamber that had been equilibrated to that temperature for 3 d prior to introduction of samples (Jones, 1995).

Physical analyses. Moisture content was determined by the standard air-oven method and results were calculated on a dry basis. Water activity (a_w) was determined using a Hygroskop DT-2 humidity analyzer (Rotronic Instrument Corp., Huntington, N.Y., U.S.A.). Texture analysis was performed with a model TP-2A Texture Press (Food Technology Corp., Rockville, Md., U.S.A.) to determine the integral and maximum force of shear employing a Kramer shear cell in contrast to the Warner-Bratzler and panel methods reported by Phillips and Falcone (1988). Sample item weight was recorded prior to the Kramer shear processing. Tristimulus color expressed as CIE L* a* b* values was assessed using a Pacific Scientific colorimeter (model XL 800). Hue angles were derived as the arctangent of the ratio of CIE a* to CIE b* expressed as degrees. Chroma values were calculated as the square root of the sum of the squared values of both CIE a* and CIE b* (Nielsen, 1998).

Chemical analyses. Fat and protein contents were determined by AOAC procedures (AOAC, 1990) and expressed on dry matter basis. Product slurry pH was determined with 5 g of sample in 4 mL of distilled deionized water with an Accumet model 50 meter standardized with a buffer at pH 7.01. Malonaldehyde content was measured using the TBARS analysis (AOAC, 1990; Agbo et al., 1992). The method of distillation was that of Tarladgis et al. (1960) as modified by Ke et al. (1984). Propylgallate (100 mg) and EDTA (100 mg) were added during blending of samples as recommended by Rhee (1978) to retard any further development of rancidity. TBARS values were expressed as micromoles malonaldehyde/g ground sample. Peroxide values of oil samples were determined using the official method of the American Oil Chemists' Society scaled to permit determination of peroxides in 0.50 g of oil (AOCS, 1990; Agbo et al., 1992). The determination of available lysine was by FDNB method (Pellett and Young, 1980).

Statistical analysis. Principal factor analysis procedure (SAS Institute, Inc., 1985) was used to indicate relations of several measures applying SAS® Proprietary Software Release 6.08 (SAS Institute Inc., SAS Campus Drive, Cary, N.C., U.S.A.). A matrix with 18 variables by 60 observations was analyzed. As a preliminary procedure, the observations were subjected to "maximum-likelihood factor analysis" to indicate the most appropriate number of factors to execute in the "principal factor analysis" with a varimax rotation. Subsequent assessments of trends and differences or changes of variables were conducted with the SAS® general linear model (GLM) procedures with covariables considered based on factor analysis and by regression procedures.

RESULTS & DISCUSSION

THE 18 VARIABLES, INCLUDING REPLICATION, WEEKS OF STORage, pH, integral (shear work), force (peak shear), CIE L* a* b* color, hue angle and chroma, water activity (a_W), peroxide value (POV), malonaldehyde content (TBARS), available lysine, fat%, moisture%, protein% and weight of sample placed into the shear cell were placed in the 60 observation matrix for the common factor analysis. The initial factor method indicated five prime factors based on eigenvalue criteria. However, the maximum-likelihood factor analysis indicated that 6 factors were sufficient. Both varimax and promax rotations were tentatively considered but the varimax alternative has provided a greater estimate of final communality estimate (13.9 vs 10.6 for promax). The varimax rotated factor pattern for the data set with 6 factors was arranged in descending order of variances explained (Table 1), and each variable with strongest association to any particular factor was arranged in descending rank order. The stronger associations of variables to any factor are in **boldface.** Factor 1 variations were associated with duration of storage stress although the most positive association (0.988) was with the CIE a* measures and most negative (−0.930) with the measured pH. Factor 2 included a cluster of variables associated with Kramer shear measurements. Factor 3 was associated with the variation introduced by multiple replications. Measured

protein variation was most associated with this factor. Factor 4 was associated with variation of fat levels (0.676) and negatively with levels of available lysine (−0.614). Factor 5 was most associated with the variation of moisture in the products while factor 6 was most associated with TBARS variation.

To display interactions of the six factors as many as 15 scatter plots could be prepared from the tabulated data. However, Fig. 1 shows only selected plots of patterns of interactions in which the cluster patterns highlighted were shown to have dependence upon two designed independent variables, time duration of the study (Fig. 1a and Fig. 1b) and replication of product preparations (Fig. 1c and Fig. 1d). As expected, the dominant factor of variation coincided with the passing of time. It is clear that the coordinated variation of pH with time may have substantial impact on other variables. All color measures were also related to this factor 1 with very high correlations of CIE a* and hue angle values with lesser effects on chroma and CIE b* values and a negative correlation with product lightness (CIE L*).

The general linear model procedure applied to pH levels showed a highly significant decrease from an average 6.75 to 5.86 over 4 wk (Fig. 2) with a cubic regression equation accounted for 98% of this variation. This decrease suggested that chemical alterations occurred during storage. Some microorganisms may survive and grow at 60 °C but the possibility of spoilage was reduced by the low moisture content. Measures that most coincided with the "time-pH" factor included the color shift (increased CIE a* and derived hue angle values) with declining product lightness (CIE L*). Factors contributing to the noted decrease in pH were likely the chemical degradation leading to nonenzymatic browning. Changes of the color parameters (Fig. 3) were a function of storage time. CIE L* values decreased (from average of 80.4 to 61.1) with time of storage. The cubic fitted curve had an r^2 of 0.876. Along

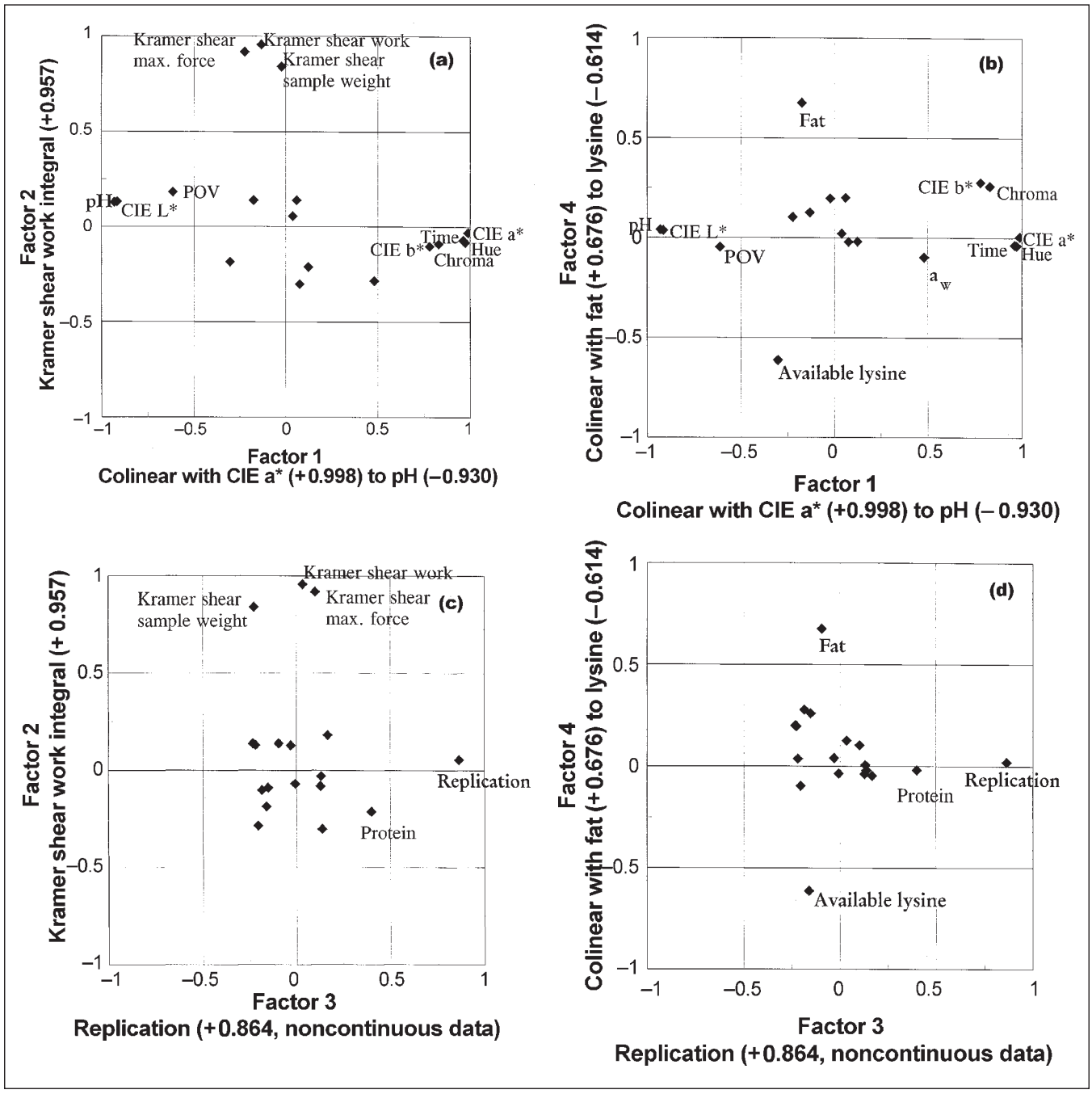

Fig. 1—Selected Varimax rotation factor scatter plots.

Table 2—Textural shearing measure of prototype meal bar

Treatment (Wk of storage)	Shear force integral (work)	Peak force of shearing (kN)
0 (Control)	886.[a]	8.50[a]
1	730.[b]	5.85[b]
2	741.[b]	6.12[b]
3	689.[b]	5.77[b]
4	788.[ab]	6.65[b]
Correlations:		
Week	−0.183	−0.246
Replication	0.075	0.118
Sample wt.	0.861	0.815
Effects:	Rep wk Rep*wk	Rep wk Sample wt
r^2	0.828	0.828

General Linear Model (GLM) with Tukey's Studentized Range Test showing results with weakly correlated fixed effects of Week and Replication and either their Interaction, or the covariable measure of Shear Sample Wt in the procedure.
[a,b]Means with the same superscript letter are not significantly different. 12 observations per average value. Treatments were weeks of storage at 60 °C.

with darkening, the color hue angle progressed from slight greenish-yellow of −11.2° to the yellow-orange of hue angle 18.2°. The chroma character closely followed the CIE b* values since the CIE a* values were quite minor. The significant change of chroma value occurred by the second week. Cubic regression curves for fitting the respective chroma and hue angle measures to experimental data had respectively r^2 values of 0.897 and 0.958. One or more browning reaction processes were suspected as the product became less light while increasing more chroma. Porter et al. (1993) reported decreases in visual color attributes of military rations stored in container vans through the summer months in the Yuma, Ariz. desert. Shaw et al. (1997) calculated the Arrhenius activation energy of 26 kcal/mole for the temperature dependence of sensory and instrumental degradations of these stored rations.

Replication was referenced colinear (0.864) with the third factor identified in the data set (Table 1). Replication factor interactions were shown in Fig. 1c and Fig. 1d. Clearly, this indicated that the preparation of replicate lots of products was variable and several of the measures produced on evaluation of the stored products were dependent upon the specific batch or preparation. The GLM procedures should be more effective with consideration of replication in the analysis of variance tables. Thus, in all efforts reported, the variable replication was checked and, if appropriate, placed into the models.

The cluster of measures associated with the Kramer shear device were the focus of factor 2 (Fig. 1a). These 3 measures had small values of colinearity with factor 1, suggesting that storage time and the indicated degradations associated with storage were bases for variations of these texture measures. Similarly, the correlations of shear force integral and peak shear force with weeks of storage were slight (−0.183 and −0.246, respectively). Intuitively, the amounts of force and work to shear a sample should be expected to depend upon the weight of the sample sheared. Only the combination of the effects of weeks and replication and the correlated sample weight data (Table 2) were sufficient to show separation of treatment of weeks effect ($p \leq 0.05$).

While the data indicate that the control products were the most resistant to shear, there is also indication that the products from the final period of storage were not different from the control in terms of integrated force to shear. The implication seems to be that the reductions in the early weeks of storage were subsequently reversed. This may indicate an initial softening of texture (perhaps by the added components of the filling and enrobing materials absorbing into the wafer bar) but ultimately countered by some form of age hardening. All products evaluated were seen to have no shear texture differences on any significant bases of time. The variations that were blocked out in terms of replication effect and weight of sample placed into the test cell need to be minimized.

Fat percentage was colinear (0.676) with factor 4 while available lysine was negatively colinear (−0.614) with this factor (Fig. 1b and Fig. 1d). Both had some fractional colinearity with factor 1, but neither was significantly differentiated by the classes of weeks of storage time even with the replication block variation included in the model. The indicated inverse relation of fat level to available lysine ($r = -0.394$) prompted the hypothesis that increased fat in the product should lubricate extrusion and lessen the thermal development by shear resistance and consequently protect lysine from thermal destruction. Based on that hypothesis, the test for any effect of time of storage on available lysine in a general linear model procedure also included fat level as a covariable (Table 3). The GLM procedure with fixed effects and interactions yielded an

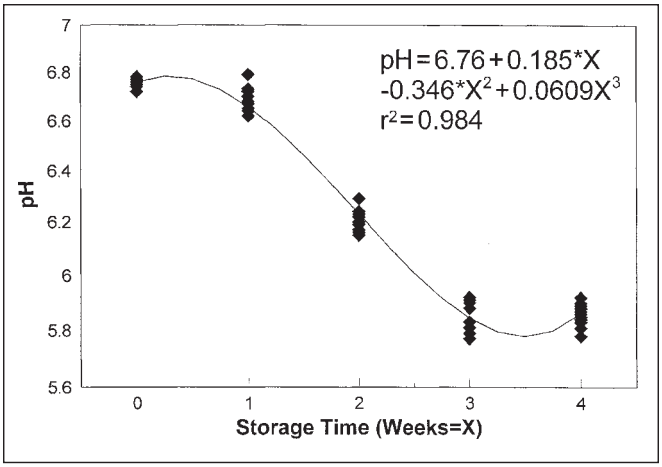

Fig. 2—pH of slurries stored prototype meal bars held for various times at 60 °C in an accelerated storage challenge.

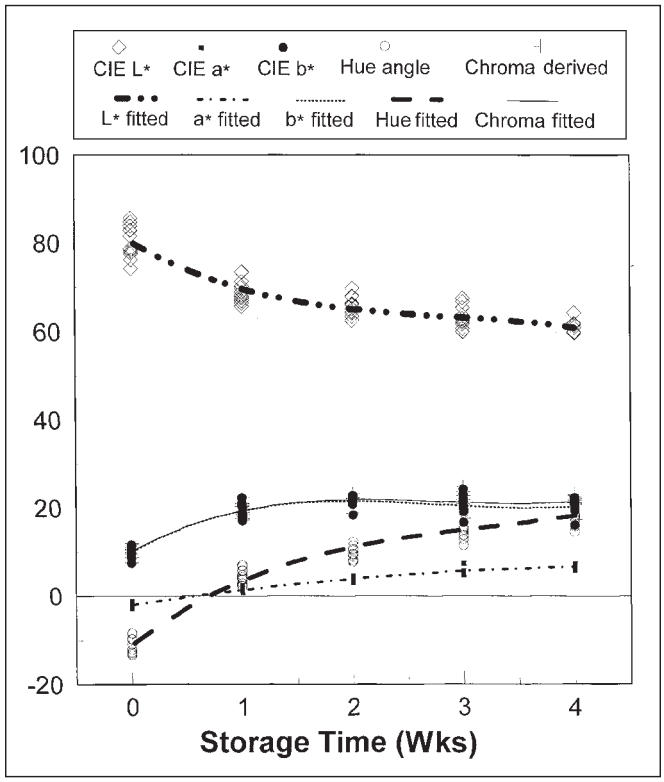

Fig. 3—Progression of CIE values for prototype meal bar with storage time held at 60 °C.

Table 3—Chemical and physical measures through storage period

Treatment (wk of storage)	Available lysine (%)	Malonaldehyde TBARS µmoles/g	Peroxide values meq/kg	Water activity (a_w)
0	3.91[a]	0.0016[a]	4.9[a]	0.53[b]
1	3.78[ab]	0.0009[b]	3.2[b]	0.57[a]
2	2.95[b]	0.0014[ab]	2.9[b]	0.57[a]
3	2.96[b]	0.0014[ab]	3.2[b]	0.57[a]
4	3.16[ab]	0.0013[ab]	2.9[b]	0.57[a]
Correlation:				
Week	–0.254	0.092	–0.552	0.470
Replication	–0.158	–0.212	0.105	–0.154
Fat (% db)	–0.394	0.197	0.108	–0.129
Effects	Rep Wk Rep*Wk Fat%(db)	Wk	Wk Rep*Wk	Wk Rep
r^2	0.709	0.235	0.821	0.566

General Linear Model (GLM) with Tukey's Studentized Range Test with only the significant fixed effects and covariable (for available lysine only) in models as illustrated. [a,b]Means with the same letter are not significantly different. 12 observations per average value. Samples were stored at 60°C.

$r^2 = 0.654$ compared to an $r^2 = 0.709$ with the fat-level covariable as well, but the former was not significant ($p \geq 0.05$). There was no consistent trend to diminish available lysine as a consequence of increased time in storage. But a significant change in the level of available lysine from the control at zero time was seen by the second and third weeks. This trend was not sustained, however, leaving question of its consistency.

There was a high association of CIE b* and TBARS (Factor 6) with an inverse relationship (Table 1). But correlation analysis revealed only a small ($r = –0.107$) association of these variables most colinear with factor 6. By considering the possibility that the TBARS variable could be explained by the variability of the CIE b* readings alternate performances of GLM procedure were tested with time (weeks) or time and covariable CIE b* models. The r^2-values with the alternate models indicated that the covariable model did not increase extent of the variation explained (Table 3).

Protein content (7.72% db ± 0.51 STD) did not change with replication or with treatment. This enabled a stable reference for contrasting the products by treatment time and replication. Similarly, fat content (26.4% db ± 1.1 STD) was not significantly a factor of the experimental effects.

Other physical factors

There were significant changes in moisture due to effects of replication which was not characteristic for the weeks of storage. The products showed higher moisture in replications 2 and 3 with means of 6.55 and 6.53%, in contrast to 5.85 and 5.99% for replications 1 and 4. This difference, due likely to inconsistencies in assembling the product or drying wafer components, was significant by contrasts ($p \leq 0.05$). Mean moisture contents for the durations of treatment ranged from 5.93 to 6.38% (dry weight basis) with an overall mean of 6.22% db ± 0.56 STD. These values were clearly between the contrasted levels noted by the replications.

Variation in water activity (a_w) was displayed among the treatment of weeks as well as by replication. A slight increase occurred as only a step increase displayed after the first week of storage rather than a linear trend over time (Table 3). The level of increase was significant compared to the initial non-stored products, but probably was not enough to affect the stored products. The extreme values of a_w from 0.50 to 0.59 were within the accepted range for low-moisture products.

Chemical factors

TBARS from 0.0009 to 0.0016 µmoles/g indicated a significant effect due to treatment time but with no clear trend (low r^2 value). The effect of treatment time appears to be minor to the overall stability of the product shown by the generally low levels of TBARS throughout storage. Peroxide values were shown to change primarily due to weeks of treatment. Values ranged about the mean of 3.4 meq/kg ± 0.94 STD with initial values highest. Oxidation in this prototype product was not excessive.

CONCLUSION

CHANGES OF COLOR WERE SHOWN WITH A DECREASE IN LIGHTness (CIE L* 80 to 61) and shifts in hue angle from slight greenish yellow to orange yellow with increases in chroma due to weeks of storage. The pH decreased from 6.8 to 5.6 concurrent with these changes, likely as a consequence of chemical changes. Other quality factors showed some variation but less conclusive trends were evident. The principal factor analysis applied to quality measures of this complex food product during severe storage conditions provided more effective evaluation than more customary analysis of variance and regression analysis based upon design effects and covariables.

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