# PREPARATION AND STORAGE OF SWEET POTATO FLAKES FORTIFIED WITH PLANT PROTEIN CONCENTRATES AND ISOLATES


## ABSTRACT

Sweet potato flakes supplemented with soy flour, soy flour plus DL-methionine, cottonseed flour and wheat gluten flour were prepared. The fortified flakes had higher protein calorie to total calorie ratios but had lower water-binding capacity than flakes with no supplementary material. The amino acid pattern of soy flour, soy plus methionine and cottonseed flour formulations compared favorably with that of non-supplemented flakes. Each formulation was stored at 23° and 40°C under nitrogen for 8.25 months. Although the levels of several amino acids appeared to change significantly during storage, only glycine in the gluten formulation linearly decreased. Tyrosine in the soy formulation appeared to increase during storage. Flakes stored at 40°C appeared to develop off flavors and to lose water-binding capacity.


## INTRODUCTION

ALTHOUGH THE SWEET POTATO is recognized as a good source of pro-vitamin A, it is not widely known that it contains a significant amount of protein with high nutritional quality. A recent study (Purcell et al., 1972) showed that the chemical score (Bender, 1973) of sweet potato protein is about 80 and that it contains more lysine than is needed for amino acid balance. To make sweet potatoes available throughout the year and to provide a sweet potato product for institutional use, dehydrated flakes were developed (Deobald and McLemore, 1962; Hoover, 1967). Calculations indicate that a one cup serving of flakes provides a five-fold excess of the recommended daily allowance (RDA) of vitamin A, 4.0% RDA of protein and 9.4% RDA of calories (Watt and Merrill, 1963). Thus, if consumption could be increased, sweet potato flakes could be used to alleviate the increasing vitamin A deficit which this country is now experiencing (HEW, 1974). However, due to the low protein calorie to total calorie ratio (PCR), meals designed to provide a weekly supply of vitamin A from sweet potato flakes may exceed calorie requirements before satisfying protein needs. It is believed that improvement in the PCR of this product may promote greater institutional consumption of sweet potato flakes as one means of increasing the intake of vitamin A.

Incorporation of plant proteins into the flakes is the most feasible means of improving the PCR. Prudent selection of the protein could increase both protein content and chemical score. Calculations based on reported amino acid content suggest that wheat, soy and cottonseed proteins could be used (Johnson and Lay, 1974). Since sweet potato protein, like that of most plant material, is deficient in sulfur containing amino acids, protein quality can be substantially improved by the addition of small amounts of DL-methionine. This amino acid has been used as a supplement in cowpea powder (Onayemi and Potter, 1976) and soybean-based foods (Bookwalter et al., 1975).

Little information is available on storage-induced changes in amino acid content of high-carbohydrate, high-protein foods. Onayemi and Potter (1976) found that in dried cowpea powder amino acids were not affected by storage at 37°C for 24 wk. Betschart and Kinsella (1974) found that amino acid levels in soybean leaf protein concentrate varied during storage at 27°C, but that no clearly defined losses occurred. However, neither product has a reducing sugar content as high as that of dehydrated sweet potato flakes. Reactions of reducing carbohydrates with free amino groups of protein molecules, referred to as nonenzymatic browning or the Maillard reaction, commonly occur in food systems (Reynolds, 1965). Basic amino acid residues of peptides with free amino groups such as lysine, arginine and tryptophan are the most susceptible to degradation during browning reactions and their loss reduces the nutritional value of the food.

Similarly, there are no reports concerning the effects of storage on the rheological properties of sweet potato flakes, although storage-related changes in carotene, ascorbic acid and lipid content have been described (Deobald and McLemore, 1964; Walter and Purcell, 1974). Our objective was to study the effect plant protein supplementation of sweet potato flakes had upon the textural properties, protein chemical score, sensory qualities and storage stability of the flakes.

## MATERIALS & METHODS

### Flake preparation

Cured Jewel sweet potatoes ("jumbo") procured on the open market were lye-peeled, hand-trimmed, and cut into 2-in. cubes. These cubes were then cooked for 25 min by a thermal screw heated with steam. After cooking, the cubes were thoroughly mixed with the desired additives and blended in a Fitzmill equipped with a 0.03-in. screen. The resulting slurry was dried on a 12 × 19 in. double-drum drier heated with steam at 80 psi and a retention time of 30 sec. The drum-dried material was ground into flakes in a coffee grinder and 75-g samples were sealed in no. 303 cans under nitrogen gas. Ten cans per formulation were then stored at 23°C and 40°C. Flakes from each formulation were retained for zero time analysis.

Five formulations were prepared: (1) 70% sweet potato solids, 20% soy flour (Central Soya) and 10% sucrose; (2) 69% sweet potato solids, 20% soy flour, 1% DL-methionine and 10% sucrose; (3) 70% sweet potato solids, 20% wheat gluten (NB Co) and 10% sucrose; (4) 70% sweet potato solids, 20% defatted cottonseed flour (LPC, Southern Regional Laboratory), and 10% sucrose; (5) sweet potato solids only (control). Sucrose was used to remedy the decrease in sweetness caused by supplement addition and to retain good flaking qualities. To prevent darkening, 5.5 g of sodium sulfite was added to each formulation (Hoover, 1963). Cans of each formulation were removed from storage at 1, 2, 4 and 8.25 months for analysis.

### Amino acid analysis

Duplicate samples from each formulation containing about 5 mg of protein were hydrolyzed with 6N HCl in evacuated, sealed tubes at 100°C for 16 hr. Unpublished data from this laboratory have shown these hydrolysis conditions to be optimum for sweet potato protein. Each hydrolysate was evaporated in vacuo, taken up in 0.5N acetic acid and filtered. The Filtrate was subjected to clean-up on a Dowex 50W ion exchange resin column (Pataki, 1968). Analyses were conducted on a Beckman Model 119 Automatic Amino Acid Analyzer. Since cystine-cysteine and tryptophan are destroyed by acid hydrolysis, they were quantitated by colorimetric analysis of an enzymatic hydrolysate. Duplicate weighed flake samples, containing about 60 mg of protein, were suspended in 7 ml of filter sterilized, 0.02M phosphate buffer containing 4 mg of fungal amyloglucosidase and incubated aseptically for 16 hr. The mixture was neutralized with 1.4N NaOH and then 6 ml of filter-sterilized, 0.2M phosphate buffer, pH 7.5, containing 3 mg of Pronase (Sigma Chemical) were added aseptically. The slurry was incu-

bated at 34°C for 24 hr, then autoclaved at 121°C for 20 min. After cooling, the mixture was acidified to pH 2.1 with HCl and immediately poured onto an ion exchange column of Dowex 50W ($H^+$) for cleanup (Pataki, 1968). After cleanup, the amino acids were taken up in 6 ml of 0.2M phosphate buffer, pH 7.5, and analyzed for tryptophan (Spies, 1968) and for cysteine (Patrick and Swaisgood, 1975).

**Carotene content**

β-carotene (pro-vitamin A) was extracted from duplicate, 3-g samples of each formulation with hexane-acetone (1-1) after reconstitution with boiling water (Purcell and Walter, 1968).

**Viscosity measurement**

Flakes were reconstituted with boiling water (four parts water to one part flakes). Viscosities were measured on duplicate samples with a Haake Rotovisko rotary viscometer. Each sample was tested at each of ten rotor speeds, and the percent galvanometer deflection recorded. Apparent viscosity values were derived by multiplying the percent galvanometer deflection by the rotor speed and a cell constant (Walter et al., 1976).

**Nonenzymatic browning**

Duplicate 1.00-g samples were shaken on a rotary shaker with 20 ml of 0.2M sodium acetate buffer (pH 5.5, 70°C) for 20 min at 200 rpm. Then, 0.1g filter aid was added and the mixture centrifuged at 3000 rpm for 10 min. The supernatant was filtered with Whatman no. 5 filter paper and the absorbancy at 390 nm determined (Labuza et al., 1970).

**Sensory evaluation**

A duo-trio test was used in which flakes from each treatment held at −5°C (standard) were compared to those flakes which had been stored at 23°C or 40°C. The flakes were reconstituted into a puree with boiling water (1:2). One tablespoon of the cooled puree was placed on a plate divided into three sections. Two sections were coded with three digit numbers and the third section was designated as the standard. The standard and one of the numbered sections contained identical purees, while the third section contained a puree of the same formulation but a different storage temperature. Each panelist was located in a darkened booth illuminated by a red filtered lamp. The panelist was asked to taste each sample and to indicate which was identical to the standard as well as which was preferred. Eighteen untrained panelists were used. The panel was made up of staff members and graduate students from the Department of Food Science.

*Table 1—Protein calories to total calories ratio (PCR) of control and protein enriched-sweet potato flakes*

| Flake content | Protein calories / Total calories |
|---|---|
| Sweet potato solids (Control) | 0.093 |
| Sweet potato solids + soy flour | 0.185 |
| Sweet potato solids + cottonseed flour | 0.217 |
| Sweet potato solids + gluten | 0.257 |

*Table 2—Amino acid composition[a] of sweet potato flakes fortified with plant proteins*

| Amino acid | Formulation: Control | Soy flour | Soy flour +methionine | Cottonseed flour | Gluten | FAO[b] |
|---|---|---|---|---|---|---|
| Isoleucine | 5.83 | 5.63 | 5.74 | 4.64 | 5.49 | 4.0 |
| Leucine | 8.83 | 9.92 | 9.59 | 8.08 | 9.64 | 7.8 |
| Lysine | 5.42 | 5.68 | 5.93 | 4.60 | 2.51 | 5.4 |
| Methionine | 1.66 | 1.42 | 2.78 | 1.53 | 1.35 | 3.5 |
| Cystine | 0.62 | 0.56 | 0.56 | 0.54 | 0.64 | |
| Phenylalanine | 7.69 | 6.63 | 6.42 | 6.76 | 7.15 | 6.1 |
| Tyrosine | 4.39 | 4.19 | 4.12 | 3.90 | 4.52 | |
| Threonine | 7.48 | 5.55 | 5.56 | 4.95 | 4.37 | 4.0 |
| Tryptophane | 1.31 | 1.23 | 1.16 | 1.26 | 1.15 | 1.0 |
| Valine | 8.66 | 7.07 | 6.86 | 7.22 | 5.85 | 5.0 |
| Total EAA[c] | 51.89 | 47.88 | 48.72 | 43.48 | 42.67 | |
| Alanine | 7.84 | 6.11 | 6.14 | 5.85 | 4.79 | |
| Arginine | 5.86 | 7.68 | 7.70 | 11.32 | 4.75 | |
| Aspartic acid | 25.50 | 17.53 | 17.72 | 15.16 | 9.39 | |
| Glutamic acid | 12.53 | 21.67 | 20.58 | 21.53 | 40.94 | |
| Glycine | 5.09 | 4.77 | 5.09 | 4.86 | 4.60 | |
| Histidine | 1.96 | 2.38 | 2.28 | 2.00 | 2.35 | |
| Proline | 5.13 | 5.87 | 5.78 | 4.67 | 14.47 | |
| Serine | 7.30 | 6.50 | 6.20 | 5.98 | 6.84 | |
| Total NEAA[d] | 71.21 | 72.51 | 71.49 | 71.37 | 88.13 | |
| EAA/NEAA | 0.72 | 0.66 | 0.68 | 0.61 | 0.48 | |

[a] Grams of amino acid per 16g of nitrogen recovered
[b] FAO reference protein (FAO/WHO, 1973)
[c] Essential amino acids
[d] Nonessential amino acids

**Carbohydrate content**

Extraction and measurement methods were as described by Walter et al. (1976). Briefly, the sugar and dextrin fractions, respectively, were removed from the flakes with 90:10 (v/v) ethanol-water. Starch was then extracted from the dextrin-free residue with 0.5N NaOH. Sugar content was assayed by the Phenol-sulfuric acid procedure (Dubois et al., 1956). Dextrin and starch levels were measured by the amyloglucosidase-glucose-oxidase method of Dekker and Richards (1971).

**Reflectance**

The Hunter Color and Color Difference Meter (Model D25D2A) was used to record the color of reconstituted flake samples. The instrument was standardized against a white tile (L = 94; "a" = 12; "b" = 2.3). The reflectance measurements were run on a portion of the samples prepared for viscosity determination.

**Statistical methods**

Analysis of variance (ANOVA) for each amino acid was calculated for zero time values to determine formulation effects upon flake amino acid composition. In addition, regression analyses of variance for each amino acid were performed considering storage temperature, storage time, and the time × temperature interactions as sources of variation. For determination of individual formulation regression coefficients, subsequent regression analyses were performed for each amino acid displaying a storage × time effect. In these latter analyses, the source interaction was dropped from the model since storage time and temperature had been established as independent factors. Similarly, the dependent variable apparent viscosity was subjected to regression analysis of variance of the same sources of variation as used for amino acid composition. Differences in Hunter Color values for zero time samples with respect to formulation were determined by ANOVA. Linear regression analyses of absorbancy versus time were performed in order to identify formulations in which nonenzymatic browning pigments were formed.

## RESULTS & DISCUSSION

### Freshly prepared flakes

**Protein content and quality.** Sweet potatoes used in this study contained 8.76% (dry basis, db) protein (Kjeldahl nitrogen × 6.25) and had a ratio of protein calories to total calories (PCR) of 0.093. This protein level is high for sweet potatoes probably because they had been stored for 6 months, that is, metabolic consumption of carbohydrate in storage may have caused an apparent increase in nitrogen levels. Purcell et al. (1972) showed that 80% of the cultivars contain from 4.5 to 7.0% (db) protein, and our experience with the Jewel cultivar has indicated a protein range of 4–6% at harvest. Consequently, the protein level of the sweet potatoes must be measured and the amount of fortifying material adjusted accordingly if the flakes are to contain a specified level of protein.

Preparation of sweet potato flakes with soy flour, cottonseed flour and gluten increased the protein levels to 17.1, 20.1 and 23.8%, respectively. Even though the pro-vitamin A level was decreased by about 30% through fortification, a 1 cup serving still provided a 3.5-fold excess of the RDA for vitamin A. Moreover, the PCR values of all the fortified flakes (Table 1) were higher than 0.118, the national average for all foods (Lachance, 1972).

Each plant protein used in this study had its own characteristic amino acid composition (Table 2). All of the

flakes were deficient in total sulfur with chemical scores relative to FAO/WHO (1973) amino acid pattern of 65, 57, 95, 59 and 57 for control, soy flour, soy flour plus methionine, cottonseed flour and gluten formulations, respectively. In addition, the cottonseed and gluten formulations were deficient in lysine with chemical scores of 85 and 46, respectively.

The ratio between essential and nonessential amino acids, EAA/NEAA, was highest for the control flakes and the flakes with soy plus methionine (Table 2). The ratios for flakes with soy and cottonseed flour respectively were 7% and 15% lower than those for control flakes. Gluten enriched flakes had the lowest ratio. This ratio is of some significance in that an unbalanced protein which contains an excess of nonessential amino acids can lead to an increased demand for certain essential amino acids such as methionine (Harper and Beneveng a, 1970). Thus, the higher the value of EAA/NEAA, the more efficiently the food can be utilized for protein synthesis (FAO/WHO, 1973). The amino acid content of wheat gluten enriched flakes was the most severely unbalanced because of excessive amounts of glutamic acid and proline. Flakes enriched with either soy flour and with cottonseed flour were comparable in both chemical score and EAA/NEAA ratio. Fortification of either with methionine could raise the chemical score and improve both amino acid balance and protein content.

The total weight of the hydrolyzed amino acids (Table 2) was from 14–30.8% greater than that expected from the parent protein because of the addition of a molecule of water for each peptide bond hydrolyzed. In addition sweet potato protein contains about 14% nitrogen due to high levels of aspartic and glutamic acids.

**Viscosity.** At each rotor speed, apparent viscosity was higher for the control flakes than for fortified flakes (Fig. 1). Apparently, dilution of the starch with the supplementary material decreased its water-binding capacity, and the decrease was reflected in lowered viscosities of the reconstituted flakes. Although proteins are water-binding agents, they were not as effective as the starch. Walter et al. (1976) reported that puree from sweet potato flakes behaved as a pseudoplastic fluid. The soy and cottonseed flour formulations also showed pseudoplastic flow, although the degree of shear thinning was much less than that of control flakes. The gluten formulation did not appear to be affected by the rate of shear.

**Chromaticity.** Hunter Color Meter "a" values indicated that control flakes were significantly redder than any of the fortified flakes (Table 3). Flakes with cottonseed flour had only half the "a" value of the control. They had a brownish color quite unlike that of the control or any of the other fortified flakes. The "b" values which measure yellowness were much more similar than were the redness values. Visually, the control samples appeared to be the most orange. The color of the gluten and soy flour samples were like that of the control but less intensely orange.

**Carbohydrate composition.** Addition of proteinaceous material to sweet potato had the effect of diluting all carbohydrate fractions. Thus, sugar, dextrin and starch levels were highest in control flakes, while fortified flakes had similar carbohydrate levels (Table 4).

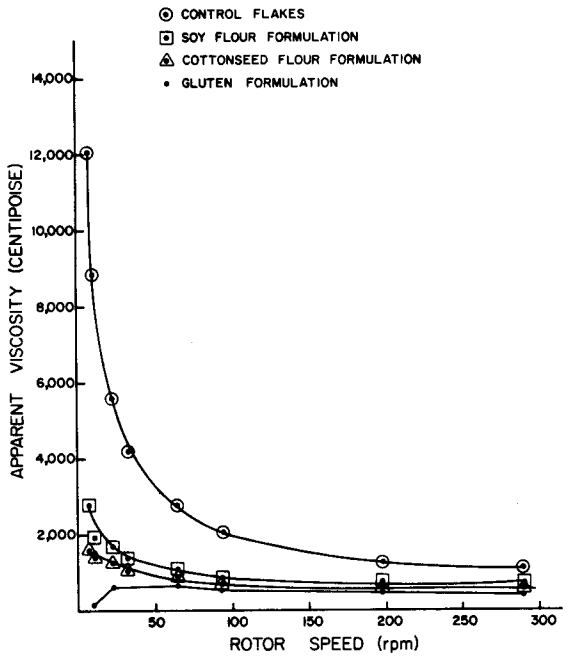


*Fig. 1—Apparent viscosity of reconstituted sweet potato flake formulations as a function of rotor speed.*

*Table 3—Reflectance of reconstituted control and fortified sweet potato flakes*

| Flake sample | Hunter Color Meter values | |
|---|---|---|
| | "a" | "b" |
| Control | 22.7 | 29.0 |
| Soy flour fortified | 15.3 | 27.2 |
| Gluten fortified | 18.6 | 27.3 |
| Cottonseed flour fortified | 10.7 | 24.2 |
| LSD 0.05 | 3.2 | 1.1 |
| 0.01 | 5.9 | 2.0 |

*Table 4—Carbohydrate composition[a] of control and protein fortified sweet potato flakes*

| Flake sample | Sugars | Dextrins | Starch |
|---|---|---|---|
| Control | 51.20 | 17.60 | 7.74 |
| Soy flour fortified | 44.80 | 12.50 | 4.76 |
| Gluten fortified | 46.00 | 12.20 | 4.54 |
| Cottonseed flour fortified | 45.80 | 11.90 | 6.89 |

[a] Grams in 100g of flakes

### Stored flakes

**Amino acid stability.** Statistical analysis of the data was employed to determine whether the amino acid content changed significantly during storage at either 23° or 40°C. Table 5 presents regression ANOVA data only for those amino acids that were affected by storage. The F values indicate that the levels of alanine, glycine, leucine, methionine, serine, tyrosine and valine changed during storage. The absence of a significant storage time by temperature interaction for any of these amino acids indicated storage time changes were independent of temperature. That is, the amino acid composition changed with time regardless of temperature. Because of the nature of the procedures used to perform the regression analyses reported in Table 5, the derived F values do not inherently imply a significant linear change over time.

Subsequent linear regression analyses showed that the levels of only two amino acids changed linearly during storage. The individual formulation regression coefficients derived for these two amino acids are given in Table 6. Only glycine in the gluten formulation decreased linearly during storage. The positive regression coefficient for tyrosine in the soy formulation

*Table 5—Regression analysis of variance of the amino acid composition of control and fortified sweet potato flakes stored under nitrogen*

| Source | df | Alanine | | Glycine | | Leucine | | Methionine | | Serine | | Tyrosine | | Valine | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean Square | F | Mean Square | F | Mean Square | F | Mean Square | F | Mean Square | F | Mean Square | F | Mean Square | F |
| Storage time (ST) | 4 | 0.2134 | 3.62* | 0.2633 | 4.56** | 0.6401 | 3.21* | 0.8868 | 49.96** | 0.8784 | 3.55* | 0.3159 | 6.13** | 0.8313 | 3.30* |
| Temperature | 1 | 0.2387 | 4.05 | 0.5578 | 9.65** | 0.0106 | 0.05 | 0.0256 | 1.44 | 0.0392 | 0.16 | 0.0912 | 1.77 | 0.4682 | 1.86 |
| ST X Temp | 3 | 0.0947 | 1.61 | 0.1299 | 2.25 | 0.1403 | 0.70 | 0.0284 | 1.60 | 0.3609 | 1.46 | 0.0074 | 0.14 | 0.6487 | 2.57 |
| Residual | 45 | 0.0589 | | 0.0578 | | 0.1995 | | 0.0178 | | 0.2472 | | 0.0515 | | 0.2521 | |

* $P \leq 0.05$
** $P \leq 0.01$

indicated an increase in tyrosine with time probably due to greater relative stability. The fact that most of the amino acids were stable during storage did not mean that the biological availability remained unchanged. Animal studies will be necessary to determine changes in this value.

**Viscosity changes.** Viscosity changed significantly with storage. Regression analysis (Table 7) showed that the viscosities of control and cottonseed flour reconstituted flakes increased during storage at 23°C. In contrast, viscosities of control, cotton and soy formulations decreased during storage at 40°C. Viscosity of the gluten formulation appeared to be independent of storage conditions. Examination of the pooled viscosity data led us to question whether the apparent increased viscosities for 23°C stored formulations were real. The data (Fig. 2) showed that the increase occurred primarily during the interval between the 4 and 8.25 month samplings; whereas, decreases occurred consistently with storage at 40°C. We can offer no explanation for the increased viscosities at 23°C, if indeed they were not the result of instrumental or procedural errors during the 8.25-month analysis. In a subsequent study conducted on flakes stored at 23°C in air, we observed no significant change in viscosity. The decreased viscosities caused by the 40°C storage may indicate a loss in the capacity of the flakes to bind water. Since the control flakes had both the greatest negative regression coefficient and the highest starch and dextrin content (Table 4), we suggest that changes in the starch or dextrin components were responsible.

**Nonenzymatic browning products.** The extent of brown pigment production in the formulations was evaluated from changes in optical absorbance of their aqueous extracts. Regression analysis of the data indicated that significant changes ($P \leq 0.05$) occurred only in the soy-methionine and cottonseed formulations.

The browning reaction is one of the more important chemical changes occurring in dehydrated foods. The extent of the reaction depends upon the water activity of the food (Labuza et al., 1970) as well as protein and carbohydrate levels. Although the water activity was not measured, the flakes were maintained at a 4–6.3% moisture level, and this should have been low enough to prevent significant browning. Our observations confirmed this. The soy-methionine formulation stored at 23°C appeared to have lost water-soluble pigment. We have no logical explanation for this change except to note that it was an apparent decrease in pigment rather than an increase as would be expected from browning. On the other hand, the soy-methionine formulation stored at 40°C did form pigment, but only a 10% increase in absorbance was observed for the entire 8.25-month storage. The absorbancy of cottonseed enriched flakes stored at 40°C increased 76.8%. Perhaps its higher moisture level of 6.3% versus 4.0% for the soy-methionine formulation was a factor in the pigment production. However, the actual amino acid loss due to browning was minimal as determined by regression ANOVA.

**Sensory evaluation.** Taste panelists were not able to detect any storage time differences (0.05 level) due to storage time at

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*Table 6—Formulation regression coefficients for amino acid composition on storage time*

| Amino acid | Formulation | $\beta^a$ |
|---|---|---|
| Glycine | Gluten | −0.0339* |
| Tyrosine | Soy | 0.0607* |

[a] Slope in grams of amino acid/16g nitrogen month$^{-1}$
* Significant at $P \leq 0.05$

*Table 7—Effects of storage temperature on viscosity of reconstituted sweet potato flakes*

| Formulation | $\beta_{23}$[a] | $\beta_{40}$[a] |
|---|---|---|
| Control | 0.6154* | −1.513* |
| Cotton | 0.5811* | −0.6054** |
| Gluten | 0.2669 | 0.1658 |
| Soy | 0.3324 | −0.5292* |

[a] Regression coefficients for viscosity on storage time at 23°C and 40°C, respectively.
* Significant at $P \leq 0.05$.
** Significant at $P \leq 0.01$.

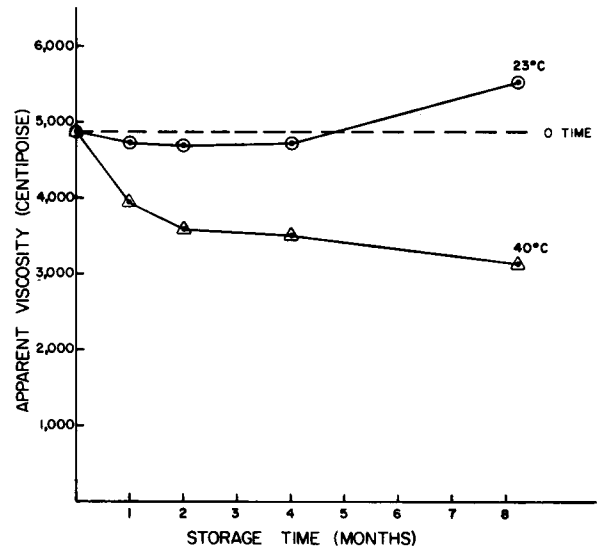


*Fig. 2—Apparent viscosity of reconstituted sweet potato flakes stored at 23°C and 40°C. Data pooled over all formulations. Rotor speed 97.2 rpm.*

23°C. They did detect changes in flakes stored at 40°C for 4 months. When significant differences were observed, samples stored at −5°C were preferred. Since the fundamental purpose of the sensory test was to evaluate flavor changes occurring during storage, the panelists were not asked to indicate preferences between control and fortified flakes. Reconstituted flakes are usually prepared for consumption in combination with spices and toppings, which tend to modify flavor. Thus, further studies are needed to determine the ingredients which will promote consumer acceptance.

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