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Physicochemical and Sensory Characteristic Changes in Fortified Peanut Spreads after 3 Months of Storage at Different Temperatures

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Three amino acid-balanced, vitamin- and mineral-fortified peanut spreads were stored at 4, 23, and 40 °C for 3 months. These were 69.6% peanut/19% soybean−40.5% fat, 61.9% peanut/19% soybean−44.5% fat, and 74.1% peanut/14% nonfat dry milk (NFDM)−40% fat. The peanut spreads were fortified with vitamin A, thiamin, riboflavin, vitamin B_6, vitamin C, calcium, and iron to provide 33.3% of the Recommended Dietary Allowances for children. Water-soluble vitamins were quite stable in deaerated peanut spreads. The antioxidant activity of phytochemicals in soybean prevented vitamin A degradation in soy-containing spreads, whereas the NFDM spread lost 70% of the initial content. Instron analysis detected major changes in texture when peanut spreads were stored at 40 °C, suggesting that the polymorphic form of lipid transformed and the proper crystallization of stabilizer was destroyed. Panelists did not detect the texture changes in peanut spreads stored at different temperatures. At 40 °C, the primary deteriorative changes in sensory quality were increased browning and the development of "soybean" and "oxidized" flavors as well as decreased "roasted peanutty" flavor.

KEYWORDS: Fortified; peanut spread; vitamin; texture; storage

INTRODUCTION

Peanuts (*Arachis hypogaea* L.) are an important source of edible vegetable oil and vegetable protein. Peanuts, which are grown on ∼1.5 million acres in the United States (*1*), are an excellent source of folate, niacin, vitamin E, and essential (linoleic) fatty acid. When peanuts are roasted, the sugars and free amino acids react to produce the typical roasted peanutty flavor that transforms peanuts into a palatable plant-derived food.

Peanut butter accounts for approximately half of the total food use of peanuts in the United States. Peanut butter is manufactured by grinding shelled, roasted, blanched peanuts into a homogeneous paste with the addition of salt, sugar, oil, and usually stabilizer. This protein-rich product has become a staple in the American diet and is consumed by children, middle-aged, and elderly persons of both sexes. It has a pleasing peanutty flavor, is convenient to use, and is microbiologically stable at ambient temperature due to low moisture content (<2%) (*2*). Nowadays, consumers demand more nutritious, healthy, and convenient foods. However, peanut protein is deficient in lysine, and peanuts are deficient in some vitamins and minerals for growing children such as vitamin A, thiamin, riboflavin, vitamin B_6, vitamin C, calcium, and iron. On the other hand, soybeans contain a relatively high amount of lysine and so does nonfat dry milk (NFDM) powder. Soybeans also contain other valuable components, such as phospholipids, isoflavones, vitamins, and minerals. These valuable components make soybean and NFDM powder good supplements for peanut spread. We hypothesize that a peanut-based spread fortified with 14% NFDM or 19% roasted soybean as well as vitamin A, thiamin, riboflavin, vitamin B_6, vitamin C, calcium, and iron can be made palatable and would be a convenient food that contributes to a nutritious diet.

A product should no longer be sold to the consumer when the initial quality is lost. Quality losses include an unacceptable loss in nutrient value, an undesirable change in flavor or color, or the development of an undesirable texture (*3*). Visual appearance is one of the important characteristics of foods in determining their selection prior to actual consumption. An extreme shift in the color of a food, even though accompanied by no change in flavor, can make it completely unacceptable to consumers.

Rancidity, the result of lipid oxidation, is one of the major causes of food spoilage and off-flavor. Peanuts contain 47−50% fat, of which 76−82% is unsaturated fatty acid. This makes them prone to develop rancid off-flavors through lipid oxidation (*4*).

The overall objective of this study was to determine changes in the physicochemical and sensory characteristics of peanut

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Table 1. Protein Quality Profile of Peanut Spreads Containing 19% Roasted Soybean or 14% Nonfat Dried Milk

		computed ratio		
amino acid	ideal ratio[a] for 6–12-year-olds	all-peanut	with 19% roasted soybean	with 14% NFDM[b]
histidine	19	24	25.2	25.25
isoleucine	28	34	38.36	40.20
leucine	44	64	68.42	71.36
lysine	44	35	44.20	44.97
methionine + cystine	22	24	25.87	26.73
phenylalanine + tyrosine	22	91	89.74	91.76
threonine	28	33	36.21	36.07
tryptophan	9	9	10.92	10.52
valine	25	25	43.32	46.77

[a] Ratios are in milligrams of amino acid per gram of protein (mg/g of protein). [b] Amino acid profiles were calculated from data in the ESHA Food Processor software.

Table 2. Formulation for Peanut Spread Samples

ingredient[a]	all-peanut control	PSM[b]	PSSA[c]	PSSB[d]
peanut (%)	89.5	74.1	69.6	61.9
soybean (%)	0	0	19.0	19.0
milk (%)	0	14.0	0	0
peanut oil (%)	2.0	2.1	1.5	8.9
stabilizer (%)	1.5	1.2	0.9	1.2
total fat (%)	47.9	40.0	40.5	44.5
vitamin A (mg/100 g)	0	8.31	9.61	9.61
vitamin B_1 (mg/100 g)	0	0.70	0.69	0.69
vitamin B_2 (mg/100 g)	0	0.94	1.05	1.05
vitamin B_6 (mg/100 g)	0	1.25	1.26	1.26
vitamin C (mg/100 g)	0	45.09	46.01	46.01
calcium (mg/100 g)	0	1591	1911	1911
iron (mg/100 g)	0	34.26	31.86	31.86

[a] All treatments contain 6.0% sugar and 1.0% salt. [b] PSM, peanut spread fortified with milk at a 40% total fat content. [c] PSSA, peanut spread fortified with soybean at a 40.5% total fat content. [d] PSSB, peanut spread fortified with soybean at a 44.5% total fat content.

spreads fortified with protein, vitamins, and minerals stored at three different temperatures (4, 23, and 40 °C) for 3 months. Specific objectives were to evaluate the color, vitamin retention, instrumental texture, and sensory profile of these peanut spreads after 3 months of storage at three different temperatures.

MATERIALS AND METHODS

Materials. Medium-roasted Georgia Green peanuts ($L^* = 57.70$, $a^* = 9.33$, $b^* = 31.77$) containing 49.6% fat and 23.60% protein (dry basis), peanut oil, fine powdered salt, and white powdered sugar were donated by Tara Foods, Albany, GA. Roasted soybeans containing 19.3% fat and 43.53% protein (dry basis) were obtained from Solnuts, Inc. (Hudson, IA). NFDM powder fortified with vitamins A and D (34.77% protein) was purchased from a Kroger supermarket in Griffin, GA. A commercial stabilizer (Fix-X) with a melting point of 65.5 °C was obtained from Proctor & Gamble (Cincinnati, OH). It is a fully hydrogenated blend of rapeseed and cottonseed oils containing 33–37% C22:0 (behenic acid). All of the vitamins were obtained from Roche Vitamins Inc., Parsippany, NJ. Calcium carbonate was obtained from Specialty Minerals Inc., Adams, MA. Ferric orthophosphate was obtained from Wright Nutrition Inc., Crowley, CA.

Peanut Spread Preparation. The amino acid-balanced peanut spreads were obtained by combining roasted peanuts with roasted soybeans or NFDM powder in proportions to satisfy the amino acid profile (**Table 1**). The samples used in this study were (**Table 2**) a control (all-peanut spread) and three peanut spreads fortified with five vitamins and two minerals to result in one-third of Recommended Dietary Allowances (RDAs) value per serving size (32 g) for school-age children. These fortified formulations contained (a) 14% NFDM powder at a 40% total fat content (PSM), (b) 19% roasted soybean at a 40.5% total fat content (PSSA), and (c) 19% roasted soybean at a 44.5% total fat content (PSSB). The procedure for preparing the peanut spread was adapted from that of Woodroof (*2*). Medium-roasted peanuts and roasted soybeans were coarsely ground in a natural peanut butter mill (Old Tyme Food Products Corp., East Longmeadow, MA). The coarsely ground paste along with stabilizer, peanut oil, white powdered sugar, salt, and NFDM were passed through a Morehouse mill (Morehouse Industries, Los Angeles, CA) for a second grind. The mill was set with a stone clearance of four notches (0.1 mm) and maintained at 75 °C using a hot water jacket. Each peanut spread was stirred and deaerated under alternate cycles of vacuum (20 in.Hg) and nitrogen for 10 min in a heated, stirred glass kettle, and then the mixture of vitamins and minerals was blended into the peanut spread (65 °C) under an atmosphere of nitrogen for 5 min. The peanut spreads were immediately deposited into wide-mouth plastic jars and sealed with screw-cap plastic lids with a foil liner. Peanut spreads in the plastic jars were allowed to set at 5 °C in a cooler overnight.

Storage and Sampling. Samples from each replication of freshly prepared peanut spreads were stored at 4, 23, and 40 °C in the dark. Samples were removed from storage, re-equilibrated to room temperature, and evaluated for color, vitamin content, instrumental texture, and descriptive sensory characteristics after 3 months of storage.

Color Evaluation. Hunter color values were obtained using an XL800 series Gardner colorimeter with an XL845 circumferential sensor (Pacific Scientific, Bethesda, MD). The colorimeter was calibrated using a yellow reference standard tile ($L = 79.56$, $a = -2.17$, $b = 22.98$) to measure L^* (whiteness/darkness), a^* (red/green), and b^* (yellow/blue) values. Each sample was evenly spread on the bottom of the colorimeter sample cup, a depth of 10 mm. Four sets of readings were obtained per sample by rotating the cup a quarter of a turn each time. The psychometric color terms chroma, hue angle, and delta E were calculated from the a^* and b^* values using the formulas chroma $= [(a^*)^2 + (b^*)^2]^{1/2}$, hue angle $= \tan^{-1} b^*/a^*$, and delta $E = [(a^* - a_0^*)^2 + (b^* - b_0^*)^2 + (L^* - L_0^*)^2]^{1/2}$, respectively.

Vitamin Analysis. Vitamin A was analyzed using an HPLC method described by Lee and others (*5*). Thiamin, riboflavin, and vitamin B_6 (pyridoxine hydrochloride) were determined by microbiological assay. Extraction of thiamin and riboflavin was conducted using the procedures described by Shah (*6*) and Ball (*7*). Extraction of vitamin B_6 was conducted using the procedures described by Polansky and others (*8*). The vitamin concentration of a known amount of sample was estimated from the growth response when specific microorganisms were cultured in broth containing extracts of the sample as the only source of the vitamin. *Lactobacillus viridescens* ATCC 12706 was used to assay thiamin, *Lactobacillus rhamnosus* ATCC 7469 was used in the assay of riboflavin, and *Saccharomyces uvarium* ATCC 9080 was cultured for the assay of vitamin B_6. Ascorbic acid was extracted with metaphosphoric acid and acetic acid and quantified by fluorometric analysis using AOAC Official Method 967.22 (*9*). Standard curves for all of the vitamin assays were constructed. All samples were analyzed in duplicate.

Instrumental Texture Evaluation. The procedure was adapted from that of Muego and others (*10*), a modified texture profile analysis (TPA) using an Instron universal testing machine. A flat plate, 93 mm in diameter, was attached to a 50 kg compression load cell fitted into the crosshead of an Instron universal testing machine (model 1122, Instron Crop., Canton, MA). Another flat plate, 150 mm in diameter, was attached to the wear plate of the loading frame. A 2.5 g dollop of each spread was positioned on the center of the bottom plate and compressed at a speed of 20 mm/min until the clearance between the two plates reached 2 mm. Hardness was interpreted as the peak force (N) of the first compression cycle. Adhesiveness (J) and adhesive force (N) were interpreted as the area and peak force that occurred during the upstroke of the first compression cycle, respectively. Cohesiveness was measured as the area ratio of the second and first compression curves. Gumminess was calculated as the product of hardness and cohesiveness. Triplicate

Table 3. Terms Used in Descriptive Analysis of Peanut Spreads[a]

attribute	definition
appearance	
brown color[b]	intensity of brown color from light to dark brown
surface oiliness[d]	amount of oiliness on surface
spreadability[b]	ease of spread of sample on bread
aromatics	
roasted peanutty[e]	aroma associated with medium-roasted peanuts
roasted soybean	aroma associated with roasted soybean
oxidized[c,e]	aroma associated with stale peanuts and rancid fats
milky	aroma associated with cow's milk
vitamin	aroma associated with vitamin A or B-complex
woody/hulls[e]	aroma associated with base peanut character and related to dry wood and peanut hulls and skin
metallic[e,f]	aroma associated with iron and copper
taste	
sweet[c,e]	taste on the tongue associated with sugars
salty[e]	taste on the tongue associated with sodium chloride/salt
bitter[c,e]	taste on the tongue associated with bitter agents such as caffeine
sour[e]	taste on the tongue associated with citric acid
texture	
prior to mastication	
stickiness[b]	amount of product adhering to lips
first compression	
hardness[b,g]	force required to compress between tongue and palate
graininess[b,c]	amount of particles or granules perceived in the mouth
adhesiveness[c,d,g]	force required to remove sample from roof of the mouth
cohesiveness[d]	amount of sample that deforms rather than shears/cuts (ability to stay together)
masticatory	
cohesiveness of mass[d]	degree of mass holds together
residual	
mouth-coating[b]	amount of residual perceived in mouth after sample is expectorated
mouth dryness[b]	drying sensation on palate
oily feeling[b,c]	amount of oil perceived in mouth after sample is expectorated
adhesiveness to teeth[d]	amount of sample left on the teeth

[a] Attributes listed in order perceived by panelists. [b] Reference *16*. [c] Reference *26*. [d] Reference *12*. [e] Reference *14*. [f] Reference *15*. [g] Reference *27*.

measurements were conducted for each peanut spread formulation stored at different temperatures.

Sensory Evaluation. *Descriptive Analysis.* Prospective members of the descriptive panel were recruited from a pool of previously trained panelists and students from the University of Georgia, Griffin campus. Panelists were recruited on the basis of the following criteria: natural dentition, no food allergies, nonsmokers, between the ages of 21 and 50, eat peanut butter at least twice a month, available for all sessions, interest in participating, and able to verbally communicate about the product (*11*). Potential panelists with no prior descriptive experience were recruited after a series of screening tests that consisted of two sections, a taste test and an aroma test. In the taste test, panelists were asked to correctly identify five coded aqueous solutions of sucrose, sodium chloride, caffeine, citric acid, and one unknown in 5 min. In the aroma test, panelists were asked to correctly identify five of seven aromatics including banana, anise, pineapple, orange, vanilla, peppermint, and lemon aromatics in seven 120 mL glass bottles in 10 min.

Panelists were required to complete and sign a consent form approved by the University of Georgia Institutional Review Board prior to participating in the training and testing sessions. An honorarium of $12 per session was provided at the conclusion of the test to the panelists who were not employed by the University of Georgia.

Panel Training. Ten panelists (three males and seven females) were selected. Panelists were trained on descriptive analysis test procedures as described by Meilgaard and others (*12*) in six 2-h training sessions for a total of 12 h. Panelists evaluated samples using a "hybrid" descriptive analysis method (*13*), a combination of some aspects of both the Quantitative Descriptive Analysis (QDA) (Tragon Corp., Redwood City, CA) and the Spectrum Analysis (Sensory Spectum, Inc., Chatham, NJ) methods. A 150 mm unstructured line rating scale (0−150) with anchors at 12.5 and 137.5 mm was used at training and testing.

During the first day of training, panelists were given an overview of sensory evaluation and an introduction to the use of the computers to be used for data collection. On the second day, panelists initially were asked to evaluate the peanut spreads and to make a list of the descriptors for their appearance, flavor, mouthfeel, and aftertaste. A list of attributes and definitions, previously used to describe peanut butter (*14*−*16*), was presented to panelists. Panelists then decided on a final list of attributes that was comprehensive with definitions and agreed upon all panelists. The list included 2 appearance, 1 spreadability, 11 flavor, and 10 texture attributes (**Table 3**). Panelists also determined references to be used during the evaluations to help them evaluate the color, flavor, and texture terms. Each panelist rated the attribute intensity of each reference by first evaluating the reference for a particular attribute and then giving an intensity rating between 0 and 150 using flashcards. Those panelists who did not rate within 10 points of the average were asked to re-evaluate and adjust their rating until a consensus was reached. The mean intensity rating was calculated and used as the attribute intensity rating for that particular reference (**Table 4**).

Calibration of the panel continued from the third session to the last training session. Consensus scores were obtained on a fresh all-peanut spread, which was used as a warm-up sample (**Table 5**) and presented to each panelist as the initial sample during training and testing sessions to increase reliability of attribute intensity ratings (*17*) on the fourth session. During the remaining days of training, panelists practiced evaluating each peanut spread sample using a computerized ballot (Compusense, version 2.4, Compusense, Inc., Guelph, ON, Canada), with 24 attributes, listed vertically, in their order of appearance. Individual panelist's ratings were analyzed for mean ratings and standard deviations after each training session, and results were distributed to each panelist prior to the next session to provide feedback on their performance.

Descriptive Test Procedures. The test was conducted in an environmentally controlled sensory laboratory with partitioned booths illuminated with two 50-W indoor reflector flood lamps. Each trained panelist rated 24 attributes on four formulations stored at three different temperatures for four times (two processing replications in duplicate). A total of 48 samples were evaluated in a balance sequential monadic order. Those samples were served along with warm-up samples for four testing days. Three or four samples were evaluated during each

Table 4. Standard References and Intensities Used in Descriptive Analysis of Peanut Spreads

attribute	reference	intensity[a] (mm)
brown color	corrugated cardboard, L^* = 57.99, a^* = 7.47, b^* = 25.38 (Safco Products Co., New Hop, MN)	45
	Jif peanut butter (Procter & Gamble, Cincinnati, OH)	60
surface oiliness	Jif peanut butter (Procter & Gamble, Cincinnati, OH)	45
spreadability[b]	Philadelphia cream cheese (Kraft Foods, Glenview, IL)	95
	Kraft mayonnaise (Kraft Foods, Glenview, IL)	145
roasted peanutty[b]	Planter's roasted peanuts (Nabisco Inc., East Hanover, NJ)	65
roasted soybean	dry-roasted soybeans (Solnut, Inc., Hudson, IA)	60
oxidized	oxidized peanuts	40
milky[c]	American cheese (Kraft Foods, Glenview, IL)	30
	Carnation powdered milk (Nestle Inc., Solon, OH)	40
vitamin	0.02% vitamin A and 0.003% vitamin B-complex in double-deionized water	55
woody/hulls	peanut skin	35
metallic	1.0% ferrous sulfate in double-deionized water	70
sweet	2.0% surcose in double-deionized water (Dixie Crystals Savannah Foods & Industries, Inc.)	20
	5.0% surcose in double-deionized water (Dixie Crystals Savannah Foods & Industries, Inc.)	50
	10.0% surcose in double-deionized water (Dixie Crystals Savannah Foods & Industries, Inc.)	100
salty	0.2% sodium chloride in double-deionized water (Fisher Scientific, Fair Lawn, NJ)	25
	0.35% sodium chloride in double-deionized water (Fisher Scientific, Fair Lawn, NJ)	50
bitter	0.05% caffeine in double-deionized water (Fisher Scientific, Fair Lawn, NJ)	20
	0.08% caffeine in double-deionized water (Fisher Scientific, Fair Lawn, NJ)	50
sour	0.05% citric acid in double-deionized water	20
	0.08% citric acid in double-deionized water (Fisher Scientific, Fair Lawn, NJ)	50
stickiness[b]	cheese sauce, Cheddar flavor (Kroger Co., Cincinnati, OH)	20
hardness[b]	Philadelphia cream cheese (Kraft Foods, Glenview, IL)	20
graininess[b]	Jif peanut butter (Procter & Gamble, Cincinnati, OH)	0
	cream of wheat (Nabisco Inc., East Hanover, NJ)	120
adhesiveness[b]	Philadelphia cream cheese (Kraft Foods, Glenview, IL)	45
cohesiveness[c]	Jell-o instant vanilla pudding (Kraft Foods, Glenview, IL)	50
cohesiveness of mass	American cheese (Kraft Foods, Glenview, IL)	90
mouth-coating[b]	Phillips' Milk of Magnesia (Bayer Corp., Morristown, NJ)	65
mouth drying[b]	Phillips' Milk of Magnesia (Bayer Corp., Morristown, NJ)	55
oily feeling[b]	cheese sauce, Cheddar flavor (Kroger Co., Cincinnati, OH)	20
	Kraft mayonnaise (Kraft Foods, Glenview, IL)	50
adhesiveness to teeth[c]	American cheese (Kraft Foods, Glenview, IL)	90

[a] Rated on a 150 mm unstructured line scale with anchors at 12.5 and 137.5 mm. [b] Reference *16*. [c] Reference *12*.

session for a total of 14 samples in 1 day using a computerized ballot described above. A compulsory 3 min break was taken between each session.

Forty grams of each sample, in covered 3.25 oz plastic cups coded with three-digit random numbers, was served at ambient temperature. Four slices of white bread cut into fourths were provided for rating spreadability. Panelists were instructed to use 1 teaspoon of sample for evaluating spreadability attributes, 1 teaspoon for evaluating flavor, and 1 teaspoon for evaluating each of the stages of textural evaluation—prior to mastication, first compression, masticatory, and residual. Panelists were also instructed to expectorate and eat some unsalted cracker and then rinse with water after each sample.

Statistical Analysis. SAS statistical software was used (*18*) to analyze all of the data. Cluster analysis was used to determine if any of the trained panelists were outliners. Ratings of one trained panelist, an outlier, were deleted from all analyses.

Analysis of variance, the general linear model procedure (PROC GLM), was used to determine significant differences among treatments on physicochemical measurements and descriptive sensory evaluation. Fishers's least significant difference test (LSD) was performed to determine which sample means were significantly different (α = 0.05).

RESULTS AND DISCUSSION

Physiochemical Measurements. *Color.* All of the color data are shown in **Table 6** for the four different formulas. After 3 months of storage, L^*, a^*, b^*, calculated chroma, hue angle, and delta E of all formulas stored at 4 °C exhibited less change than those stored at 23 and 40 °C did. L^* value, chroma, hue angle, and delta E of all-peanut control stored at 40 °C were all significantly different from those of samples stored at 4 °C. The increasing hue angle suggested a shift from red to yellow color, possibly due to different light refraction by surface oil. The slightly higher L^* value is thought to be due to oil separation (sheen) at the surface. L^* value, hue angle, and delta E of PSM and PSSA stored at 23 and 40 °C were significantly different from those stored at 4 °C. Chroma, hue angle, and delta E of PSSB stored at 23 and 40 °C were significantly different from PSSB stored at 4 °C. The observed changes indicated a slightly redder and darker color.

Vitamins. Vitamin A was reduced by ~70% in PSM when samples were stored at 23 or 40 °C (**Table 7**). The degradation of vitamin A in foods occurs mainly through reactions involving either autoxidation or geometric isomerization (*19*). Elevated temperature has been shown to promote both trans-to-cis isomerization and autoxidation. For PSSA and PSSB stored at room temperature (**Table 7**), there was no significant difference in vitamin A concentration. The phytochemicals present in soybean have been shown to possess antioxidant activity (*20*, *21*). Those phytochemicals may have prevented severe degradation of vitamins A and C.

There were no significant losses of thiamin or riboflavin for all fortified samples. However, the stability of water-soluble vitamins in food has been shown to be strongly influenced by water activity. In the absence of oxidizing lipids, water-soluble vitamins generally exhibited little degradation at water activity less than or equal to monolayer hydration ($a_w \sim 0.2-0.3$) (*19*). At 4 °C, thiamin, riboflavin, vitamin B_6, and vitamin C exhibited excellent stability under conditions of low water activity. Vitamin B_6 was reduced by ~10−20% when samples were stored at 40 °C. Although vitamin C was essentially insoluble

Table 5. Warm-up Sample[a] Intensity Ratings

attribute	intensity rating[b]
appearance	
brown color	63
surface oiliness	70
spreadability	87
aromatics	
roasted peanutty	52
roasted soybean	0
oxidized	0
milky	0
vitamin	0
woody/hulls	26
metallic	0
taste	
sweet	24
salty	30
bitter	6
sour	0
texture	
stickiness	14
hardness	30
graininess	10
adhesiveness	68
cohesiveness	73
cohesiveness of mass	70
mouth-coating	68
mouth dryness	57
oily feeling	30
adhesiveness to teeth	100

[a] Fresh processed all-peanut spread consisted of 89.5% peanut, 2% peanut oil, 1.5% stabilizer, 6.0% sugar, and 1.0% salt. [b] A 150 mm unstructured line scale was used. Intensity scores were agreed upon by consensus by the descriptive panel during the training.

in oil, it was surprisingly effective as an antioxidant when dispersed in oil. Consequently, vitamin C was reduced according to the increasing storage temperature for all fortified spreads. In general, one needs to maintain low storage temperature for peanut spreads to preserve the important nutrients.

Instrumental Texture. Hardness, adhesiveness, and gumminess measurements decreased as the stored temperature increased (**Table 8**). PSM contained >7% lactose, and it is hypothesized that the crystallization characteristics of lactose altered the texture profile of PSM. Therefore, PSM stored at 4 °C had the highest readings of hardness, adhesiveness, and gumminess. There were no significant differences in adhesive force and cohesiveness among treatments (data not shown). The texture of peanut butters and spreads is affected by a number of processing and storage variables. These differ considerably between products made by large-scale commercial processes and experimental processes such as those practiced in this study. Making peanut spreads involved grinding, which was a very crucial operation that affects the structure and texture of the spread by breaking the cell walls and dispersing the fat, starch, and protein bodies (*22*). Transformation of one polymorphic form of lipid into another takes place in the solid state without melting the lipid (*23*). As is practiced with commercial peanut butter, the peanut spread was tempered (in this case, overnight at 5 °C) so that the peanut oil and stabilizer could form a stable crystalline mixture through the transformation of one polymorphic form into another. High-temperature storage could either prevent solidification or destroy the proper crystallization of stabilizer as well as cause the change of hardness, adhesiveness, and gumminess. Our findings agreed with the report of Hinds and others (*24*) that temperature was the most significant factor affecting the texture properties of peanut spreads.

Sensory Analysis. Mean intensity ratings of descriptive attributes for the all-peanut control, PSM, PSSA, and PSSB stored at three different temperatures are shown in **Tables 9**, **10**, **11**, and **12**, respectively. There were no significant differences in the intensities of brown color of the stored all-peanut control and PSM (**Tables 9** and **10**). Brown color intensities increased in the PSSA and PSSB stored at 40 °C (**Tables 11** and **12**), probably due to the browning reaction. PSSB stored at 40 °C had a significant difference in surface oiliness rating from that of PSSB stored at 4 °C due to the oil separation caused by the high fat content, low ratio of stabilizer to fat, and elevated stored temperature. There were no significant differences among the temperature treatments on the intensities of spreadability

Table 6. Color Measurements of Peanut Spreads after 3 Months of Storage[a]

treament	L^{*b}	a^{*c}	b^{*d}	chroma[e]	hue angle[f]	delta E^g
all-peanut (fresh)	55.79c	12.18a	40.66ab	42.46a	73.33ab	
all-peanut (at 4 °C)	55.10d	12.67a	40.21bc	42.17a	72.52b	1.01b
all-peanut (at 23 °C)	56.44b	11.65ab	41.41a	43.02a	74.27ab	1.58b
all-peanut (at 40 °C)	56.99a	10.75b	39.14c	40.59b	74.64a	2.54a
MSE[8]	0.024	0.466	0.732	0.559	1.167	0.224
PSM (fresh)	64.20a	7.93b	36.10	36.96	77.61a	
PSM (at 4 °C)	64.23a	7.73b	35.77	36.60	77.80a	0.39b
PSM (at 23 °C)	63.12c	9.54a	35.60	36.89	75.00b	2.00a
PSM (at 40 °C)	63.93b	9.41a	36.00	37.21	75.34b	1.51a
MSE[8]	0.022	0.335	0.959	0.83	1.121	0.31
PSSA (fresh)	58.86	11.04ab	41.61a	43.05a	74.14a	
PSSA (at 4 °C)	58.51	10.36b	41.00ab	42.29b	75.81a	0.98b
PSSA (at 23 °C)	58.27	10.75b	41.33a	42.70ab	75.41a	0.71b
PSSA (at 40 °C)	57.87	12.24a	40.65b	42.45ab	73.24b	1.83a
MSE[8]	0.004	0.141	0.145	0.135	0.273	0.133
PSSB (fresh)	59.75a	10.05b	42.92a	44.08a	76.82a	
PSSB (at 4 °C)	59.25bc	9.62b	42.36a	43.46a	77.19a	1.09b
PSSB (at 23 °C)	59.37b	11.08a	39.18b	40.72b	74.22b	3.90a
PSSB (at 40 °C)	59.20c	11.42a	39.62b	41.24b	73.91b	3.62a
MSE[h]	0.007	0.693	0.760	0.490	1.732	1.073

[a] Mean intensities in a column for each formulation not followed by the same letter are significantly different ($\alpha = 0.05$) as determined by Fisher's least significant difference test (LSD). [b] Measures the lightness of the peanut spread from 0 = dark to 100 = light. [c] Measures colors in the region of green to red. [d] Measures colors in the region of blue to yellow. [e] Chroma = $[(a^*)^2 + (b^*)^2]^{1/2}$. [f] Hue angle = $\tan^{-1} b^*/a^*$. [g] Delta $E = [(a^* - a_0^*)^2 + (b^* - b_0^*)^2 + (L^* - L_0^*)^2]^{1/2}$. [h] MSE, mean square error.

Table 7. Vitamin Measurements of Peanut Spreads after 3 Months of Storage[a]

treatment	vitamin A (mg/100 g)	thiamin	riboflavin	vitamin B_6	vitamin C
PSM (fresh)	0.885a	0.688	1.041	1.252a	45.532a
PSM (at 4 °C)	0.770a	0.692	1.069	1.126a	34.555b
PSM (at 23 °C)	0.235b	0.659	1.121	0.925b	34.135b
PSM (at 40 °C)	0.270b	0.708	1.056	0.889b	31.111c
MSE[b]	0.002	0.0001	0.002	0.128	1.023
PSSA (fresh)	1.140a	0.701	1.062	1.251a	42.912a
PSSA (at 4 °C)	1.125a	0.680	1.081	1.039b	38.078c
PSSA (at 23 °C)	1.170a	0.712	1.079	1.100b	41.341b
PSSA (at 40 °C)	0.880b	0.719	1.086	1.083b	37.852c
MSE[b]	0.006	0.0004	0.0005	0.0004	0.326
PSSB (fresh)	1.045ab	0.682	1.043	1.245a	42.895b
PSSB (at 4 °C)	1.115a	0.664	1.037	1.099ab	44.347a
PSSB (at 23 °C)	1.010b	0.661	1.024	1.092ab	39.351c
PSSB (at 40 °C)	0.965b	0.713	0.985	0.966b	39.042c
MSE[b]	0.001	0.001	0.004	0.004	0.089

[a] Mean intensities in a column for each formulation not followed by the same letter are significantly different ($\alpha = 0.05$) as determined by Fisher's least significant difference test (LSD). [b] MSE, mean square error.

Table 8. Instrumental Texture Profile of Peanut Spreads after 3 Months of Storage[a]

treatment	hardness	adhesiveness	gumminess
all-peanut (fresh)	5.75 ± 0.72a	6.71 ± 0.75a	6.19 ± 0.81a
all-peanut (at 4 °C)	5.81 ± 0.69a	5.60 ± 0.66a	5.73 ± 0.84ab
all-peanut (at 23 °C)	5.02 ± 1.06a	5.27 ± 1.22a	4.63 ± 1.12b
all-peanut (at 40 °C)	2.91 ± 0.46b	3.18 ± 0.39b	2.41 ± 0.26c
PSM (fresh)	5.23 ± 0.55b	6.01 ± 0.61b	7.63 ± 0.46a
PSM (at 4 °C)	7.52 ± 0.16 a	9.06 ± 0.50a	7.63 ± 0.08a
PSM (at 23 °C)	4.85 ± 0.83bc	5.30 ± 0.98b	4.43 ± 0.36b
PSM (at 40 °C)	3.70 ± 1.00c	4.15 ± 0.75c	3.74 ± 0.53b
PSSA (fresh)	4.72 ± 0.81a	6.51 ± 0.56a	5.44 ± 0.36a
PSSA (at 4 °C)	3.78 ± 0.76ab	3.91 ± 0.31b	3.85 ± 0.44b
PSSA (at 23 °C)	3.07 ± 0.06b	3.63 ± 0.27b	3.39 ± 0.51b
PSSA (at 40 °C)	2.61 ± 0.70b	3.35 ± 0.54b	3.06 ± 0.64b
PSSB (fresh)	5.51 ± 0.46a	6.21 ± 0.53a	5.22 ± 0.39a
PSSB (at 4 °C)	3.96 ± 0.36b	4.90 ± 0.66b	4.07 ± 0.62b
PSSB (at 23°C)	3.28 ± 0.50bc	3.85 ± 0.27c	2.98 ± 0.33c
PSSB (at 40 °C)	2.70 ± 0.64c	3.39 ± 0.63c	2.53 ± 0.49c

[a] Mean ± SD in a column for each formulation not followed by the same letter are significantly different ($\alpha = 0.05$) as determined by Fisher's least significant difference test (LSD).

for all formulations. When the storage temperature for the all-peanut control was increased, the roasted peanutty flavor significantly decreased and the roasted soybean and oxidized flavors increased (**Table 9**). Roasted soybean flavor also increased in PSSB as storage temperature increased (**Table 12**). Roasted soybean possessed a peanut butter-like aroma (*25*), which was present in PSSA and PSSB. This might have resulted in some confusion between roasted peanutty flavor and roasted soybean flavor for some panelists. On the other hand, other panelists were more sensitive to soybean and therefore rated high on roasted soybean flavor and low on roasted peanutty flavor. Consequently, the standard deviations were high on roasted peanutty and roasted soybean flavors. At 40 °C, all samples exhibited slightly oxidized flavor but only the all-peanut control was significantly different from the 4 °C sample. The intensities of oxidized flavor were significantly increased when 4 °C samples were compared to 40 °C samples because lipid

Table 9. Mean Intensity Rating of Color, Flavor, and Texture Attributes of All-Peanut Control[a,b]

attribute	4 °C (treatment)	23 °C	40 °C
brown color	61.57 ± 4.18	61.79 ± 3.06	59.34 ± 5.89
surface oiliness	70.02 ± 2.84	69.97 ± 2.51	71.14 ± 4.42
spreadability	87.79 ± 3.5	87.91 ± 3.10	89.98 ± 3.48
roasted peanutty	49.79 ± 5.83a	47.54 ± 6.96a	42.71 ± 14.13b
roasted soybean	1.34 ± 3.08b	1.40 ± 3.90b	9.78 ± 16.23a
oxidized	6.06 ± 9.58bc	10.10 ± 11.16ab	11.88 ± 11.66a
milk	1.01 ± 2.11	1.68 ± 4.21	1.86 ± 4.38
vitamin	4.89 ± 9.97	4.37 ± 9.76	3.84 ± 4.57
woody/hulls	20.33 ± 8.21	18.18 ± 9.84	16.47 ± 10.26
metallic	2.42 ± 10.31	1.90 ± 6.88	1.05 ± 2.62
sweet	22.53 ± 2.99	21.87 ± 3.39	21.81 ± 3.50
salty	28.25 ± 3.05	27.51 ± 3.72	27.96 ± 3.68
bitter	6.31 ± 3.38	6.96 ± 4.18	6.35 ± 4.04
sour	1.02 ± 2.00	1.67 ± 3.01	1.69 ± 3.21
stickiness	14.33 ± 1.49	14.60 ± 1.41	15.21 ± 2.05
hardness	28.80 ± 3.35	28.76 ± 2.35	27.40 ± 2.95
graininess	9.34 ± 4.69	10.24 ± 4.13	10.43 ± 5.52
adhesiveness	67.79 ± 2.58	67.99 ± 2.38	67.72 ± 4.66
cohesiveness	72.02 ± 2.06	72.47 ± 2.89	72.07 ± 2.59
cohesiveness of mass	70.04 ± 1.82	69.86 ± 2.20	70.43 ± 2.51
mouth-coating	68.46 ± 2.51	67.96 ± 2.66	68.64 ± 2.40
mouth dryness	57.91 ± 3.47	57.65 ± 3.07	57.87 ± 2.44
oily feeling	28.75 ± 2.73	29.97 ± 4.58	29.46 ± 1.92
adhesiveness to teeth	99.61 ± 2.45	99.88 ± 3.03	99.99 ± 2.29

[a] Ratings are based on a 150 mm scale with anchors at 12.5 and 137.5 mm for slight and strong, respectively. Nine trained descriptive panelists rated each attribute for each treatment a total of four times (two processing replications in duplicate) at day 90. [b] Means with different letters in each row are significantly different ($\alpha = 0.05$) as determined by Fisher's least significant difference test (LSD).

Table 10. Mean Intensity Rating of Color, Flavor, and Texture Attributes of PSM Spread[a,b]

attribute	4 °C (treatment)	23 °C	40 °C
brown color	44.58 ± 5.86	46.40 ± 6.45	46.36 ± 5.34
surface oiliness	66.84 ± 8.66	68.21 ± 8.14	69.87 ± 6.90
spreadability	88.63 ± 4.17	88.67 ± 4.06	88.59 ± 3.78
roasted peanutty	43.09 ± 10.52	38.71 ± 13.05	39.66 ± 12.14
roasted soybean	2.38 ± 6.93	1.32 ± 3.16	3.38 ± 10.48
oxidized	6.10 ± 16.57	12.07 ± 15.91	9.96 ± 10.37
milk	23.49 ± 6.04	21.19 ± 7.63	22.48 ± 8.29
vitamin	5.57 ± 4.39b	5.96 ± 4.10ab	8.76 ± 9.82a
woody/hulls	13.04 ± 8.34	12.91 ± 8.51	12.86 ± 8.91
metallic	1.76 ± 2.88	2.05 ± 3.37	4.44 ± 11.52
sweet	24.47 ± 3.31	24.06 ± 3.79	23.56 ± 3.87
salty	27.64 ± 6.60	27.56 ± 6.63	27.29 ± 6.10
bitter	4.75 ± 3.82	5.11 ± 3.82	4.95 ± 3.90
sour	3.42 ± 4.07	3.30 ± 3.92	3.07 ± 3.80
stickiness	13.96 ± 1.79	14.68 ± 2.42	14.37 ± 1.92
hardness	28.47 ± 3.26	27.83 ± 3.61	27.11 ± 3.07
graininess	9.45 ± 4.95	9.17 ± 4.74	9.68 ± 4.24
adhesiveness	66.70 ± 3.45	66.96 ± 4.35	67.09 ± 3.48
cohesiveness	72.38 ± 3.62	72.27 ± 2.79	71.41 ± 3.01
cohesiveness of mass	70.46 ± 3.78	70.67 ± 4.00	69.96 ± 3.26
mouth-coating	67.99 ± 3.11	68.00 ± 4.84	68.31 ± 3.54
mouth dryness	56.66 ± 3.08	57.54 ± 3.43	56.74 ± 2.87
oily feeling	29.57 ± 12.77	28.02 ± 3.25	28.10 ± 2.35
adhesiveness to teeth	99.53 ± 3.01	100.07 ± 2.86	99.87 ± 3.03

[a] Ratings are based on a 150 mm scale with anchors at 12.5 and 137.5 mm for slight and strong, respectively. Nine trained descriptive panelists rated each attribute for each treatment a total of four times (two processing replications in duplicate) at day 90. [b] Means with different letters in each row are significantly different ($\alpha = 0.05$) as determined by Fisher's least significant difference test (LSD).

Table 11. Mean Intensity Rating of Color, Flavor, and Texture Attributes of PSSA Spread[a,b]

attribute	treatment 4 °C	23 °C	40 °C
brown color	55.21 ± 5.48b	54.61 ± 6.26b	58.41 ± 5.22a
surface oiliness	72.59 ± 4.38	70.45 ± 7.87	70.53 ± 2.96
spreadability	88.16 ± 3.28	88.45 ± 3.12	87.58 ± 3.98
roasted peanutty	38.17 ± 12.30	40.14 ± 11.03	36.73 ± 13.49
roasted soybean	24.95 ± 19.18	19.21 ± 17.59	25.39 ± 19.56
oxidized	7.00 ± 8.74	10.62 ± 13.45	12.09 ± 12.16
milk	5.82 ± 8.23	5.50 ± 8.28	4.49 ± 8.72
vitamin	5.29 ± 6.89	5.22 ± 4.43	7.59 ± 9.74
woody/hulls	13.45 ± 9.48	13.53 ± 9.04	14.36 ± 9.32
metallic	3.70 ± 11.75	2.05 ± 3.35	3.96 ± 6.66
sweet	22.02 ± 3.01	20.99 ± 4.26	20.38 ± 4.24
salty	28.89 ± 3.64	27.17 ± 4.65	27.24 ± 4.71
bitter	5.34 ± 3.17	5.56 ± 4.14	6.62 ± 4.15
sour	1.52 ± 2.44	2.98 ± 3.95	2.89 ± 3.44
stickiness	14.30 ± 2.12	14.85 ± 2.10	15.30 ± 2.20
hardness	29.12 ± 2.94	28.96 ± 3.45	28.92 ± 2.49
graininess	16.77 ± 6.48	17.69 ± 8.93	17.72 ± 8.68
adhesiveness	69.93 ± 3.67	69.82 ± 4.06	68.38 ± 3.48
cohesiveness	73.53 ± 3.39	74.07 ± 3.60	73.13 ± 3.12
cohesiveness of mass	72.23 ± 5.61	72.12 ± 5.15	70.96 ± 2.88
mouth-coating	69.62 ± 4.26	70.20 ± 3.88	69.40 ± 2.86
mouth dryness	9.63 ± 3.85	58.96 ± 4.40	58.45 ± 3.05
oily feeling	28.63 ± 4.33	27.94 ± 4.13	29.19 ± 2.79
adhesiveness to teeth	101.10 ± 3.32	102.10 ± 5.08	100.81 ± 3.26

[a] Ratings are based on a 150 mm scale with anchors at 12.5 and 137.5 mm for slight and strong, respectively. Nine trained descriptive panelists rated each attribute for each treatment a total of four times (two processing replications in duplicate) at day 90. [b] Means with different letters in each row are significantly different ($\alpha = 0.05$) as determined by Fisher's least significant difference test (LSD).

Table 12. Mean Intensity Rating of Color, Flavor, and Texture Attributes of PSSB Spread[a,b]

attribute	treatment 4 °C	23 °C	40 °C
brown color	52.39 ± 5.89b	52.92 ± 6.53b	56.06 ± 5.82a
surface oiliness	70.17 ± 3.70b	70.66 ± 3.51ab	72.27 ± 4.75a
spreadability	90.90 ± 4.77	90.16 ± 4.60	90.11 ± 5.42
roasted peanutty	35.96 ± 15.90	36.34 ± 11.89	30.04 ± 16.76
roasted soybean	24.25 ± 20.44b	28.97 ± 19.09ab	33.72 ± 18.91a
oxidized	7.81 ± 9.96	8.01 ± 13.16	11.95 ± 12.28
milk	10.52 ± 12.08	6.91 ± 9.59	5.54 ± 10.30
vitamin	5.83 ± 4.26	5.39 ± 4.38	8.45 ± 11.52
woody/hulls	12.96 ± 9.43	13.98 ± 8.22	11.53 ± 9.22
metallic	2.00 ± 2.82	3.62 ± 11.73	5.41 ± 13.53
sweet	22.43 ± 3.9	22.17 ± 3.71	21.94 ± 3.72
salty	28.06 ± 3.81	27.78 ± 3.71	27.86 ± 5.76
bitter	4.86 ± 3.73	5.05 ± 3.77	5.89 ± 4.73
sour	1.92 ± 2.91	2.40 ± 3.24	3.16 ± 3.64
stickiness	15.62 ± 2.56	16.45 ± 2.63	15.64 ± 3.17
hardness	26.96 ± 3.19	26.53 ± 3.72	26.72 ± 2.73
graininess	18.75 ± 7.22	20.01 ± 9.05	20.37 ± 8.61
adhesiveness	66.91 ± 5.26	67.02 ± 3.73	67.73 ± 5.07
cohesiveness	71.55 ± 3.71	71.36 ± 3.03	71.92 ± 3.24
cohesiveness of mass	70.41 ± 4.09	69.69 ± 3.94	69.48 ± 3.91
mouth-coating	68.58 ± 3.10	68.78 ± 3.11	68.03 ± 3.38
mouth dryness	57.26 ± 2.87	58.04 ± 3.16	57.92 ± 4.08
oily feeling	29.08 ± 3.50	28.81 ± 3.35	29.01 ± 3.05
adhesiveness to teeth	99.87 ± 2.78	99.81 ± 3.23	99.78 ± 4.17

[a] Ratings are based on a 150 mm scale with anchors at 12.5 and 137.5 mm for slight and strong, respectively. Nine trained descriptive panelists rated each attribute for each treatment a total of four times (two processing replications in duplicate) at day 90. [b] Means with different letters in each row are significantly different ($\alpha = 0.05$) as determined by Fisher's least significant difference test (LSD).

oxidation was promoted by high temperature, but the ratings were all lower than 20, which indicated that oxidized flavor was barely detectable. The short storage time of 3 months did not cause severe oxidation but only reduced peanutty flavor in the all-peanut control, increased vitamin flavor in PSM, and increased soybean flavor in the all-peanut control and PSSB. In addition, the phytochemicals in soybean, vitamin A, and vitamin C in the spread could have prevented those spreads from oxidizing. The trained panelists also found that those peanut spreads had barely detectable vitamin, metallic, bitter, and sour flavors, although PSM, PSSA, and PSSB were fortified with small amounts of vitamins and minerals. There were no significant differences in sensory texture profiles for any treatment. Although the change in instrumental texture profiles was apparent, consumers did not detect the texture change in peanut spreads stored at different temperatures. Flavor changes were the primary signs of deterioration for the stored peanut spreads.

Conclusion. Differences in texture profiles of the stored peanut spreads were detected by Instron analysis but not by trained panelists. Instrumental texture profiles of peanut spreads were significantly affected by storage temperature. Water-soluble vitamins were more stable than vitamin A in peanut spreads. The antioxidant activity of phytochemicals in soybeans protected vitamins A and C from degradation. Vitamins A and C can serve as antioxidants in peanut spreads to maintain the quality and nutrients.

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