Characteristics of Peanut Kernels Roasted under Various Atmospheric Environments

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Peanut kernels (Tainan 9, a Spanish cultivar) were roasted in a stainless steel vessel (600 mL) at 210 °C under a continuous flow of air, N_2, CO_2, and O_2 at 1.3 L/min (LPM) and without aeration as a control, for 0, 10, 18, and 25 min. Hunter L values of the deskinned kernels decreased while a and b values increased with roasting time. The most and the least significant changes in color of peanuts occurred under O_2 and CO_2 atmospheres, respectively. The best flavor was obtained by roasting peanuts under N_2 or CO_2 for 18 min. Decreases of total α-amino nitrogen, glucose, sucrose, and conarachin contents and specific lipoxygenase activity were dependent on the extent of heat treatment (roasting time) rather than on atmospheric gas composition. Peanuts roasted under O_2 for 25 min were more stable during initial stages of an oven test at 62 °C compared to peanuts roasted under other types of atmospheric gas.

INTRODUCTION

When raw peanuts are roasted or oil fried, a pleasant "peanutty" flavor is produced in a rather short period of time. A marked flavor difference resulting from roasting or frying is well recognized by the consumer. Roasting vs frying of peanuts has been evaluated on the basis of peanut butter by Young et al. (1974b) and Metwalli et al. (1975) and on the headspace volatiles and flavor profiles of roasted peanuts by How (1985). Fried peanuts were preferred to roasted peanuts. One of the most significant differences between roasting and deep frying of peanuts is the involvement of air during the process of heat treatment. Considerable variation in flavor and other sensory characteristics of roasted and fried peanuts suggests that flavor formation is undoubtedly affected by the gaseous atmosphere in contact with peanuts during the roasting or frying process.

Some conventional roasters are heated via natural gas flames; e.g., with the Bauer roaster (Bauer and Bros. Co.) (Woodroff, 1983) abundant carbon dioxide is produced simultaneously in the atmospheric environment during roasting. Some roasters are designed such that burning fuel does not come in direct contact with peanuts. Others use electricity as the heat source, which does not create a significant alteration in the roasting atmosphere. Depending upon the type of roaster used, unique peanut flavor and other sensory characteristics eventually result. In the literature, the effect of modified atmospheric conditions on roasting characteristics has been rarely studied. The effect is of interest to peanut processors and peanut scientists. A minor economic alteration of atmospheric conditions during roasting of peanuts might enhance flavor formation.

In this study, the objective was to investigate the effect of various atmospheric gas conditions on roasting characteristics of peanut kernels. Investigations included determination of color, sensory evaluations, chemical analysis of the flavor-related components, determination of lipoxygenase activities, quantitation and SDS–PAGE analyses of peanut conarachin, and determination of storage stabilities of the roasted peanuts.

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MATERIALS AND METHODS

Peanuts. Freshly harvested (1988 crop) and dried (7.30 ± 0.30% moisture) peanuts (Tainan 9, a Spanish cultivar) were hand shelled, visually sorted, packaged in polyethylene/nylon laminated bags, and stored under refrigeration (4 °C) until used in roasting experiments. For each experiment, bags of peanut kernels were removed from the refrigerator and tempered at room temperature overnight before opening.

Peanut Roasting, Color Determination, and Sensory Evaluation of the Deskinned Roasted Kernels. A high-pressure reactor vessel (600 cm^3) (Berghof 575001, Berghof GmbH) equipped with a gas-flushing device and a stirrer (Figure 1) was used to roast peanut kernels. The heating mantle temperature was controlled at 210 °C and tempered 2 h before peanuts were roasted. The atmospheric conditions applied to peanuts consisted of flushing the vessel at a rate of 1.3 L/min (LPM) (flow rate was calibrated and controlled according to the molecular weights of gases) with air, nitrogen, carbon dioxide, and oxygen. Peanuts roasted under an air atmosphere without flushing served as the control. For the entire time of roasting (0, 10, 18, or 25 min), 60 g of peanut kernels was mixed with the stirrer adjusted at 85 ± 5 rpm. After roasting, the kernels were spread on a tray, cooled at room temperature, deskinned manually, and stored in brown sample vials at −18 °C until subjected to analyses. The colors of the deskinned kernels, expressed as Hunter L, a, and b values, were measured (Tsai et al., 1988). For sensory evaluation, five trained panelists were instructed to use a category hedonic scale (9 to 1) to evaluate flavor notes; 6–9 indicated an increased intensity increment of the peanutty flavor; 5 was the midpoint; 4 to 1 indicated an increased intensity increment of the unpleasant off-flavor.

Determinations of Total α-Amino Nitrogen, Soluble Carbohydrate, Sucrose, Glucose Contents, and Lipoxygenase Activity. Unroasted and roasted peanut kernels were freeze-dried (Lab Conco Freeze Drier 80), ground with a cyclone mill to prepare peanut meals, and defatted with n-hexane. Methanol–chloroform–water (MCW) extraction and determination of total α-amino nitrogen, soluble carbohydrate, and glucose contents were done according to the procedure of Young et al. (1974a) with modifications by Rodriguez et al. (1989) and Chiou et al. (1991). Sucrose contents were determined with a HPLC (Alcott 760 pump) equipped with a refractive index detector (ERC-7515A, Erma Co. Inc.). A carbohydrate analysis column (HC-75, Hamilton Co.) was operated at 90 °C and a flow rate of 1.2 mL/min; water was used as an eluent. The injection volume was 20 μL, which was prepared by vacuum drying 0.1 mL of MCW extract followed with rehydration of 2.0 mL of deionized water.

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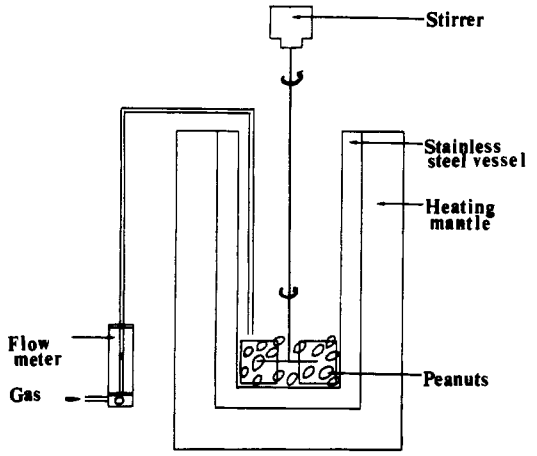

Figure 1. Schematic illustration of the apparatus used for roasting peanut kernels under various atmospheric environments.

For lipoxygenase activity determination, the procedure reported by Chen and Whitaker (1986) was followed with minor modification. The peanut meals were homogenized (5000 rpm, 2 min, ACE homogenizer) with precooled acetone (−20 °C) in a ratio of 1:10 (w/v) and filtered through a filter paper (Toyo Advantech 2) to prepare acetone powders. In a 50-mL flask, 50 mg of acetone powder was weighed and 10 mL of sodium phosphate buffer (pH 7.0, 0.2 M containing 5% NaCl at 4 °C) was added. The flask was sealed with a rubber stopper and shaken on an orbital shaker (160 rpm) for 1 h at 4 °C. Then 1.5 mL of the suspension was withdrawn in an Eppendorf tube and centrifuged for 30 s in an Eppendorf centrifuge to prepare crude lipoxygenase solution. An aliquot (0.1 mL) of enzyme solution was mixed with 2.4 mL of phosphate buffer (pH 7.0, 0.2 M at 25 °C) and 0.5 mL of substrate solution in a quartz cuvette. The absorbance (234 nm) at 25 °C was spectrophotometrically (Hitachi U-2000) monitored by using a time-scanning mode. A unit of enzyme activity was defined as the amount of enzyme that produced a change in optical density of 1.0/min at 234 nm. The stock substrate solution was prepared by mixing 80 μL of linolic acid, 80 μL of Tween 20, and 5 mL of deionized water; 0.5 mL of NaOH (0.1 N) was subsequently added to make the solution clear. Deionized water was then added to the solution to reach a final volume of 25 mL. The solution was stored at 4 °C for later use in enzyme activity assays. Prior to enzyme activity determination, 1 mL of the stock solution was mixed with 4 mL of phosphate buffer (pH 7.0, 0.2 M) in a brown bottle, flushed with oxygen for 2 min, allowed to equilibrate at 25 °C for 10 min, and emersed in an ice bath for use. The protein content in each acetone-defatted powder was determined according to the Kjeldahl method (5.46 × N) (AOAC, 1985). The specific lipoxygenase activity was determined by dividing the total enzyme activity units by the protein content expressed as absorbance unit increments per minute per gram of protein in the acetone powder used for enzyme extraction.

Oil Stability of Peanut Kernels during Storage. Unroasted and roasted peanut kernels were lyophilized, deskinned, split, and stored in open brown sample vials at 62 ± 2 °C to determine stability. After a given time of storage, four or five peanut splits were removed from each vial and pressed hydraulically to prepare oil samples. The conjugated diene hydroperoxide (CDHP) content, expressed as CDHP units per milligram of the expressed peanut oil, was determined according to the procedures reported by St. Angelo et al. (1975) and Yoon et al. (1985) with minor modification described by Chiou et al. (1991).

Peanut Conarachin Extraction and Electrophoretic Analyses. The procedure for extracting and electrophoretically analyzing conarachin described by Chiou (1990) was followed with minor modification. Acetone powder containing 100 mg of protein was homogenized with 8 mL of 60% $(NH_4)_2SO_4$-saturated sodium phosphate buffer (pH 7.9, 0.2 M) and allowed to stand for 30 min with occasional shaking at room temperature for protein extraction. After centrifugation of the suspension at 12000*g* for 20 min at 20 °C, 5 mL of supernatant was withdrawn and combined with 0.915 g of $(NH_4)_2SO_4$ powder to yield 85% saturation; a 30-min waiting period followed to facilitate protein precipitation. The precipitate was pelleted by centrifugation as described above and dissolved in 5 mL of phosphate buffer (0.05 M, pH 7.9) to prepare the conarachin solution. The protein contents were quantitated according to the Lowry et al. (1951) method. Conarachins extracted from unroasted peanuts as well as from peanuts roasted under various atmospheric gas conditions for 10 min at 210 °C were electrophoretically analyzed (Laemmli, 1970; Chiou et al., 1991).

Statistics. Two replicate experiments were conducted. Means of the determinations with standard deviation are reported.

RESULTS AND DISCUSSION

Color characteristics of deskinned unroasted and roasted peanut kernels, expressed as Hunter *L*, *a*, and *b* values, are shown in Table I. In general, Hunter *L* values decreased while *a* and *b* values increased with time of roasting. Decreases in *L* values resulted in visibly darker color and were significantly affected by the atmospheric gas composition. When peanut kernels were roasted for 25 min, the lowest *L* value was observed for kernels roasted under an oxygen environment. Effects from other gases, in decreasing order, were roasting without aeration (control) and flushing with nitrogen, air, and carbon dioxide. Undoubtedly, changes in color of peanut kernels during roasting were influenced by the amount of oxygen present in the atmosphere. However, *L* values of kernels roasted under a nitrogen atmosphere were not significantly different from those of kernels roasted under air, which suggests that nitrogen might be involved in the discoloration process. When kernels were roasted without aeration (control), *L* values also changed considerably. This might be attributed to a slightly higher temperature which occurred due to slower mass transfer in water evaporation in peanuts not subjected to aeration compared to peanuts roasted under aeration or flushing with test gases (Figure 1).

During roasting, *a* values increased with roasting time and were influenced by atmospheric gas conditions. The most obvious change among samples was observed when peanuts were roasted for 18 min (Table I). The highest *a* value was observed for peanuts roasted under an oxygen environment, followed in order by kernels roasted without aeration and under nitrogen, air, and carbon dioxide.

When peanut kernels were roasted for up to 18 min, *b* values steadily increased. After 25 min of roasting, some *b* values decreased slightly. Atmospheric gas composition had a less marked effect on *b* values. After 25 min of roasting, the highest and lowest *b* values were observed for peanuts roasted under carbon dioxide and oxygen, respectively.

Category hedonic scores indicating the sensory peanutty flavor intensity of peanut kernels roasted under various atmospheric conditions are presented in Figure 2. When peanuts were lightly roasted for 10 min, all sensory scores were less than 5 and were essentially independent of atmospheric conditions. After 18 min of roasting, the highest flavor score was obtained by roasting peanut kernels under carbon dioxide and under an ambient environment. These scores were followed in decreasing order for peanuts roasted under nitrogen, under air, without aeration, and under oxygen in the environment. When peanuts were roasted under oxygen for 18 min, the flavor score was 3.5 and unpleasant off-flavors were detected. Therefore, elevated temperature in combination with elevated atmospheric oxygen content facilitates the formation of the off-flavors. Most peanuts roasted for 25 min were over-roasted and received lower scores compared to those roasted for 18 min. The lowest score was observed

Table I. Color Variations of Peanut Kernels Roasted under Various Atmospheric Gas Environments

gas environment	color determination[a]											
	L at roasting time of				a at roasting time of				b at roasting time of			
	0 min	10 min	18 min	25 min	0 min	10 min	18 min	25 min	0 min	10 min	18 min	25 min
W/O	69.3 ± 0.1	66.2 ± 0.3	51.8 ± 1.2	43.2 ± 0.1	3.7 ± 0.1	6.5 ± 0.1	15.7 ± 0.4	17.6 ± 0.4	15.4 ± 0.1	19.6 ± 0.2	21.4 ± 0.7	19.0 ± 0.1
air	69.3 ± 0.1	66.7 ± 0.4	56.9 ± 0.4	46.1 ± 0.9	3.7 ± 0.1	5.9 ± 0.1	14.2 ± 0.4	17.8 ± 0.1	15.4 ± 0.1	19.0 ± 0.1	22.5 ± 0.1	20.4 ± 0.3
N_2	69.3 ± 0.1	67.2 ± 0.1	54.3 ± 0.3	45.0 ± 1.5	3.7 ± 0.1	5.5 ± 0.6	15.5 ± 0.3	17.5 ± 0.6	15.4 ± 0.1	19.1 ± 0.3	22.2 ± 0.1	20.0 ± 1.0
CO_2	69.3 ± 0.1	67.8 ± 0.1	59.9 ± 0.2	48.0 ± 1.2	3.7 ± 0.1	4.5 ± 0.1	12.5 ± 0.1	17.2 ± 0.5	15.4 ± 0.1	17.8 ± 0.2	22.0 ± 0.1	20.9 ± 0.6
O_2	69.3 ± 0.1	65.6 ± 0.2	52.0 ± 0.6	40.6 ± 0.3	3.7 ± 0.1	7.2 ± 0.1	16.1 ± 0.1	17.8 ± 0.4	15.4 ± 0.1	20.3 ± 0.1	21.6 ± 0.2	18.0 ± 0.3

[a] Mean of 60 determinations with standard deviation.

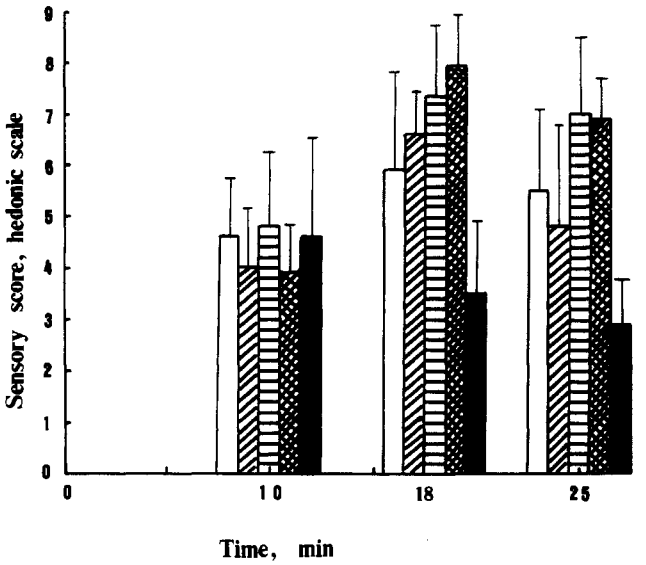

Figure 2. Sensory evaluation scores of peanut kernels roasted under various atmospheric gas environments: (open bar) without aeration (control); (diagonally lined bar) air; (horizontally lined bar) nitrogen; (cross-hatched bar) carbon dioxide; (black bar) oxygen.

for peanuts roasted under oxygen, followed in order by peanuts roasted under air, without aeration, under carbon dioxide, and under nitrogen.

Total α-amino nitrogen contents in peanut kernels subjected to roasting under various conditions of atmospheric gas are presented in Table II. The free amino acids decreased significantly with time of roasting. Roasting time, i.e., the extent of heat treatment, governed the change of total α-amino nitrogen. However, the effect of atmospheric composition on the total α-amino nitrogen content was not significant. A correlation in the α-amino nitrogen content and sensory evaluation scores (Figure 2) did not exist. Although amino acids are the precursors for the peanutty flavor formation (Newell et al., 1967; Mason et al., 1969; Rodriguez et al., 1989), their attributes and function related to flavor development during roasting have not been clearly defined. According to the studies of Newell et al. (1967), amino acids are classified as typical and atypical peanut flavor precursors. The involvement of atypical flavor precursors does not always contribute positively to peanutty flavor formation. In a previous study (Chiou et al., 1991), changes in specific amino acid content in peanuts during roasting was significantly affected by the nature and extent of heat treatment, internal temperature, and moisture content of kernels.

Soluble carbohydrate analyses (Table II) revealed that sugar concentration in peanuts was higher than that reported by Oupadissakoon et al. (1980) and Rodriguez et al. (1989) but lower than that reported by Mason et al. (1969). In this study, except for peanuts roasted under oxygen for 25 min, total soluble carbohydrate increased as a result of roasting. Sucrose, except for peanuts roasted under air, increased slightly in the early stage of roasting, i.e., the first 10 min of roasting. Oupadissakoon and Young (1984) deep-fried peanuts at 147 °C for 9–14 min and reported that sucrose contents in some roasted peanuts were higher than the contents in unroasted peanuts. Glucose content also increased during the first 10 min when peanuts were roasted under gas-flushing conditions. Therefore, changes in carbohydrate composition during peanut roasting were variable. In general, soluble carbohydrate, sucrose, and glucose contents increased considerably in the early stage of roasting and then decreased with roasting time.

Changes in glucose content were not completely consistent with changes in total soluble carbohydrate and sucrose contents. When peanuts were roasted for 10 min, the glucose content remained essentially unchanged. The glucose content subsequently decreased with time of roasting. After 25 min, the lowest glucose content was observed in peanuts roasted under nitrogen, followed in order for peanuts roasted under oxygen, without aeration, under carbon dioxide, and under air. This order does not correlate with the order of color change as influenced by roasting conditions (Table I), indicating that glucose played only a partial role in browning reactions related to color and flavor development. A considerable amount of soluble carbohydrate, sucrose, and glucose was reduced in peanuts roasted under oxygen for 25 min. At the same time, flavor was judged less desirable (Figure 2). On the other hand, peanuts roasted under carbon dioxide for 18 min had the best organoleptic flavor quality. Soluble carbohydrate, sucrose, and glucose were still present in substantial concentrations in these peanuts. Since the concentrations of soluble carbohydrate, sucrose, and glucose may increase due to hydrolysis of insoluble carbohydrates or otherwise decrease due to involvement in further chemical reactions, an explanation for changes in flavor as influenced by the amount of soluble carbohydrate, sucrose, or glucose in roasted peanuts cannot be offered.

Specific lipoxygenase activities in unroasted peanuts and in peanuts roasted under various atmospheric gases are illustrated in Figure 3. Under a given roasting condition, the specific activity significantly decreased with roasting time. In all cases, after 25 min of roasting, most lipoxygenase was inactivated. However, the type of atmospheric environment influenced the rate of inactivation. When peanuts were roasted under an oxygen environment, lipoxygenase was most labile to heat inactivation. After 18 min of roasting, most lipoxygenase in peanuts roasted under oxygen, without aeration, or under nitrogen was heat denatured and retained less than 40 units/g of protein of specific activity. However, when peanuts were roasted under air and carbon dioxide

Table II. Total α-Amino Nitrogen, Soluble Carbohydrate, Sucrose, Glucose, and Conarachin Contents in Peanut Kernels Roasted under Various Atmospheric Gas Environments

gas environment	roasting time, min	α-amino nitrogen,[a] mg of amino acid/g of protein	soluble carbohydrate,[a] mg/g of defatted meal	sucrose,[a] mg/g of defatted meal	glucose,[a] mg/g of defatted meal	conarachin,[a] OD at 660 nm
before roasting	0	7.65 ± 0.77	86.24 ± 6.60	75.30 ± 3.18	0.417 ± 0.026	0.276 ± 0.012
W/O	10	6.37 ± 0.15	97.38 ± 0.96	77.56 ± 7.44	0.398 ± 0.012	0.059 ± 0.003
	18	3.21 ± 0.15	95.63 ± 1.28	82.64 ± 1.52	0.323 ± 0.007	0.004 ± 0.001
	25	1.41 ± 0.10	94.67 ± 1.43	68.04 ± 3.04	0.289 ± 0.019	
air	10	5.93 ± 0.41	90.86 ± 2.71	70.96 ± 0.64	0.404 ± 0.016	0.085 ± 0.011
	18	3.89 ± 0.33	99.61 ± 1.28	72.48 ± 6.50	0.356 ± 0.006	0.011 ± 0.001
	25	1.75 ± 0.13	90.85 ± 2.07	68.40 ± 13.32	0.305 ± 0.009	
N_2	10	6.21 ± 0.71	97.30 ± 1.36	81.50 ± 0.78	0.406 ± 0.010	0.071 ± 0.001
	18	3.51 ± 0.21	100.48 ± 1.03	81.12 ± 1.30	0.312 ± 0.009	0.007 ± 0.001
	25	1.51 ± 0.13	87.91 ± 1.03	70.02 ± 1.72	0.266 ± 0.017	
CO_2	10	6.39 ± 0.54	94.67 ± 5.41	79.82 ± 3.12	0.411 ± 0.013	0.084 ± 0.004
	18	4.27 ± 0.25	96.90 ± 7.48	71.04 ± 7.98	0.320 ± 0.012	0.018 ± 0.003
	25	1.66 ± 0.16	91.81 ± 1.75	67.42 ± 4.58	0.302 ± 0.006	
O_2	10	6.12 ± 0.55	97.38 ± 0.64	81.68 ± 3.18	0.408 ± 0.002	0.065 ± 0.004
	18	3.23 ± 0.14	95.23 ± 1.35	80.80 ± 2.46	0.314 ± 0.001	0.001 ± 0.001
	25	1.47 ± 0.06	83.30 ± 1.20	61.14 ± 6.16	0.282 ± 0.002	

[a] Mean of two determinations from two duplicate experiments.

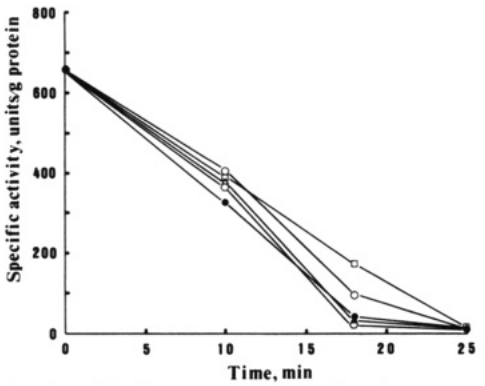

Figure 3. Specific lipoxygenase activities in peanut kernels roasted under various atmospheric gas environments: (○) without aeration; (○) air; (△) nitrogen; (□) carbon dioxide; (●) oxygen.

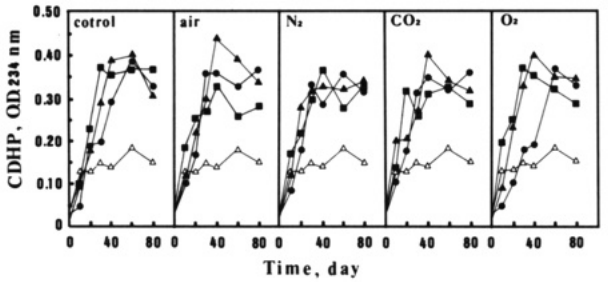

Figure 4. Changes of peanut oil CDHP units during storage of unroasted peanuts (control, △) and peanuts roasted under various atmospheric environments for 10 (■), 18 (▲), and 25 min (●).

environments for 18 min, specific activities were 100 and 170 units/g of protein, respectively.

Changes of peanut oil CDHP units during storage of unroasted and roasted peanut splits at 62 ± 2 °C for 80 days are shown in Figure 4. Since peanuts were stored exposed to air, abundant oxygen in the atmospheric environment facilitated the process of oil oxidation. The CDHP levels in unroasted peanuts were significantly lower than in roasted peanuts. This is in agreement with the observation reported by St. Angelo and Ory (1975). On the basis of the initial rate of increase in CDHP (slope of the curve), peanuts roasted for 25 and 10 min had the greatest and the least stability against oxidation, respectively. After 10 min of roasting, about half of the specific lipoxygenase activity was inactivated (Figure 3). Roasting causes changes in physicochemical properties, which might in turn alter the rate of oil oxidation. Analysis of oils obtained from peanuts subjected to various roasting conditions has revealed that roasting renders oils more stable against oxidation during storage (Cheng et al., 1987; Huang et al., 1988). A comparison of the effects of atmospheric gas content on oil stability indicated that peanuts roasted under oxygen for 25 min were the most stable product, followed in order by peanuts roasted without aeration, under nitrogen, under air, and under carbon dioxide. This order was in contradiction to the flavor order (Figure 2). Off-flavor was formed in peanuts roasted under oxygen for 25 min. Therefore, the formation of off-flavor during roasting did not necessarily correlate or promote subsequent oil oxidation.

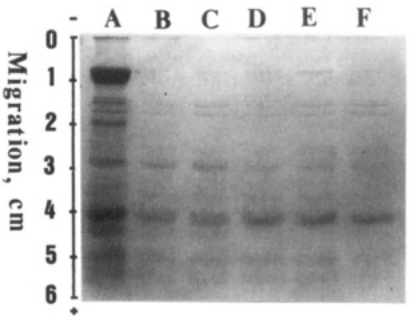

Figure 5. SDS–PAGE analyses of peanut conarachins extracted from unroasted peanuts and peanuts roasted under various atmospheric gas environments for 10 min: (A) unroasted; (B) without aeration; (C) air; (D) nitrogen; (E) carbon dioxide; (F) oxygen.

Conarachin content in unroasted peanuts and in peanuts roasted under various atmospheric environments is shown in Table II. After 10 min of roasting, most conarachins were heat denatured and insoluble in the extraction buffers. The lowest amount of conarachin was detected in peanuts roasted without aeration and under oxygen, followed in order by peanuts roasted under nitrogen, carbon dioxide, and air. The SDS–PAGE patterns (Figure 5) indicate that the major conarachin is located at 0.5–1.0

cm of migration. This subunit decreases dramatically when peanuts are roasted for 10 min. This is in agreement with the observation that conarachin is considerably less heat resistant than arachin (Chiou, 1990). The ease of heat denaturation might render conarachin an amino acid source from which flavor precursors are released through hydrolysis during the early stage of roasting and flavor attributes are developed during later stages of roasting. Basha and Young (1985) observed that methionine-rich polypeptides are denatured rapidly during peanut frying and suggested that these polypeptides may be involved in peanut flavor formation. However, the major and minor protein subunits in the conarachin fraction are complex and their tendencies to heat denaturation are different from one another. Further studies designed to more clearly understand relationships among various peanut proteins, amino acids, and monocarbohydrates as they affect flavor formation are needed.

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Registry No. Sucrose, 57-50-1; glucose, 50-99-7; nitrogen, 7727-37-9; carbon dioxide, 124-38-9; oxygen, 7782-44-7; lipoxygenase, 9029-60-1.