CHANGES IN SENSORY AND PHYSICOCHEMICAL PROPERTIES OF ROASTED PEANUTS IN INTERMEDIATE MOISTURE FOODS

by

CHOW MING LEE

(Under the Direction of William L. Kerr)

ABSTRACT

Roasted peanuts were stored at four temperatures (23, 30, 35, 40°C) and five equilibrium relative humidity (0.33, 0.44, 0.54, 0.67, 0.75 a_w). Samples were removed after storage between 0 and 91 d and evaluated for their descriptive, consumer and physicochemical profiles. Sensory and instrumental attributes were significantly ($p<0.05$) affected by storage time and water activity. In addition to storage time and water activity, flavor attributes such as roasted peanutty and cardboard flavor, consumer aroma and flavor acceptance, and consumer intensity ratings of staled/oxidized/rancid and roasted peanutty ratings significantly ($p<0.05$) changed with increasing storage temperature. Roasted peanuts retained its best sensory characteristics if stored at 23°C and between 0.33 and 0.41 a_w. When stored at 0.4, 0.5, 0.6 and 0.7 a_w, the shelf life (consumer acceptance ≥ 5.0) of roasted peanuts was estimated to be 73, 40, 20 and 4 d at 23°C, 50, 26, 13, 4 d at 30°C, 40, 22, 12, 4 d at 35°C, and 30, 15, 10, 3 d at 40°C, respectively. Instrumental measurements such as color and moisture can be used to predict ($p<0.05$, $R^2>0.70$) the acceptance of stored roasted peanuts.

INDEX WORDS: Peanuts, Instron, Descriptive analysis, Sensory evaluation, Consumer acceptance, ASLT, Shelf life, PLSR, Physicochemical measurement, Flavor volatile, Weibull Hazard method, Kinetics, Multivariate analysis

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DEDICATION

To my mom, dad, wife and my sons.

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SECTION I

INTRODUCTION

The quality of intermediate moisture foods (IMF) has been studied extensively in a model system or in a real food system (Labuza *et al*., 1971; Labuza *et al*., 1972; Gopalakrishna & Prabhakar 1983; Borges & Peleg 1997). Intermediate moisture foods are foods with a water activity (a_w) of 0.6-0.85. The rate of reactivity in terms of lipid oxidation, non-enzymatic browning and enzymatic activity is the greatest in the range encompassing intermediate moisture foods (Labuza *et al*., 1972). In foods of water activity in the range of 0.6 to 0.7, water serves as a medium for mobilizing previously unavailable trace metal that promotes increase in lipid oxidation (Labuza *et al*., 1971; Labuza *et al*., 1972).

Roasted peanuts are among the most common nuts used in the confectionery industry, and are used among low to high moisture foods such as caramel and nougat (Broekel 1982). Since the water activity of such ingredients are much higher than that of roasted peanuts, the keep quality or shelf life of roasted peanuts is of great interest to researchers. Labuza and Hyman (1998) suggested that moisture tend to migrate from an area of higher a_w to an area of lower a_w due to a non-equilibrium state. Hung & Chinnan (1989) found that roasted peanuts ($a_w \leq 0.1$) became soggy when exposed to environments of a_w between 0.5 and 0.8. Similarly, Felland and Koehler (1997) found peanut butters formulated to achieve higher a_w (0.29-0.56) resulted in a product that is darker, higher off-flavor and possibly decreases the shelf life by half. Critical water activity (a_c) whereby products became unacceptable (between 'neither like nor dislike' and 'dislike slightly') among snack food products such as saltines and puffed corn curls were found to be in the range of 0.35-0.50 (Katz & Labuza 1981).

Sensory evaluation is one of the most sensitive methods of determining shelf life of food. The ability to determine the sensory shelf life is particularly critical when such changes could be a predecessor to microbiological changes that makes the food unsafe. While consumers are the

ideal candidates for determining shelf life (Anon. 1974), shelf life tests involving consumer tests are costly and are potentially detrimental to the reputation of manufacturers due to the nature of failed products. Alternatively, objective measurements using trained panels, instrumental methods, or statistical failure models can be used in place of consumer tests if reliable relationships to consumer acceptance are first established.

While shelf life conducted at typical storage condition allows the most accurate measurement, it is sometimes necessary to predict the shelf life using accelerated shelf life testing. Accelerated shelf life testing typically involves the use of temperature to simulate a faster rate of change. Depending on the product, the change in temperature is typically an increase but fluctuating temperature can also be used to simulate drastic distributing conditions. In addition to temperature, light and water activity can also be used in accelerated tests.

The objective of this dissertation were to evaluate roasted peanuts stored at room temperature and elevated temperatures, and at various water activity conditions in terms of (1) sensory profiles, including descriptive analysis and consumer acceptance, (2) physicochemical changes, (3) relationships between descriptive ratings and consumer acceptance ratings, (4) relationships between sensory profiles and physicochemical profiles.

REFERENCES

Anonymous. 1974. Shelf life of foods. Inst. Of Food Technologists Expert Panel on Food Safety and Nutrition. J. Food Sci. 39:861

Borges, A. and Peleg, M. 1997. Effect of water activity on the mechanical properties of selected legumes and nuts. J. Sci. Food Agric 75(4):463-471.

Broekel, R. 1982. The great American candy bar book. Boston: Houghton Mifflin Co. 160 p.

Felland, S.L. and Koehler, P.E. 1997. Sensory, chemical, and physical changes in increased water activity peanut butter products. J. Food Quality 20(2):145-156.

Gopalakrishna, A.G. and Prabhakar, J.V. 1983. Effect of water activity on autoxidation of raw peanut oil. J. Amer. Oil Chemists' Soc. 60(5): 968-970.

Hung, Y.C. and Chinnan, M.S. 1989. Mechanical texture measurement of whole and chopped peanuts. Peanut Sci. 16(2):32-37.

Katz, E.E and Labuza, T.P. 1981. Effect of water activity on the sensory crispness and mechanical deformation of snack food products. J. Food Sci. 46:403-409.

Labuza, T.P., Heidelbaugh, N.D., Silver, M., and Arel, M. 1971. Oxidation at intermediate moisture contents. J. Amer. Oil Chem. Soc. 46:86-90.

Labuza, T.P. and Hyman, C.R. 1998. Moisture migration and control in multi-domain foods. Trends in Food Sci. & Technol. 9:47-55.

Labuza, T.P., McNally, L., Gallagher, D., Hawkes, J., and Hurt, F. 1972. Stability of intermediate moisture foods. 1. Lipid Oixidation. J. Food Sci. 37(1):154-159.

SECTION II

REVIEW OF LITERATURE[1]

[1] Lee, C.M. and A. V. A. Resurreccion. To be submitted to *Comprehensive Reviews in Food Science & Food Safety*.

ABSTRACT

Quality of peanuts and peanut butter are critical to the marketability of peanut and peanut-derived products such as candy. The quality of peanuts can be attributed to their physiological nature, production location, maturity and postharvest handling. Roasted peanuts and peanut butters have their own distinctive processing requirement and specialized procedures are used to suit their intended use. The quality of roasted peanut and peanut butter has long been investigated using sensory, instrumental, and physico-chemical measurements. The use of sensory shelf life evaluation is crucial to maintaining product that is acceptable in the market. This can be accomplished by using difference tests, consumer acceptance testing, and descriptive analysis or Weibull Hazard method. The concept of accelerated shelf life testing is explained and relates to peanut or peanut products. Finally, statistical methods that are useful in relating sensory and instrumental measurement of food properties are explained.

I. PEANUT

A. Introduction

The U.S. is the world's third largest producer of peanuts (Schaub 1990). About 50% of peanuts are processed into peanut butter and about 20% of peanuts are used as ingredients in candy products (Schaub 1990). Peanuts and peanut butter are among the most common ingredients used in the confectionery industry, and are used among low to high moisture foods such as caramel and nougat (Broekel 1982). Peanuts or peanut butters are used in America's 3 most popular candies, including Snickers, Reeses Peanut Butter Cups and Peanut M&M's (Schaub 1990).

The quality of peanuts and peanuts product is affected by many factors including physiological factors, post-harvest factors, temperature and moisture of surrounding environment. Labuza and Hyman (1998) discussed how moisture migrates from an area of higher a_w to an area of lower a_w due to a non-equilibrium state. Hung and Chinnan (1989) found that roasted peanuts ($a_w \leq 0.1$) became soggy when exposed to environments of a_w between 0.5 and 0.8. Similarly, Felland and Koehler (1997) found peanut butters formulated to achieve higher a_w (0.29-0.56) resulted in a product that is darker, has higher off-flavor and possibly has decreased a shelf life by half. Critical water activity (a_c) whereby products became unacceptable (between 'neither like nor dislike' and 'dislike slightly' on hedonic scale) among snack food products such as saltines and puffed corn curls were found to be in the range of 0.35-0.50 (Katz and Labuza 1981).

Gas chromatography is the preferred instrument for analyzing off-flavor volatiles from stored roasted peanuts (Bett and Boylston 1992; Braddock and others 1995; Mate and others 1996; Brannan and others 1999). Hexanal and pentanal were used successfully as the indicator

compounds in relating the extent of off-flavor development (Braddock and others 1995; Mate and others 1996; Brunton and others 2000). The introduction of gas chromatography/mass-spectrophotometry (GC/MS) technology allows scientists to quantify a large number of flavor components in a food system in a short time and at a high accuracy. Most of the recent work on peanut flavor volatiles is based on GC/MS technology (Burroni and others 1997; Braddock and others 1995; Warner and others 1996; Bett and Boylston 1992; Ku and others 1998)

B. CHEMICAL COMPONENTS OF PEANUTS

Peanuts are consumed over the world for their flavor and nutritious benefits. Utilization of peanuts and peanut ingredients are influenced by cultural and technological capability. Since peanuts are planted around the world in different climates and harvested under different conditions, the variability in their physicochemical and sensory properties is high. The major compositional components of peanuts are lipids, protein, and carbohydrates (Table 2.1).

1. Oil

The fatty constituents of peanuts (Table 2.2) are found predominantly in the cotyledons and in lesser quantity in germs and testas (Woodroof 1983). Among the 4 major types of peanuts (runner, Virginia, Valencia, and Spanish), the average oil content is about 44-56% (Ahmed & Young 1982; Cobb and Johnson 1973; Holaday and Pearson 1974). Peanuts contain approximately equal amount of fatty and non-fatty constituents (Woodroof 1983). The oil composition of matured peanut seed consists of 95% triacylglycerol that is composed mainly of palmitic, oleic and linoleic acids (Ahmed and Young 1982; Sheppard and Rudolf 1991; Norden and others 1987; Sanders 1979; Sanders 1980; Sahasrabubhe and Farn 1964). The triacylglycerol of peanuts are usually composed of different types of fatty acids at different *sn*

positions, such as the *sn*-1 position, which usually consists of saturated fatty such as palmitic or stearic (Cobb and Johnson 1973; Sanders 1979; Sanders 1980). Increasing oleic or linoleic acids in the oil composition results in greater percentage of such fatty acids position at *sn*-2 rather than *sn*-1 or *sn*-3 positions (Sanders 1982; Sanders 1979). Unsaturated fatty acids and long chain fatty acids consisting of 20-24 carbon skeletons are usually found in the sn-3 position (Cobb and Johnson 1973). The fatty acid composition of peanut oil consists of 76-82% unsaturated fatty acids, including 40-45% as oleic acid and 30-35% linoleic acid (Fore and others 1953). Thirty percent of the free fatty acid is linoleic acid, resulting in great potential for oxidative deterioration in peanuts (Conkerton and St. Angelo 1983). Compared with peanuts of the Spanish variety, Runner and Virginia peanuts are higher in oleic acids (Fore and others 1953). Higher hydrocarbons such as $C_{15}H_{30}$ and $C_{19}H_{38}$ are found in small quantities (1.8 g/ton) and are responsible for the flavor characteristics of peanut oil (Woodroof 1983). Peanut oil carries the peanut flavor, especially when heated or roasted (Woodroof 1983).

2. Protein

Among the 4 major types of peanuts (runner, Virginia, Valencia, and Spanish), the average protein content is about 25% (Ahmed & Young 1982; Cobb and Johnson 1973; Holaday and Pearson 1974). The variation of protein in peanuts is due to genotypes and growing seasons (Young and Hammons 1973). Peanuts are easily digested and consist of large amount of essential amino acids, including arginine (Pickett 1941). The digestibility index for peanut protein is 89% (Woodroof 1983). As shown in Table 2.3, there are at least 16 free amino acids in peanuts that contribute to the reactions that occur during peanut roasting (Woodroof 1983).

3. Carbohydrates

The carbohydrate content of peanuts is approximately 19%, consisting of about 0.5-5% of starch, 4-7% of sucrose, 2% cellulose (Pickett and Holley 1952; Woodroof 1983). Browning of roasted peanuts, which is accelerated with increasing temperature, is primarily due to sucrose and to a lesser extent, crude fiber (Woodroof 1983).

4. Moisture

The moisture content of raw peanuts ranges from 5 to 7%, and is reduced during roasting to below 2%, thus retarding staling and rancidity changes (Woodroof 1983).

As shown in Table 2.4, the moisture content of roasted peanuts used in candies or bakery goods increase up to 6.5% (Woodroof 1983).

5. Minerals and Vitamins

About 3% of peanuts is ash, consisting of 26 inorganic constituents (Table 2.5) is primarily, potassium, magnesium phosphorus and sulfur (Woodroof 1983). Maximum stability in peanuts is found when tocopherol is about 0.05% (Woodroof 1983). Peanuts are a good source of vitamins such as riboflavin, thiamin, niacin and Vitamin E (Woodroof 1983). Roasting (up to 300 °F) and blanching of peanuts destroy most of thiamin but very little of niacin, choline and riboflavin (Woodroof 1983).

6. Volatile components

During roasting, 98% of the volatile components are carbon dioxide (Pickett and Holley 1952). Peanut flavor in candy is improved if the peanuts are first roasted to a light brown color with a moisture content of less than 3% (Woodroof 1983).

7. Color

The color of the testa is due to tannins and cathecol-type compouns (Ahmed and Young 1982). The color of the cotyledons and that of peanut oil is due to carotenoids, including lutein and β-carotene (Pattee and Purcell 1967). Concentration of carotenoid decreases with increasing maturity, possibly due to increasing oil content (Pattee and others 1969a). Roasted peanut color is primarily due to sugar-amine Maillard reaction and to a lesser extent, caramelization of sugars (Mason and others 1966).

8. Other components

The red skins of peanuts contain tannin, thiamin and leuco-anthocyanin (Stansbury and others 1950). Saponins accounts for the bitterness in peanuts, especially in the hearts that contain 20 times the amount of saponins (Dieckert and Morris 1958; Fisher 1959). Resveratrol is found in fresh peanuts, roasted peanuts, peanut butter and boiled peanuts at concentration of 0.01, 0.055, 0.324, 5.138 μg/g, respectively (Sanders and others 2000). Researchers agree that the resveratrol found in peanuts are *trans*-resveratrol (Langcake and Pryce 1977; Aguamah and others 1981), while others found the presence of both *trans*- and *cis*- isomers (Ingham 1976; Keen and Ingham 1976).

C. FACTORS AFFECTING QUALITY OF PEANUTS

Good peanuts are described as having full, pleasant, natural flavor with a tender texture, as contrast to off-flavors, hard texture and loose skins (Woodroof 1983). Peanut flavor such as nuttiness, sweetness and bitterness is related to variety, growing conditions, harvest methods, storage and processing (Woodroof 1983). Cultivar affects the proximate compositions, oleic/linoleic ratio, resveratrol, shelf stability of peanut products. Variation in composition such

as the ratio of total tocopherol/percent linoleic acid was found to account for 87% of the variability in stability of cold pressed oil (Hokes 1977).

1. Production location

Significant correlation between production location and total oil content and protein was found (Holaday and Pearson 1974). The spatial arrangement of fatty acids on the triacylglycerol molecule was related to production location (Sanders 1982). Changes in the structure and composition of triacylglycerol results in varying nutritional content (Raghavan and Ganguly 1969), shelf life (Sahasrabubhe and Farn 1964), and physiological aspects of peanuts (Kritchevski and others 1971). The fatty acid composition of peanut oil changes with cooler climate production location and consisted of higher degree of unsaturation and lower oleic/linoleic ratio.(Holaday and Pearson 1974; Sanders 1982; Young and others 1974). Correlation analysis suggests that lower oleic/linoleic ratio among peanuts grown in cooler region led to a shorter shelf life (Fore and others 1953). Tocopherol contents of peanuts from different origin, such as China, United States and Argentina, were found to be different (Sanders and others 1992). Compared to China and Argentina, peanuts grown in the United States had lower copper and iron contents (Sanders and others 1992).

2. Maturity

Percentage of oil in peanuts increased significantly before decreasing significantly again during maturation (Sanders 1982; Sanders and others 1982; Pattee and others 1974). Rapid change in oil percentage occurs during the early maturity stages, i.e. during the times of rapid increase in dry seed weight (Sanders and others 1982; Pattee and others 1974). While no literature was found to relate percentage oil and the shelf life of peanuts, maturity has been found to relate highly to flavor and shelf life potential (Sanders and others 1993). Mature seeds contain

more total oil, triacylglycerol, and oleic/linoleic acid ratio, and less free fatty acids, polar lipids, monoacylglycerols and diacylglycerols (Sanders and others 1982; Pattee and others 1974). The percentage of free fatty acid decreased from 4.5 to 0.7% as Florunner peanuts matured (Sanders 1980). Free fatty acids such as oleic acid decreased from 0.8 to 0.05% and oil oven stability increased with maturity (Sanders and others 1982). Increased maturity of peanut kernel resulted in decreasing resveratrol concentration (Sobolev and Cole 1999).

3. Postharvest handling

Postharvest handling such as combining, drying, transporting and blanching may result in damage to peanuts, thus making them vulnerable to flavor deterioration (St. Angelo 1996). When liberated during postharvest handling, whether by physiological or by artificial stress, enzymes such as lipoxygenase in raw peanuts oxidize unsaturated fatty acids rapidly (St. Angelo 1996). Roasted peanuts consist of higher oil content on the external surface and are susceptible to non-enzymatic oxidation of its unsaturated fatty acids (St. Angelo and Ory 1972; St. Angelo and others 1977; St. Angel and others 1979). In addition to hard texture and poor flavor and color, peanuts subjected to rapid drying at temperatures above 120 °F are also difficult to blanch (Woodroof 1983). Postharvest handling did not result in changes in polyunsaturaed fatty acids (Fore and others 1953).

4. Color

Tannins and carotenoids, which are predominantly present in the testa and oil contribute to the color of raw peanut (Ahmed and Young 1982). The carotenoid pigments found in oil are lutein and β-carotene (Pattee and Purcell 1967). The same researchers also found that mature seeds contain the highest concentration of these pigments, or approximately 60 μg of β-carotene and 138 μg of lutein per liter of peanut oil (Pattee and Purcell 1967). In contrast, the carotenoid

present in mature peanuts was found to be less than 1.0 mg/l of oil, indicating that carotenoid concentration decreases with increasing maturity (Pattee and Purcell 1967)

Roasting of peanuts results in a desirable peanut kernel color, and this is well-liked by consumers. Consumers, to a certain extent, associate roasted color with the quality of roasted peanut. The browning that occurs during roasting is due to the sugar-amino acid reaction, followed by subsequent production of melanins (Hodge 1953). Additional brown color is contributed by the caramelization of sugars. Browning of peanuts during roasting is directly proportional to time and temperature of roasting. The color of peanut butters, when added with water, became darker with storage (Felland and Koehler 1997).

2. *Texture*

Texture of peanuts is expected to be crunchy but not hard, and is a factor in consumer acceptance. When peanuts are present in high moisture conditions such as ice cream, or in intermediate moisture conditions like caramel, the texture becomes soggy with increasing time and is rejected by some consumers.

3. *Enzymatic and non-enzymatic oxidation*

Oxidation plays an important role in the deterioration of many food products. This is especially true among products with high lipid or high unsaturated fat, and results in the production of undesirable odors and flavors (Frankel 1980). The undesirable odor and flavors are primarily due to low molecular weight components of the oxidative breakdown of free fatty acids. Researchers are very keen in slowing or preventing the he changes in quality due to oxidation.

The process of autoxidation, or oxygen-mediated oxidation, includes stages of initiation, propagation and termination (Simic and Taylor 1987). The initiation stage involves the

production of free radicals and termination stage results in the production of non-radical products. The chemical reaction equations are best stated as follows:

Initiation: $RH + 0_2 \longrightarrow R^*$

Propagation: $R^* + 0_2 \longleftrightarrow ROO^*$

$ROO^* + RH \longrightarrow ROOH + R^*$

Termination: $ROO^* + ROO^* \longrightarrow$ non-radical products

$ROO^* + R^* \longrightarrow$ non-radical products

$R^* + R^* \longrightarrow$ non-radical products (St. Angelo 1996)

During the initiation phase, oxygen (O_2) and an organic substrate (RH) such as an unsaturated fatty acid branch of a fat molecule react to produce free radicals (R*). Free radicals are compounds having an unpaired electron. The propagation stage is then initiated by the free radical to form a peroxy radical ROO*, and subsequent chain-reaction results in more free radicals being produced (St. Angelo 1996). During the termination stage, a free radical reacts with another free radical to produce a ketone, alcohol or oxygen, and amount to the production of non-radical compounds (St. Angelo 1996).

Autoxidation of polyunsaturated lipids of food involves a free radical chain reaction that is most frequently initiated by exposing lipids to light, heat, ionizing radiation, metal ions, or metallo-protein catalysts (Shahidi and others 1992). Ory and St. Angelo (1982) report that lipoxygenase is the principal enzyme that catalyzes oxidation of polyunsaturated fatty acids in raw peanuts. The lipoxygenase enzyme has a pH optimum of 6.2 (Ory and St. Angelo 1982), however it is heat-labile, losing all activity at temperatures above 40°C and is therefore denatured by roasting temperatures (Ory and St. Angelo 1982). St. Angelo and Ory (1975)

showed that in high fat products like peanut butter the activity of lipoxygenase is increased when the amount of water is also increased.

Oxidation of peanuts and peanut products has been measured by various procedures, such as the thiobarbituric acid (TBA) test (Felland and Koehler 1997) and peroxide value (PV) (Ory and St. Angelo 1982). Also, lipoxygenase and peroxidase activity was used by Mitchell and Malphrus (1977) as a measurement of lipid oxidation in Spanish peanuts.

4. Heat treatment

The use of heat treatment on food changes its nutritional, sensory and texture quality. When heat treatment is applied to peanuts, there is a negative effect on the nutritive value. However, heat treatments such as roasting results in a desirable flavor and texture that is enjoyed by consumers all over the world. Roasting of peanuts results in lower concentrations of amino acids, including lysine, threonine, and methionine (Neucere and others 1969; Panacholy and others 1978). The decrease in lysine, theronine and methionine are 15, 11 and 10%, respectively (Panacholy and others 1978). Heat treatment, when applied to protein, may have denatured the protein structure or affect the structure in its primary structure.

5. *Mold contamination*

Improper storage conditions, including temperature and moisture, leads to the development of mold in raw peanut kernels. Mold contamination can lead to discoloration of the testae, or in the case of heavy infestation, destruction of kernels when aflatoxin is produced. Aflatoxin is produced when peanuts are contaminated with strains of *Aspergillus flavus* or *A. Parasiticus* (Sanders 1983). Since *Aspergillus* occurs naturally, it is critical that the storage condition of peanuts be controlled. It is also a known carcinogen and is tested by peanut buyers all over the world.

Mold growth in peanuts is usually a result of high moisture or relative humidity (Woodroof 1983). The peanut seed contains some moisture, but there is range of moisture content during harvest that makes it vulnerable to mold contamination, or between 12 to 30 % (Sanders 1983). Usually, the mold is introduced to a batch of peanuts by kernels that were previously contaminated before harvesting, during shelling or during handling.

Mold contamination is best prevented by (1) rapid drying of peanut kernels after digging using inverted windrows in the field or forced air drying facilities, and (2) storage in a low moisture atmosphere, such as 65 to 70 % relative humidity (Sanders 1983). There are no commercially feasible techniques for washing or sterilizing peanuts, making prevention such as those discussed above the best measures.

II. ROASTED PEANUTS AND PEANUT BUTTER

Peanuts (*Arachis hypogaea*) are the most popular legumes used for snacking. The United States is the world's largest exporter of peanuts and maintaining its quality is a key factor in improving demand. Different varieties of peanuts are used in confectionery. The Runner variety is medium size, liable to split during processing, more difficult to blanch, and are used in confectionery products (Minifie 1999). In contrast, Spanish variety peanuts are small, blanched easily and are used in peanut brittle, nut cluster or when small nuts are preferred (Minifie 1999).

Typically, peanut contains about 50% oil and 28% protein (St. Angelo 1996), with oleic and linolenic acids as the predominant fatty acids. The later has been identified as the potential fatty acid that results in off-flavor development via lipid oxidation (St. Angelo 1996). The linolenic content of Runner and Spanish varieties are 22% and 34.2% (Minifie 1999), suggesting a possible difference in oxidative deterioration. Peanuts are the most common nuts used in the

confectionery industry. To achieve a desired flavor profile, nuts are roasted prior to use in low to intermediate moisture foods such as caramel and nougat (Broekel 1982). Storing roasted peanuts in oxygen free environment is necessary to prevent non-enzymatic peroxidation of the fatty acids (St. Angel and others 1977). Samples stored at 21 °C undergo temperature and humidity fluctuations, and roasted samples were slightly and strongly rancid after 4 and 6 weeks, respectively (Alikonis and Cosler 1961). Both roasted peanuts and peanut butter are susceptible to non-enzymatic oxidative changes when stored above freezing temperature and are exposed to oxygen.

A. Processing

Peanuts are processed and utilized in a variety of manners, making them one of the most versatile crops. The advantages of using peanuts as an ingredient include a pleasing aroma and flavor; crunchy texture; high protein, energy, minerals and niacin; and the ability to store and ship to anywhere in the world (McWatters 1983). Consumption of peanuts occurs in many forms such as canned, oil-roasted, dry-roasted, salted, boilded, toasted, peanut butter, and as a vegetable oil. Peanut oil is also preferred by many cultures in the world for cooking**,** compared to the United States where peanuts are used for snacks, peanut butter, and candy production.

1. *Blanching*

Blanching is used to clean peanut kernels from dust, mold, foreign material and filth (Woodroof 1983). Blanching also removes the skins and hearts for peanuts to be used in salting. Also, blanching usually results in a peanut that is milder in taste due to the removal of both (a) tannins in the skin, and (b) bitter flavor present in the hearts (Woodroof 1983). Depending on the end product, the blanching processes are different for salting peanut and peanut butter,

whereby the hearts are removed in the latter (Woodroof 1983). Also, the blanching stage is different according to type of roasting, such that blanching is performed before oil roasting but after dry roasting.

The main types of blanching include dry, water, spin, air impact, alkali, and hydrogen peroxide blanching. Dry blanching removes the hearts and skins of the kernel and it involves heating the shelled peanuts. In contrast, water blanching removes the skins but not the hearts. Spin blanching is similar to water blanching but uses steam instead of water. Alkali blanching is commonly used at home by soaking shelled peanuts in 1% solution of sodium hydroxide for 8 s, follow by dipping in 1% solution of hydrocholoric acid to prevent the red color of the tannins from staining the kernels (Woodroof 1983).

Each type of blanching method has its own advantages and disadvantages. For example, dry blanching results in a loss of about 12% in total weight. Water blanching and spin blanching are harsher compared with hydrogen peroxide blanching, the latter retains more of the peanut flavor and texture, does not cause splitting or shrinkage, and increases the shelf stability (Woodroof 1983).

2. *Roasting*

Similar to blanching, the type of roasting used is related to the intended use of the peanut. Peanuts used to make peanut butter are dry roasted by either batch or continuous process (Woodroof 1983). The degree of roasting of peanuts intended for candies varies with the type of candy. Large kernels are used individually, whereas smaller kernels are rolled onto a caramel-coated nougat center (Woodroof 1983).

The batch procedure for roasting peanuts involves a batch of 400 lbs that is added to a revolving oven held at 800 °F. The peanuts are heated and held at 320 °F for 40 to 60 minutes.

Roasting has a tremendous impact on the quality of the final products, and it is crucial to achieve an even color development on each kernel, without scorching, excessive oiliness or decomposition of surface fats (Woodroof 1983). In contrast, the continuous roasting process uses a continuous motion of a conveyer belt to push the peanuts against a stream of hot air. The heat transfer onto and extraction of moisture from the peanuts is improved if the peanuts are continuously agitated and eventually gathered at the lowest conveyor (Woodroof 1983).

3. *Peanut butter*.

Peanut butter carries a standard Code of Federation Regulation identity of 95% peanuts. In addition, salt, hydrogenated vegetable oil, dextrose, antioxidant, honey, lecithin, whey, flavors may be added to differentiate the peanut butter in a crowded market (Woodroof 1983). The manufacturing of peanut butter involves cleaning, shelling, and grading of peanut kernels, followed by roasting, blanching, and grounding into a paste (Freeman and others 1954). Salt, sugar, hydrogenated oil, antioxidant are added to the paste. Also, chopped peanuts may be added to the paste to achieve a 'chunky' type peanut butter. Rapid cooling after grinding is critical to remove the heat and sets the added stabilizer or hydrogenated oil rapidly to prevent oil separation. Products are then filled into container which may or may be flushed with nitrogen prior to sealing.

B. Sensory Profile

Sensory profiles of peanut and peanut butter is required to quantify the difference or changes in peanut butters. Researchers such as Gills and Resurreccion (2000) used sensory profiling to evaluate compare the changes in stored peanut butter stabilized with palm oil and

hydrogenated vegetable oil. Peanut butters with varying amount of stabilizer were used to correlate with an instrumental method of texture profile analysis (Lee and Resurreccion 2001).

1. *Roasted Peanut*

A comprehensive sensory flavor profile or lexicon (Table 2.6) for roasted peanuts was developed by Johnsen and others (1988). Since then, researchers have added descriptors to the list, including fermented/fruity (Sanders and others 1989; Sanders and others 1990), crunchiness (Braddock and others 1995; Mugendi and others 1998; Baker IV 2002), rancid/oxidized (Brannan and others 1999), green and sweet oxidatively rancid (Warner and others 1996). Comparing between fresh and oxidized peanut paste made from the same roasted peanut source, oxidized peanut were found to have lower roasted peanutty, sweet aromatic and sweet, and higher cardboard and painty intensities (Civille and Dus 1991). Cardboardy intensity was higher in high oleic peanuts due to lower hexanal and higher nonanal production during storage (Baker IV 2002). Raw peanut (beany), cooked peanut, roasted peanut, sweet aromatic, woody/hull/skins, grainy, sulfur, sweet, bitter, chalky were among the attributes used in the descriptive analysis of a peanut paste (Muego and others 1990). Stale taste increased but roasted peanutty remained unchanged in roasted peanut paste stored at -23 C, indicating that oxidation was taking place even at such a low temperature (Pattee and others 1999). Comparing between fresh and oxidized peanut paste made from the same peanut source, oxidized peanut were found to have lower roasted peanutty, sweet aromatic and sweet, and higher cardboard and painty intensity (Civille and Dus 1991)

2. *Peanut Butter*

The lexicon for the descriptive analysis of peanut butter was recently developed by McNeill and others (2002). A total of 22 peanut butters were evaluated before a lexicon consisting of 4 appearances, 19 flavors and 12 texture descriptors were developed (McNeill and others 2002). In addition, texture profiles of peanut butter were developed by Meilgaard and others (1991), Gills and Resurreccion (2000) and more recently, by Lee and Resurreccion (2001). Summaries of the various descriptors of peanut butter appearance and flavor, and texture are shown in Table 2.7 and 2.8.

C. Instrumental Texture Tests

Objective instrumental measurements of texture may be divided into three main categories: fundamental tests, empirical tests and imitative tests (Bourne 1982). Fundamental tests make exact measurement of the defined property in known units of measurement, but exhibit poor correlation with sensory judgments (Bourne 1994). Well defined properties such as viscosity, elastic modulus, ultimate strength, shear modulus and bulk modulus are examples of fundamental measurements (Szczesniak 1963b). More opportunities remain as fundamental tests are now more widely available, faster through the incorporation of computer and software, and food scientists are exploring more about their strengths and weaknesses. Examples of such instruments are dynamic mechanical analyzer and dynamic rheometer (Bourne 1992).

Empirical tests are simple, commonly used in the quality control of the food industry, provide good correlation with sensory results, but are unacceptable in the scientific community due to it ambiguous definition and lack of scientific foundation (Bourne 1992). Bourne (1994) suggested a provoking thought in converting successful empirical tests into fundamental tests.

The last group of textural instrument is the imitative tests, which assess textural property of food in a similar manner as humans (Stone and Sidel 1993). Such instruments include the M.I.T. denture tenderometer, General Food texturometer and Instron. Results from the Instron yields measurements such as peak force and energy and are used to relate to sensory attributes.

Sensory crispness is inversely related to maximum force (Vickers 1987; Seymour and Hamann 1988; Hung and Chinnan 1989). Six different test procedures using the Instron were tested on raw, blanched or oil roasted peanuts but none of the six procedures yielded a method with high reproducibility, procedures that utilize more than one kernel half of peanuts generally yielded better precision (Vivar and Brennan 1980). Among the five Instron test cells tested by Hung and Chinnan (1989), the modified Kramer shear-compression cell was the most consistent and was well correlated with sensory rating in measuring the crunchiness. Further studies on peanuts stored in a narrower range of water activity environment of 0.5 to 0.8 a_w were recommended (Hung and Chinnan 1989).

Gills (1998) used both DMA and TPA to assess the textural properties of peanut butter stabilized with 0, 1.5, 2.0 and 2.5% palm oil and hydrogenated vegetable oils. Nine textural properties were studied, including stickiness, graininess, hardness, adhesiveness, gumminess, oiliness, mouthcoating, mouthdryness and spreadability. Samples were allowed to reach equilibrium to 25C for 3 minutes before DMA measurements. Except for spreadability, which exhibited a higher correlation coefficient of –0.64 between sensory result and loss modulus, other attributes were not correlated. The author cited high variability in DMA measurement as the possible cause for such result.

D. Gas Chromatography Flavor Profile

Nuts are roasted to achieve an improved flavor profile, including roasted peanutty flavor and sweet aromatic (Crippen and others 1992). Mason and others (1966) were the first to identify 5 pyrazines and a pyrrole that are responsible for the flavor characteristics of roasted peanuts. Pyrazine compounds in roasted peanuts are related to the degree of browning (Koehler and others 1971). Since then, many researchers have studied the flavor profile of roasted peanuts and have identified the following compounds as responsible: 2,6-dimethylpyrazine, 2-methylpyrazine, 2-ethyl-6-methylpyrazine, 2,3,5-trimethylpyrazine, pentanal, 2,5-dimethylpyrazine (Warner and others 1996; Brannan and others 1999). The two most desirable flavors in roasted peanuts are roasted peanutty and sweet aromatic flavors, but no single compound correlated with either flavor (Crippen and others 1992). Different ratios of volatiles were found to correlate well with flavor score of commercially available peanut butters (Fore and others 1976).

For freshly roasted peanuts, 2-ethyl-6-methypyrazine increased with increasing flavor preference, while pentanal was inversely related to flavor preference (Buckholz and others 1980; Buckholz and Daun 1981). GC peaks that correlated strongly with sensory acceptability were predominantly pyrazines that were within the least volatile zone, including 2-ethyl-6-methyl pyrzaine and 2-ethyl-3-methyl pyrazine. Other GC peaks correlated with sensory acceptability are 2-ethyl 3,6-dimethyl pyrazine, 2-vinyl-3,6(5)-dimethyl pyrazine, isovaleraldehyde, phenyl acetaldehyde, hexanal, and an unidentified compound (Buckholz and others 1980).

Dark roasted flavor was found to correlate with methylbutanal and methylpropanal, while woody/hulls/skins flavor correlated with N-methylpyrrole (Crippen and others 1992). Samples containing high level of *n*-methypyrrole were rated as musty (Young and Hovis 1990). A

summary of important flavor volatiles in roasted peanuts identified by researchers is summarized in Table 2.11.

Break point (Tb) is defined as the point between the ends of the initial monomolecular hydroperoxide decomposition catalyzed oxidation and the start of the rapid bimolecular catalyzed phase (Koelsch and others 1991). Generally, Tb is appoximately the point of threshold for unacceptability (Labuza 1971). Statistical analysis for data before and after Tb was analyzed using linear regression and nonlinear regression respectively (Koelsch and others 1991). The threshold for hexanal detection in cereals was found to be around 0.15 ppm (Fritsch and Gale 1976).

1. SPME

SPME is a simple, effective sampling method that eliminates the need for solvents or complicated laboratory setup for concentrating volatiles or non-volatiles (Anon. 1998). One of the many uses of SPME is on testing orange juice flavor compounds, which decreased with increasing temperature between 25 and 80 °C (Jia and others 1998). Compared with liquid-liquid and solid phase extraction, using the SPME can tremendously reduce extraction and handling times, from as long as 18 hours to 15 minutes (Anon. 1998).

The SPME method is sensitive to experimental conditions such as heating temperatures, heating time, sample amount, sample concentration, sample uniformity and sample matrix (Yang and Peppard 1994). If room temperature is selected as the incubation temperature, variations in room temperature can result in poor reproducibility in the results (Anon. 2001). It is critical to stabilize the sample temperature at the determined optimal temperature before the fiber is exposed (Anon. 2001.). It is necessary to equilibrate the sample to the pre-determined temperature prior to exposing the SPME fiber (Anon. 2001). However, highly accurate and

precise results can be obtained from SPME by maintaining a consistent sampling time and other sampling parameters, rather than trying to reach full equilibrium. When the analyte is at equilibrium between the fiber and the sample, a constant concentration can be extracted (Anon. 2001). Organic analytes are absorbed to the coating on the SPME fiber and this takes between 2 to 30 minutes (Anon. 1998).

After exposing the fiber for the designated time, the fiber is drawn back into the stainless steel needle and the needle is withdrawn from the sampling vial (Anon. 1998). The extraction time required is dependent on the length of time required to obtain precise extractions for the analytes with at the highest concentrations (Anon. 1998). The needle is inserted into the gas chromatograph injector, the fiber is exposed and the analytes are thermally desorbed and passed into the GC column (Anon. 1998). In general, volatile compounds require thick fiber coating, compared to a thin coating for semi-volatile analytes (Anon. 1998). In addition, the recovery of analytes may be improved by changing analytical conditions such as adding an electrolyte to the sample, adjusting the pH, or sampling the actual sample instead of the headspace, or vice versa (Anon. 1998). A consistent result using the SPME can be achieved by controlling the polarity and thickness of the fiber coating, maintaining consistent sampling time and other parameters (Anon. 1998).

E. Moisture

Moisture assays can be one of the most important analyses performed on a food product and yet one of the most difficult from which to obtain accurate and precise data (Bradley 1998). Analysis is difficult because water can be found in food as three different forms, free, adsorbed and bound. Therefore, determination of moisture with different methods may show varying

results of water present in the sample. In order to minimize variation within results several official methods with stated procedures have been developed. Usually, the preferred method of analysis is the first method listed by the Association of Official Analytical Chemists (AOAC) International (Bradley 1998). In addition, other associations such as American Association of Cereal Chemists (AACC) and Association of Oil Chemists Society (AOCS) have also published their own analysis methods.

Applications of these analysis procedures are demonstrated in the following food studies. Bett and others (1994) used the AOCS Method Bd 2-52 (1969) for moisture analysis of peanuts from several origins. Plemmons and Resurreccion (1998) determined the moisture content of roasted, defatted, salted peanuts by the vacuum oven procedure published by AACC (1983). Santos and others (1989) also used the AACC (1983) method for moisture content determination of peanut-based imitation cheese spread.

F. Color

Color evaluation should be conducted on a sample to determine color change or variation between samples. Samples may incur significant color change during storage that may cause a loss in quality and acceptability. Therefore, proper evaluation, such as Muego-Gunanasekhaaran and others (1994) study of color change in cheese-flavored spread made from peanuts, should be conducted to verify product consistency. Color measurement is also a good tool in determining desirable degrees of color change in foods, for example degree of roasting. A study conducted by Plemmons and Resurreccion (1998) measured the degree of peanut roast by measuring color lightness, L, with a Gardner Laboratory XL-800 series tristimulus colorimeter with a XL-845 circumferential sensor. Additionally, color of a product could be measured to determine how the

addition of a certain ingredient would affect the color. Collins and Sanchez (1979) used *L*, *a* and *b* values obtained with the Hunter Meter to evaluate the effect of adding flour prepared from peanut shells to peanut butter.

IV. Shelf Life

Storage stability of roasted peanuts is a function of genetic, cultural practice, post harvest handling, and composition variation. Post harvest handling in low temperature, controlled humidity, vacuum or inert gas is some of the many methods available to extend the storage stability of roasted peanuts (Shewfelt and Young 1977). Studies on the storage stability of genetically modified peanuts containing high oleic/low linoleic acids suggest an alternative in extending the shelf life of peanut products (Braddock and others 1995; Bakers 2002; Reed and others 2002).

When stored in optimum conditions such as 9-10 °C and at a humidity of <60%, roasted peanuts were stable for up to 90 days (Table 2.9) (Anon. 1978). Using regression equation provided by Grosso and Resurreccion (2002), roasted peanuts stored at 23, 30 and 40 °C were rated unacceptable (<6.0 on 9-point hedonic scale) after 21 days of storage in closed polyethylene bags (Table 2.9). Similarly, as shown in Table 2.9, roasted peanuts exposed to atmospheric conditions had a shelf life of only 21 days (Shewfelt and Young 1977). Braddock and others (1995) used an arbitrary end point of 6.0 on a 15-point descriptive scale to determine the shelf life of Florunner peanuts stored at 25 °C at 40% relative humidity and concluded that a shelf life of 47 days was predicted using peanut flavor intensity (Table 2.9). However, Grosso and Resurreccion (2002) suggested that descriptive attribute such as oxidized flavor, painty and

cardboard, rather than roasted peanutty, provided a better indication of shelf life (Grosso and Resurreccion 2002).

Researchers have disagreed on the factors that lead to the loss of roasted nut flavor commonly known as flavors-fade (Mugendi and others 1998). Degradation of lipid radicals resulting in increased concentration of hexanal, octanal and 2-octanone and a decrease in heterocyclic compounds was suggested as the main mechanism responsible for flavor fade for peanuts stored at 37 °C for 84 days (Bett and Boylston 1992). Roasted peanuts stored at 65 °C for 68 days indicated increased concentration in hexanal, heptanal, octanal and nonanal that masked the constant concentrations of pyrazines and other roasted peanut compounds (Warner and others 1996). Mugendi and others (1998) suggested otherwise and concluded that flavor fade of roasted peanuts as due to the loss of pyrazine and not due to the masking effect. Roasted peanuts were stored at 30, 40, 50 and 63 °C and measured hexanal levels had high pseudo-R^2 with change in temperature (Ramos 1995). Based on an arbitrary threshold of 15 ppm hexanal, peanuts stored at 30 °C were estimated to have a shelf life of 177.1 days (Table 2.9) using kinetic equations derived (Ramos 1995). In contrast, the regression analysis of Grosso and Resurreccion (2002) suggested a hexanal level of 2.5 ppm in roasted peanuts would prompt consumers to rate the samples as unacceptable (<6.0 on 9-point hedonic scale) when samples were stored for 21 days at 40 °C (Table 2.9).

Roasted peanut loses freshness and crispness if brought into contact with an environment or ingredients of more than 6% moisture, developing a soggy nut aroma and flavor (Woodroof 1983). For peanuts in candy, the flavor is improved when the peanuts are first roasted to a light brown color with a moisture content of less than 3% (Woodroof 1983). When stored in packages that exclude air and moisture, peanut candy with added antioxidant and stored at -18 °C has a

shelf life of more than 2 years (Woodroof 1983). Baker (2002) found that the loss of crunchiness was mostly avoided when samples (high oleic peanuts) were stored at a_w of 0.44 or lower. Peanut butters with 5% water added has a higher water activity of 0.56 and exhibited higher rate of off-flavor development and darkening, and a shorter shelf life is expected (Felland and Koehler 1997).

A. Definition

'Shelf life', more accurately termed 'estimated shelf life', has been debated over the years on its definition. Shelf life was first defined as the period between manufacture and retail purchase of a food product during which the product is of satisfactory quality, and is measured by criteria such as (a) loss of nutrient value, (b) spoilage by microorganisms, (c) loss of aesthetic qualities, (d) loss of functional properties (IFT, 1974). Dethmers (1979) suggested that the end of shelf life refers to a point whereby the samples are rated as 'different' by a certain amount as detected by a trained panel and is correlated to the changes in acceptability as rated by affective sensory tests. Criteria for determining the sensory shelf life include (a) specific difference in acceptance scale units such as 1.5, (b) failure acceptability score (c) storage life (d) just noticeable difference, usually statistical and not significance in commercial value (e) change in descriptive profile of product, or (f) statistics applied, such as hazard plotting and regression between sensory response and storage time (Dethmers 1979). Griffiths (1985) found that a significant change in descriptive rating does not always translate to an unsatisfactory acceptability, suggesting a difference between statistical and commercial significance. The stability time can be defined as a one-unit decrease in quality rating (Griffiths 1985). High quality shelf life (HQSL) and practical shelf life (PSL) refers to the shelf lives determined by trained panel and consumer panel, respectively (Labuza 2002). The ratio of HQSL and PSL

varies from 1.9 to 3.5, and usually the PSL is twice as long as HQSL (Labuza 2002). Labuza and Schmidl (1988) concluded that shelf life refers to the end of consumer quality, and is represented by the percentage of consumers who are displeased by the product.

B. Principles

Shelf life is a function of time, environmental factors, and susceptibility of product to quality change (Labuza and Szybist 1999). The most simple and logical criterion for shelf-life evaluation is using sensory evaluation of multiple samples (Bishop and White 1986). Shelf-life tests are effective only if the heterogeneity of samples is controlled and multiple samples, rather than samples from a single package, are evaluated (Maxcy and Wallen 1983).

Generally, the rate of change of a quality attribute Y may be expressed as:

$$\frac{dY}{dt} = f\{C_x, E_x\}$$

where t = time

dY/dt = rate of change

C_x = composition factors

E_x = environnemental factors (Labuza 2002)

Most reactions can be expressed in the form of:

$$\frac{dY}{dt} = k[Y]^n$$

where t = time

dY/dt = rate of change

k = rate constant

n = 0 or 1 and not >1 (Labuza and Riboh 1982).

Temperature is the most influential factor in the shelf life of food and the Arrhenius relationship has been successfully used to model the changes in rate constant with temperature:

$$k = k_0 e^{-E_A / RT}$$

where k = rate constant

k_0 = pre-exponential factor

R = gas constant, 8.314 kJ/mol°K or 1.986 kcal/mol°K

T = temperature in ºK

E_A = activation energy (Labuza and Riboh 1982)

Typical activation energies for lipid oxidation, flavor and texture, and non-enzymatic browning are 10-25, 10-30 and 25-50 kcal/mole, respectively (Labuza and others 1972; Lund 1977). The Arrhenius equation implies that a plot of ln k versus 1/T °K would yield a straight line (Labuza and Riboh 1982). In some cases, the Arrhenius plots are not linear. This may be due to changes in (a) water activity, (b) moisture, (c) physical state, (d) critical reaction with a change in temperature, (e) pH, (f) dissolved oxygen with increasing oxygen, and (g) separation of reactants due to change of physical state (Labuza and Riboh 1982). Other problems include (a) error in analytical or sensory evaluation, (b) crystallization of carbohydrates, (c) presence of 2 reactions with different Q_{10} at different temperature ranges, (d) denaturation of protein at higher temperature, (e) heterogeneity of food sample (Labuza and Riboh 1982; Labuza and Schmidl 1985). Arrhenius kinetics of food is less successful than that of drugs because food products are less homogeneous, they are tested using less precise measurements such as in consumer sensory

evaluation, and a narrow range of temperature that food can be stored at (Labuza and Riboh 1982). For roasted peanuts, the Arrhenius relationships were well fitted (R^2=0.78 to 0.91) for all chemical measurements, including hexanal by gas chromatography (Ramos 1995).

2. Q_{10}

The accelerating factor, Q_{10}, is a simplified mathematical relationship used in estimating shelf life and is expressed as:

$$Q_{10} = \frac{\text{Rate at } T + 10}{\text{Rate at } T} = \frac{\text{Shelf life at } T}{\text{Shelf life at } T + 10}$$

where T is the temperature in ºC (Labuza and Schmidl 1985).

For any temperature difference (Δ) that is not exactly 10 ºC, the expression is

$$Q_{10}^{\Delta/10} = \frac{\text{Rate at } T_2}{\text{Rate at } T_1} = \frac{\text{Shelf life at } T_1}{\text{Shelf life at } T_2}$$

where

T = temperature in ºC, and

$T_1 < T_2$ (Labuza and Schmidl 1985).

Research has shown that the Q_{10} for different product categories are (a) canned products, 1.1 - 4.0, (b) dehydrated foods, 1.5 - 10, and (c) frozen foods, 3 - 40 (Taoukis and Labuza 1996). For lipid oxidation, Q_{10} is between 1.5 and 2.0 (Labuza 1982). Q_{10} is dependence on E_A and temperature, such that the Q_{10} at 5 °C is often higher then the Q_{10} at 20 °C (Taoukis and Labuza 1996). However, this does not imply a higher reaction rate at the lower temperature. Instead, Q_{10} at 5 °C measures the magnitude of change in reaction rate between 5 and 15 °C, while Q_{10} at

20 °C measures the magnitude of change in reaction rate between 20 and 30 °C. The reaction rate at a higher temperature is usually higher than that of lower temperature and the change in the rate of reaction around higher temperatures is lesser compared to that of lower temperatures.

C. Sensory Shelf Life Evaluation

While regulatory agencies do not monitor the sensory changes in food products, sensory shelf life is determined by consumers who find the quality of the product to be less than their expectation, resulting in refusal to repurchase (Labuza and Schmidl 1988). Compared to many microbiological and physico-chemical tests, sensory test is recommended (Griffiths 1985). Sensory shelf life evaluation of food can be conducted using quality rating (scalar scoring), flavor profile, texture profile, magnitude estimation and quantitative descriptive analysis (Prell 1976). Initially, until descriptive ratings or physico-chemical measurements have been correlated with consumer ratings, the affective test is recommended for shelf life testing of foods (Stone and Sidel 1991; Meilgaard and others 1991). However, they state that no single method is completely satisfactory and it is best to use 2 or more methods to complement each other (Stone and Sidel 1991).

Stone and Sidel (1991) pointed out that results from product stability test do not necessarily translate to the date for sale or consumption. Instead it is determined by the management and marketing constraints (Labuza and Schmidl 1988). Perhaps one of the most difficult decisions in shelf life testing is sustaining the control samples from changes. For example, control samples (peanuts) were roasted, stored frozen (-20 °C) in the dark after flushing with nitrogen, and they were equilibrated at 25 °C before opening (Braddock and others 1995).

Also, control peanut samples were stored at -20 °C in glass jars flushed with nitrogen (Baker IV 2002).

1. Difference and Discrimination testing

Difference testing is the first step in sensory shelf life evaluation to ascertain a noticeable difference (Meilgaard and others 1991). Specifically, paired comparison, duo-trio tests, and triangle tests are the most commonly used in shelf life testing (Labuza and Schmidl 1988). Discrimination tests are usually conduced with the stored sample versus the control (Stone and Sidel 1992). If the difference testing shows no significant difference, no further testing is required and the study continues (Stone and Sidel 1992). On the other hand, acceptance testing should be conducted if the results from the difference test indicate significant difference between the stored sample and the control (Stone and Sidel 1992). Using difference testing solely for shelf life testing will only tell if the samples are different but they may still be acceptable.

2. Consumer Acceptance Testing.

As explained previously consumer acceptance testing is usually the next step when significant difference between the control and the sample is found. Consumer acceptance testing is usually conducted at the start of the experiment (zero time) and at least 3 more consumer tests should be conducted (Stone and Sidel 1991). However, this requires considerable time, inconvenience and expense, in addition to the negative company image of giving consumers bad products (Labuza and Schmidl 1988).

Meilgaard and others (1991) discuss the use of affective test during which consumers who instructed to score samples on a scale of ‘difference from control’. By comparing with the baseline rating of difference from control among 2 unknown control samples, significant

difference between stored sample and the control sample can be detected (Meilgaard and others 1991). Additional testing using hedonic ratings and intensity ratings were conducted when the difference from control was more than 5.0 (Meilgaard and others 1991). Criteria for the end of sensory shelf life are determined by (a) a difference on an acceptance scale, e.g. 1.5 points on a hedonic 9-point scale or (b) a designated failure acceptability score, such as 5 on a 9-point scale (Dethmers 1979). The advantage of consumer acceptance testing is that it measures practical shelf life, compared with high quality life measured by other sensory tests (Griffiths 1985).

3. Descriptive analysis.

Descriptive analysis is a sensory evaluation technique that is used to measure products by categorizing the different senses, and provide a common language for communication of the sensory experience (Moskowitz 1983). This sensory tool can be used to describe a complete sensory experience of food and used for determining sensory characteristics that attributes to the acceptance of the same product by the consumers (Stone and Sidel 1993). Attempts to correlate descriptive and consumer ratings have been one of the most important areas in sensory evaluation.

Descriptive analysis usually involves 5 to 10 panelists who are trained in detection and description of both qualitative and quantitative aspects of the sensory perception of a product (Meilgaard and others 1991). The qualitative properties of food describe the product attributes that are used in the development of the complete sensory profile, whereas the quantitative properties are related to the degree or strength of the characteristics that is present (Meilgaard and others 1991). The quantitative properties are usually rated on a measurement scale such as a line or category scale.

Types of Scales. The 3 most common types of scales used in descriptive analysis are category scale, line scale, and magnitude estimation scale (Meilgaard and others 1991). Category scales are categories labeled with words or numbers at each level, and consist of equal intervals between the categories (Meilgaard and others 1991). Magnitude estimation scale is commonly used in academic studies. This type of scale allows the panelists to first assign a number on the scale and then assigned all other ratings in contrast to the first number. It is most useful when focusing on a single attribute that has a wide range of intensity (Meilgaard and others 1991).

Line scales are the popularly used due to the ease of design and instruction. The scale can be constructed in the length of 6 in or 15 cm long, and panelists rate by placing a mark on the scale to assign an intensity level (Meilgaard and others 1991). The drawback of the line scales is getting the panelists to remember the intensities on the scale, as compared to the category scale which has numbers or words assigned to the scale. However, technology advancement such as computerized input has solved the problem by allowing the panelists to see what they are rating on the scale.

The 3 scales have been compared to identify if the best scale. However, it is generally agreed that the line scales requires more training than either the category or the magnitude estimation scales. When all 3 scales were used in the evaluation of cooked beef steaks, it was found that category and magnitude estimation scales were more sensitive than line scale (Shand and others 1985). In addition, panelists preferred category scale to line and magnitude estimation scales, with magnitude estimation as the least preferred scale (Shand and others 1985). Similarly, Pearce and others (1986) concluded that magnitude estimation and category scales were more preferred in a hedonic ratings of controlled stimulus.

Panel Selection and Training. The descriptive testing requires extensive training of the panelists and the panel leader takes grave responsibility in screening, training, moderating and leading the panel to evaluate products. Screening is the initial step in identifying panelists who are capable of becoming a descriptive panelist. The criterion for becoming a sensory panelist includes personal interest, availability, promptness, health, articulateness, attitude, job, education and physiological factors such as smoking or having denture (ASTM 1981). Screening may involves a questionnaire to survey panelists for the abovementioned criteria, and physically test panelists for their ability to distinguish simple taste and flavor.

The orientation process of descriptive analysis allows the panel leader to explain the fundamental aspects of sensory evaluation and descriptive analysis to the panelists. Panelists are introduced, and explanation of basic taste, flavor, and texture are provided. The process also allows the panelists to visualize the importance of working as a group in both the qualitative and quantitative evaluation of samples.

Panelists who are oriented are trained to evaluate a selective product in coming up with the qualitative aspects. Terms, definition and evaluation instructions are developed. Panelists first evaluate samples of different formulations or treatments, including those of extreme cases, to come up with the attributes and record them in the order of sensory perception. The panelists then agree upon a selective list of terms that are not redundant, not confusing and helps describe all the possible sensory attributes of the product. Panelists also agree upon the definitions and evaluation instructions of each attribute so that the panel can behave as one finely crafted instrument.

Descriptive panelists, in addition to deciding the qualitative and quantitative aspects of perceived attributes, also identify the order by which the descriptive attributes appear (Meilgaard

and others 1991). The categories of attributes perceived in a food product are often in the following order: appearance and color; aroma; flavor, texture and chemical feeing; and residual sensations. For each of the abovementioned sensation, further division of stages of consumption may be introduced. Lee and Resurreccion (2002) studied the texture profile of peanut butter in which panelists evaluated its texture in stages of surface, first compression, breakdown, residual and swallow. The evaluation procedure is controlled such that panelists are instructed to compress the sample 1 time to evaluate a few attributes belonging to the first compression stage, chew 7 times and evaluate for breakdown attributes, and so on. The amount of samples can also be controlled such that panelists consumed only samples that have not been agitated, and only sufficient amount is placed in the mouth for the evaluation of a few attributes.

In addition to establishing the terms, definitions and evaluation instructions, panelists also select reference standards that represent selective intensity of the descriptive attribute. Rainey (1986) discussed the importance of reference standards in training panelists. Use of reference standards can shorten the time of training and provide documentation for terminology (Rainey 1986). The moderator can also take advantage of reference standards to clarify the definitions or evaluation instructions.

The ideal set of terminology is one that is thought by and discovered by the panelists through exploring various formulations or treatments of the sample. However, this process can be shortened by providing the panelists with a list of terms and definitions that has been previously established for the same or similar product. For example, Johnsen and others (1988) and McNeill and others (2002) have previously established descriptive lexicons for roasted peanuts and peanut butters, respectively. These lexicons can be used to aid in the training of a descriptive panel in a short time and in providing accurate terms and definitions. In addition,

results from the panel can be easily interpreted by other researchers because the descriptive language is similar.

Monitoring panelist performance has long been the subject of discussion in descriptive analysis. The performance of panelists is monitored using controls and replicates samples. Non-performing panelists can be identified by checking their ratings among replicates, and against a replicated control samples whose ratings have been previously agreed upon by the panel. Graphical method such as plotting the ratings of each panelist for each attribute can be used to visualize the performance of the panelists. In addition, multivariate statistical methods such as cluster analysis (Malundo and Resurreccion 1992) and discriminant partial least squares (Thybo & Martens 2000) has been utilized to identify panelists or descriptive attributes that requires further training or clarification. The panel leader compares the results of the replicates, identify non-performing panelists, and provide feedback in the form of individual reports. The panel, together with the panel leader, can then work as a team in clarifying terms, definition, or evaluation instruction to assist non-performing panelists.

Sample Evaluation. Prior testing, panelists are familiarized and calibrated in a discussion session. During the calibration session, panelists refresh themselves with the perceived intensities of basic taste solutions, terms, definitions, evaluation instructions, reference standards and their respective intensities. In addition, panelists discuss any observations or difficulties they have from the previous session. The use of a warm-up sample has been shown to improve panel performance and the reliability of panelists (Plemmons and Resurreccion 1998; O'Mahony and others 1988). The warm-up samples can be the control sample or a replicated treatment sample that is served later during the test. Panel leader utilizes the results from the

warm up sample to compare with panelists' ratings obtained from the test, and the performance of the panel can be improved using methods previous discussed.

Test Methods. Descriptive methods are related to the subjects used in the test, the type and amount of training, the type of data generated, whether qualitative or quantitative, and the analysis of data (Stone and Sidel 1993). The usefulness of the data is dependent on the type of descriptive analysis conducted, including the Flavor Profile, Texture Profile, Quantitative Descriptive Analysis (QDA) and Spectrum Analysis.

The Flavor Profile method is one of the earlier kind of descriptive analysis developed. Flavor Profile involves 4 to 6 panelists who are screened and trained to evaluate aroma and flavor using a 7-point Flavor Profile intensity scale (Meilgaard and others 1991). Flavor Profile has been criticized on problem of one-sidedness whereby a senior member of the panel may dominate the discussion and rating, and also on the lack of accuracy for the 7-point scale to measure small change (Meilgaard and others 1991).

The Texture Profile method was developed after the Flavor Profile method to complement the lack of texture evaluation in the latter. The fundamental test procedures are the same, except that the scale used for Texture Profile has been modified line scale, making it possible to measure smaller changes. Unlike Flavor Profile, Texture Profile panelists evaluate samples independently and uses scales that are 13- or 15-point category scales, with scales such as line and magnitude estimation being introduced later in the its development (Meilgaard and others 1991).

The Quantitative Descriptive Analysis (QDA) method improved on previous descriptive methods by incorporating statistics into the selection of terms, procedure and panelists for testing a specific product (Meilgaard and others 1991). The output of QDA is known commonly as the

'spider web' that depicts the intensity of each attribute for different samples. QDA represents an improvement over methods previously developed for descriptive analysis but still it has its weaknesses such that the panelists are free to rate anywhere on the 15-cm scale without consensus among the panelists, and panel leader serves as a moderator rather than a leader (Meilgaard and others 1991).

Spectrum Analysis was developed from Flavor and Texture Profile (Stone and Sidel 1991). Extensive training, between 3 to 4 hours per day for up to 14 weeks, is one of the characteristics of Spectrum Analysis but the most important aspect is the use of standard reference and reference intensity provided with the method (Stone and Sidel 1991). Unlike QDA, The panel leader plays an important role and exerts more influence on the panelists. Spectrum Analysis can be adapted to specific purposes such as quality assurance and shelf-life evaluation (Meilgaard and others 1991).

6. Weibull Hazard Method

Some researchers state that hedonic testing is of limited use in shelf life but commonly used (Labuza & Schmidl 1988). The recommended Weibull Hazard Method (WHM) as an effective alternative in evaluating product shelf life compared to conducting large scale consumer tests or descriptive analysis, the later being criticized by statisticians as ineffective in predicting consumer behavior. Based on the maximum likelihood graphical procedure, the WHM assumes that the failure pattern of a product is similar to a bathtub shape (Gacula & Kubala 1975). WHM can be used to predict the end of shelf life of products using fewer consumers than shelf life testing using consumers, thereby appearing to be more efficient and less costly to run.

Testing. When using WHM to evaluate the shelf life of a product, Products are rated as acceptable (+) or unacceptable (-) in a sequential monadic order to best simulate consumer conditions where no direct comparison can be made (Labuza & Schmidl 1988). In WHM, rating of acceptability can also be determined by a hedonic scale and using the rating for fresh sample as a base, assign positive (+) for each rating that is less than the pre-determined difference in rating allowable (e.g. critical change in 9-point hedonic scale of 1.5), and a minus (-) for each rating that is more than the critical change (Labuza & Schmidl 1988). Alternatively, instrumental measurement can be used in Weibull Hazard Analysis such that multiple samples, rather than multiple assessors, are measured and compared with a pre-determined level for lacked of acceptability (e.g. 0.5 ppm of hexanal) in order to determine the acceptability as (+) or (-) and constructing the hazard plot (Labuza & Schmidl 1988). The number of samples added to the sampling is usually 0 or 1 due to limitation of panelist availability (Labuza & Schmidl 1988). The number of panelists required for each sampling is determined by

$$n_{i+1}=n_i+C$$

where:

C= the initial number of panelists, 0 or 1 (Labuza & Schmidl 1988).

When 50% or more of the panelists rated the sample as unacceptable, the experiment enters an acceleration phase whereby the number of panelists required for evaluating the sample is determined as

$$n_{i+1}=n_i+C+n_f$$

where

C =0 or 1

n_f =number of failed samples during the last sampling using n_i panelists (Labuza & Schmidl 1988).

During the acceleration phase, the frequency of sampling is shortened half of the original sampling frequency (Labuza & Schmidl 1988). After the acceleration phase, the test is terminated if there are no more samples available (Labuza & Schmidl 1988). A flowchart illustrating the testing procedure is shown in Figure 2.2.

Data analysis. Data collected are used to construct the hazard plot, which is useful in concluding the following: (1) the degree of fit of the data versus the model, (2) median time to product failure, and (3) percentage probability of future failures (Gacula & Kubala 1975). The hazard plot is constructed as follows:

(1) given x_i as the observed termination sample, rank all failed samples from 1 to k,

(2) assign age at termination (days) for each ranked failed sample,

(3) calculate h(x) by h(x)=(100/k), where k=reverse rank for each of the failed sample,

(4) calculate cumulative hazard for each k,

(5) plot age at termination versus cumulative hazard % on a Hazard Graph Paper or a log-log paper,

(6) check if the plot is a well-fitted straight line, and

(7) estimate the information needed to determine the shelf life of the product.

The time when the cumulative hazard equals 100% is denoted by α (Duyvesteyn and others 2001). The shape factor, β, can be obtained by drawing a line starting from the upper left dot on the Hazard Graph Paper that is parallel to the fitted line and reading the shape parameter from the scale above the graph (Fig. 9). A β value of at least 2 is necessary to determine that the panelists were independent of bias and that the failure distribution is of a bell-shape (Gacula &

Singh 1998; Gacula & Kubala 1975). For β between 2 and 4, the Weibull distribution is unskewed and is in the optimum range (Cardelli and Labuza 2001). When samples are evaluated beyond their shelf lives, more samples are judged unacceptable and this shifts β beyond the optimum range and the plot was reconstructed for a cumulative hazard of 100 (Cardelli and Labuza 2001). Alternatively, the shape factor is equivalent to the reciprocal of the slope of the fitted line on the log-log paper.

Using the 50^{th} percentile on the hazard plot, one can estimate the mean time to failure by drawing a line at the intersection of the 50% probability scale. This is designated as the nominal shelf life (NL_{50}) (Gacula & Kubala 1975). The probability of sensory failure statistic (PFS) for different storage periods can be obtained by drawing a horizontal line from the age to failure (x-axis) to the plotted line and drawing a vertical line at the intersection to intersect with PFS scale (Gacula & Kubala 1975). The reliability statistic, R(x), is calculated as R(x) = 100-PSF, is used to determine the probability that the product is within the limit of acceptability for the given shelf life estimated in time (Gacula & Kubala 1975). The process of data calculation and graph plotting is shown in Figure 2.3.

V. Accelerated Shelf Life Testing

1. Temperature

Conducting an accelerated shelf life testing (ASLT) requires careful selection of the accelerated temperatures such that the higher temperatures selected will not result in totally different physicochemical changes. If the approximate Q_{10} is not known, at least 2 temperatures are needed (Taoukis and Labuza 1996). Ideally, at least 3 temperatures that are 5 °C apart are required, including ambient temperature (Labuza, 2002). If using a single accelerated

temperature, Q_{10} must be known beforehand and the extrapolation is limited to only a small range (Labuza, 2002). ASLT conducted at temperatures > 40 ºC are not recommendation due the possibility of change in critical reactions compared with room temperature storage (Taoukis and Labuza 1996). The maximum temperature for accelerated studies on roasted peanuts should be about 40 °C (Ramos 1995) and that of almonds should not exceed 43 ºC (Harris and others 1972). For roasted peanuts, a sudden increase in the rate constant of hexanal formation was observed between 40 and 50 °C, possibly due to a change of phase from solid to liquid at higher temperature conditions (Ramos 1995). At least 3 temperatures are required for accelerated shelf life testing. If 2 temperatures are used, no statistics may be applied to evaluate the error because there is no degree of freedoms left (Labuza & Riboh 1982).

2. Water activity

Keeping quality of shelf-stable food is affected predominantly by temperature and moisture content. The availability of moisture, rather than its amount, has been identified as a more accurate precursor to reactivity and is known as water activity. Labuza and others (1970) defined water activity as follow:

$$a_w = \frac{\text{Partial pressure of water in food}}{\text{Saturation pressure of water at specific temperature}}$$

or

$$a_w = \frac{\text{Equilibrium relative humidity}}{100}$$

Water activity ranges between 0 and 1.0, where 1.0 is equivalent to more than 100% moisture (w/w). Organic and inorganic reaction rates under different water activity were reviewed

(Labuza and others 1972). Water activity influences chemical and microbial reactions such as non-enzymatic browning, enzymatic reaction, protein denaturation, lipid oxidation, degradation of vitamins, starch gelatinization and starch retrogradation (Fontana 2000). The rate of non-enzymatic browning reaches a maximum at around 0.6 to 0.7 a_w (Anon. 2003).

Chemical reactions are influenced by water activity in a complex manner by which water may act as solvent for reactants and or products, reactant, reaction product, or by affecting the activities of catalysts and inhibitors (Saguy and Karel 1980). Water activity can affect the effective concentration of reactants, activation energy, reaction rate and the reaction order (Taoukis and Labuza 1996). Generally, for every 0.1 a_w increase the rate of enzymatic and chemical reactions doubles or triples (Labuza 1982). Spoilage due to mold, yeast, or bacteria increases with a_w of more than 0.7, 0.75 and 0.8, respectively (Labuza and others 1972). The rates of deterioration due to non-enzymatic browning and lipid oxidation have been found to vary with water activity.

Intermediate moisture foods (IMF) are foods with a plastic mouthfeel, requiring no refrigeration, and have a_w of 0.6-0.85 (Labuza and others 1972). Food with water activity in the range of 0.30 to 0.75 included ingredients or foods such as pasta, spices, dried fruits, honey, rolled oats, marshmallows, jelly, jam and marmalade (Beuchat 1981). It is within the same range of a_w that both lipid oxidation and non-enzymatic browning peaks (Labuza and others 1972). Semi-moist foods, including confectionery, hardens and become unacceptable when they lose moisture (Labuza 1982). Dehydrated food refers to food with an a_w <0.6 (Labuza 1980). The BET monolayer (0.2-0.3 a_w) is the optimum stability point for dehydrated foods (Labuza 1980).

3. Using saturated salts to maintain water activity

To simulate environmental conditions of different water activity, saturated salt slurries are often used. Saturated salt slurries are prepared at the bottom of a closed container and the test objects are place inside the container above the top of the slurries. The technique was first applied to investigate the moisture sorption of food products across a range of moisture. More recently, food scientists have begun to investigate the effect of water activity and/or temperature on physicochemical changes of food products. Studies involving both changes in water activity and temperature are more complicated in modeling and are subjected to varying water activity with temperature. Examples of such variation are shown in Table 2.10 and researchers need to be wary of such changes in water activity across temperature.

Water activity can affect the effective concentration of reactants, activation energy, reaction rate and the reaction order (Taoukis and Labuza 1996). If the effect of water activity is critical to the shelf stability of the food product, failing to maintain constant water activity conditions will result in erroneous results (Taoukis and Labuza 1996). Knowing the critical moisture content or water activity, storage testing involving water activity levels can be used to predict the shelf life (Labuza and Schmidl 1985). Depending on the water activity of the product, the presence of water within may act as a pro-oxidant or antioxidant (Labuza 1971). The effect of water activity above the monolayer results in shorter shelf life with increasing temperature (Labuza 1980). Chemical reactions are influenced by water activity in a complex manner in which water may behave as a solvent for reactants and or products, reactant, reaction product, or by affecting the activities of catalysts and inhibitors (Saguy and Karel 1980). Water activity can influence kinetics in terms of activation energy, quality factor, reaction order and the pre-exponential factor (Labuza 1980). In different food system, water activity can be directly,

inversely, or not related to the activation energy (Labuza 1980). In a study on the shelf life of roasted and ground coffee, an increase of 0.1 in water activity resulted in a 60% increase in deterioration compared with a 20% decrease for each 10 °C increase (Cardelli and Labuza 2001).

Chemically pure salts, in the absence of impurities or air-borne contaminants, and distilled water are used to prepare saturated salt solutions (Labuza 2001). Test using water activity requires at least 3 values, including one at monolayer or at a water activity value as made (Labuza 2002). If an equilibrium water activity between the environment and the food product needs to be measured, it can be determined using a relative humidity monitor as that point when triplicates of samples yielded the same target water activity (Ringe and Love 1988).

A step-by-step method for preparing saturated salt slurries was described (AOAC 1995). Saturated salt slurries are made by adding distilled water slowly and under constant stirring, until at least half of the salt crystals were dissolved (Labuza 2002). The saturated salt solutions are always in the form of slurries. The formation of a solution, instead of slurry, signal that a true solution is present and the relative humidity created would be higher than anticipated (Labuza 2002). Saturated salt slurries should be best kept at an environment of ±0.1 °C so that the water activity remains within ±0.5% (ASTM 1987). The temperature dependence of selected saturated salt slurries at 23, 30, 35 and 40 ºC is illustrated in Table 2.10. A glass container with a 25 cm^3 volume per cm^2 of solution surface area is recommended and the samples should occupy most of the available headspace (ASTM 1987). The container used for such studies should be corrosion resistant and non-hygroscopic, such as glass (ASTM 1987). Hydrated chemicals are preferred to amorphous forms because they are easier to dissolve (ASTM 1987). Reference salts are place in the test container between a depth of 4 cm and 1.5 cm for lower and higher a_w soluble salts, respectively. Water is added and stirred in 2 mL increments until the salts stop dissolving, and

with minimal free water available (AOAC 1995). Mate and others (1996) explained a glass jar setup for constant water activity environment. Saturated salt slurries were stirred and additional salts were added weekly to ensure saturation every week (Baker and others 2002). A decision tree illustrating the preparation of such relative humidity chamber is illustrated in Fig. 2.4.

4. Sampling.

The frequency of sampling is a concern in ASLT that involve sensory testing, which is costly to run. Due to cost constraints, sensory testing should be conducted a few times in the beginning and more frequently toward the end of the expected shelf life (Taoukis and Labuza 1996). Selecting sampling times close to the probable end of shelf life is crucial and more frequent sampling is required at higher temperatures (Labuza and Schmidl 1985). The time interval between sampling days for temperatures below the highest ASLT temperature should be equal or less than:

$$f_2 = f_1 Q_{10}^{\Delta T/10}$$

where

f_2 = time between test at any lower temperature T_2

f_1 = time between sampling days at the highest ASLT temperature, T_1

Q_{10} = probable Q_{10} value

ΔT = T_1-T_2 °C (Taoukis and Labuza 1996).

However, there are cases where such a sampling frequency is not applicable, such as conditions of drastic increase in reaction rate with increasing temperature (Taoukis and Labuza 1996). Products with very short shelf life, such as one week, should be tested daily, whereas

products with very long shelf life of up to 2 years should be sampled every 20% of the expected shelf life (Anon. 1993). Roasted peanuts were sampled at 0, 2 (14), 4 (28), 7(49), and 10(70) wks(days) at 40 °C at 18% relative humidity and were found to exhibit linear relationship between measured sensory and peroxide value with storage time (Mugendi and others 1998). In contrast, roasted peanuts tested on 1, 7, 14, 21, 27, 45, 59 and 74-day at 25° C and 40% RH showed first order hexanal changes (none then sudden increase) and zero order sensory changes (Braddock and others 1995). For newly launched products, the frequency of sampling should increase towards the end of the shelf life (Anon. 1993).

To minimize the number of samples but increase the risk of error, a minimum of six sampling periods is required (Labuza and Schmidl 1985). A control sample representing the fresh sample evaluated on day 0 should be stored at conditions that minimize or prevent any changes, and depending on the food product, may be stored at 4, -19 or -40 °C (Taoukis and Labuza 1996). On day 0, descriptive testing is conducted to imprint the sensory characteristics of a fresh product, followed by consumer testing to record the optimum acceptability (Dethmers 1979). Multiple replicates are required for the initial testing on the control so that the precision of the sensory method can be established (Taoukis and Labuza 1996). Labuza (2002) suggested that a minimum of 5 initial samples should be evaluated. Initial values and values for stored control samples are required if sensory analyses are conducted (Taoukis and Labuza 1996). At the end of the shelve life study, further sampling beyond 100% specified shelf life should be conducted to check the margin allocated for error (Anon. 1993).

6. Data analysis

Analysis on samples stored at elevated temperatures can be used to predict the shelf life at a lower temperature. As long as the extrapolation does not extend beyond 30 °C, a plot of measured attribute versus ASLT higher temperatures (°C) can be used for predicting the shelf life at a lower temperature (Labuza and Schmidl 1985). Good linearity and fit indicates the order of reaction, whether zero-order (plot of *Y* versus time) or first-order (plot of ln *Y* versus time) (Taoukis and Labuza 1996). If the change in attribute Y is less than 50%, the statistical difference between zero- and first-order reactions is small and the error in k is less than ±5% (Labuza and Riboh 1982). Depending on the order of the reaction, the Q_{10} can be estimated from different mathematical methods (Fig. 2.1) and used for predicting the shelf life when samples are stored at a lower temperature. For both zero order reaction and first order reaction, the rate of change (*k*) is calculated as the slope of the line for each of the accelerated temperatures by plotting Y vs. time (t). The Q_{10} for a zero order is then calculated as:

$$Q_{10} = \frac{k \text{ at } (T+10\ ^\circ\text{C})}{k \text{ at } T\ ^\circ\text{C}}$$

where

Q_{10} = accelerating factor

k = slope of line for each temperature *T*

T = accelerated temperature in °C (Labuza and Schmidl 1985)

For a first order reaction, it is necessary to first plot ln Y versus time (t) and calculating the slope of the line for each accelerated temperature. An Arrhenius plot of ln *k* vs. 1/(*T* °K) is constructed, and the lines for each accelerated temperature are in the form of:

where

$$\ln k = \ln A - (\frac{E_A}{R})(\frac{1}{T})$$

k = slope of line for each temperature T from the plot of ln Y versus time (t)

ln A = intercept

E_A = activation energy

R = gas constant, 8.314 kJ/mol°K or 1.986 kcal/mol°K

T = temperature in ºK (Labuza 1982; Singh 2000)

From the ln k vs. 1/(T °K) plot, the slope of the line (E_A/R) is obtained and E_A is calculated as:

$$E_A = \text{slope x } R$$

where

E_A = activation energy

slope = slope of line of ln k vs. 1/(T ºK)

R = gas constant, 8.314 kJ/mol°K or 1.986 kcal/mol°K (Labuza 1982; Singh 2000)

Depending on the choice of unit for the gas constant, R, Q_{10} is calculated by:

$$\log Q_{10} = \frac{0.523E_A}{(T)(T+10)}$$

where

Q_{10} = accelerating factor

E_A = activation energy in kJ/mol°K

T = temperature in °K

or by

$$\log Q_{10} = \frac{2.19E_A}{(T)(T+10)}$$

where

Q_{10} = accelerating factor

E_A = activation energy in kcal/mol°K

T = temperature in °K (Labuza 1982)

Using the calculated Q_{10} from accelerated temperatures, the shelf life of the product stored at a lower temperature is predicted (Singh 2000). However, making the assumption that E_A is constant at all temperatures will result in a Q_{10} that is higher with decreasing temperature (Labuza and Riboh 1982). Using Q_{10} obtained from data of higher temperature and predicting the shelf life of products stored at lower temperature will result in a shorter than actual shelf life (Labuza and Riboh 1982). Thus the Q_{10} is a tool for estimating the shelf life at a lower temperature and having a shelf life that is much longer than the accelerated shelf life. Instead of the unreliable Q_{10}, E_a is also a good approximation for rate of reaction (Beavon 2002). The Q_{10} of most chemical reactions are between 2 to 4, with E_a ranging from 10-25 Kcal/mole (Anon. 2002). Verification of the predicted shelf life is necessary by evaluating the product at the non-accelerated temperature until the end of its expected shelf life.

According to Labuza (2002), the simple polynomial fit for an accelerated shelf life determination experiment involving 3 temperatures and 3 water activities is as follow:

$$\ln k = A + B/T + C/T^2 + Da_w + Ea_w^2$$

where

T = temperature

a_w = water activity

A = intercept

B,C,D,E = parameter estimates for $1/T$, $1/T^2$, a_w, and a_w^2, respectively

III. Relating Sensory and Instrumental Measurements of Food Properties

One area of study among food scientists is the correlation of an instrumental analysis and the sensory results. Many have found descriptive analysis to be a more accurate tool in relating to instrumental analysis (Galvez & Resurreccion 1990; Muego-Gnanasekharan and others 1990; Holt and others 1992). It is crucial that the samples tested must be of a wide range of difference but yet within the boundaries of a normal product, and a correlation coefficient of $r>0.7$ at $p<0.05$ is the minimal requirement for a establishing a meaningful relationship between the sensory result and the instrumental method (Bourne 1982). Factors affecting the accuracy of instrumental analysis have been linked to the size of sample, shape of sample, nature of plunger surface, probe type, number of replicates, percent deformation, number of compression and the nature of plunger surface (Brene 1975; Muego and others 1990).

A. Ordinary Least Squares Regression

Ordinary least squares regression (OLS) is the most commonly used statistical tool to relate a dependent variable (Y) to one or more independent variables (x). OLS assumes that the explanatory variables (x values) are independent of each other, and the number of objects should be equal or more than the explanatory variables (Kolsky 2000).

In simple linear regression analysis, the model is in the form of:

$$Y = \beta_0 + \beta_1 x + \varepsilon$$

where Y and x are the dependent and independent variables, respectively; β_0 and β_1 are the parameter estimates for the intercept and x, and ε is the error or residual (Meilgaard and others 1991). The coefficient of determination, R^2, can be computed and represents the

proportion of variability in Y that is explained by x (Meilgaard and others 1991). In sensory evaluation, an R^2>0.75 is generally considered to be acceptable (Meilgaard and others 1991).

It is also possible to perform a multiple regressions to relate Y to multiple independent variables (Gacula 1997). For example, the model of a multiple linear regression with 3 independent variables can take the form of:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_1^2 + \beta_5 x_2^2 + \beta_6 x_3^2 + \varepsilon$$

where

Y	= dependent variable
x_1, x_2, and x_3	= the independent variables;
β_0	= intercept
β_1, β_2, β_3 and β_4	= are the parameter estimates of x_1, x_2, x_3 and x_4, x_1^2, x_2^2, x_3^2, respectively
ε	= residual term.

In multiple regressions, forward, backward, or stepwise elimination must be used with OLS to prevent over-fitting (Kolsky 2000). In addition, the best model can be obtained by identifying the one that has the highest adjusted *R*-square, lowest mean square error and Mallow's C_p value (Meilgaard and others 1991).

For regression analysis, it is often useful to have many products with varying degrees of each attribute so that a better definition of attribute relationships can be obtained (Gacula 1997). In an example whereby different panels are used or if the number of subjects are different between the dependent and independent, the mean scores of Y and x's are used in regression analysis (Gacula 1997).

If the independent variables are highly correlated to each other, as in typical sensory data, the multicollinearity problem can lead to erroneous prediction models. Also, OLS is not suitable in cases where there are more independent variables than the number of treatments. Examples of possible unstable models if using OLS: (a) 6 objects (brands of cookie) and 8 explanatory variables (descriptive attributes); (b) 100 objects (panelists) and 8 explanatory variables (consumer attributes) with high strong dependencies among each other (Kolsky 2000).

B. Principal Component Analysis

Principal component analysis is commonly applied on sensory data to map the underlying data structure. The method is a variable reduction procedure such that a large number of variables can be reduced into a few principal components that are not correlated and in turn helps to visualize the importance of each attribute according to their positions and loadings on the principal components. At the same time, redundant components are also removed from the model and the user can focus on the more important aspects of the data.

A principal component is a linear combination of optimally–weighted variables (Hatcher and Stepanski 1994). The principal components plotted with each attributes and exploratory description can be used to categorize the data.

C. Factor Analysis

Factor analysis and principal components differ in terms of their model structure, and in factor analysis it is assumed that there is a smaller number factor than the observed variables, and they contribute to the correlations among the observed variables (Gacula 1997). Compared with principal component analysis, factor analysis may be more appropriate for sensory evaluation data because it is common for the sensory attributes to be combined into integrated attributes (Gacula 1997). Hatcher (1994) explains the steps in factor analysis as (1) initial

extraction of the factors, (2) determine the number of 'meaningful' factors to retain, (3) rotation to a final solution using such as varimax, promax or other methods, (4) interpret the rotated solution and (5) create factor scores. Since principal factors are uncorrelated, factor scores generated from a correlated set of independent variables can be used to correlate with consumer liking (Gacula 1997). In an example where descriptive attributes are highly correlated, factor scores were regressed against consumer acceptance ratings, or dependent variables (Moskowitz 1996).

D. Partial Least Squares Regression.

Partial least squares regression (PLSR) is a soft modeling statistical procedure that has been recently introduced to food research. PLSR is a statistical method for constructing prediction models when the predicting variables are many and are highly correlated (Tobias 2002). It is a bi-linear modeling tool that is often used in the area of chemo metrics and its usefulness in multivariate analysis of biological data such as those from sensory evaluation has been established (Petersen and others 1998).

PLSR does not assume independence of explanatory variables (x's) and it can handle as many as 10 times the number of explanatory variables as objects (Kolsky 2000). Unlike principal component regression or regression based on factor scores, linear components in PLS are established by taking both the Y's and x' into account (Garthwaite 1994). Linear components of explanatory variables are like weighted averages of predictors, and each predictor contains residual information in an exploratory variable that is unique from other components (Garthwaite 1994). PLSR calculates the optimal number of components required to construct a model without over-fitting (Kolsky 2000).

In a simulation study, univariate PLSR was found to be superior than other methods of forming prediction equations, including ordinary least squares, forward variable selection and principal components regression (Garthwaite 1994). Similarly, it was found that PLSR outperformed PCR when there is strong collinearity among the data and when there are a large number of components in the model (Kolsky 2000).

There are 2 main categories of PLSR, namely univariate and multivariate PLSR. Univariate PLSR refers to a statistical method of modeling the relationships between a dependent variable, Y, and a number of explanatory variables (Garthwaite 1994). Multivariate PLSR is similar to univariate PLSR such that in both cases, the linear components of the explanatory variables are related to the dependent variable by ordinary least square regression and equations are determined (Garthwaite 1994). In most situations, the univariate method is likely to construct better prediction equation than multivariate PLSR (Garthwaite 1994). If the Y variable that is to be predicted is not related to the remaining Y variables, then the selected Y variable should be predicted using univariate PLSR and the remaining Y variables are cross-validation is used to compare different scaling for the remaining Y variables (Garthwaite 1994).

REFERENCES

AACC. 1983. Moisture - modified vacuum-oven method. Method 44-40, pp 1-2.

Aguamah GE, Langcake P, Leworthy DP, Page JA, Pryce RJ, Strange RN. 1981. Two Novel Stilbene Phytoalexins from *Arachis Hypogaea*. Phytochemistry 20:1381-1383.

Ahmed EM, Young CT. 1982. In: Pattee He, Young CT, eds. Peanut Science and Technology. Yoakum, Texas, USA: Amer peanut Res Educ Soc, Inc. p. 655-688.

Alikonis JJ, Coster HB. 1961. Extension of shelf life of roasted and salted nuts and peanuts. Peanut J. nut World 3:16-17.

Anonymous. 1978. Roasted peanuts stay fresh one year. Food engineering 50(12):95.

Anonymous. 1993. Shelf life of foods - guidelines for its determination and prediction. Institute of Food Science & Technology. 73 p.

Anonymous. 1998. Solid phase microextraction: theory and optimization of conditions. Bulletin 923:1-8. Bellefonte, PA: Supelco, Inc.

Anonymous. 2001. Control your "T"s for better quantitation with solid phase microextraction (SPME). The Reporter 19(7):1-4.

Anonymous. 2002. Temperature. Available from http://www.mrs.umn.edu/~goochv/AnimalPhys/temperature/temperature.html. Accessed Feb 11.

Anonymous. 2003. Water activity tools – how to profit from proven product-quality techniques in 5 quick lessons. Pullman: Decagon, Inc. 12 pp.

AOAC, International. 1995. Official methods of analysis, 16th ed. Arlington, VA: Association of Official Analytical Chemists. Chapter 40, pp 1.

ASTM. 1981. Guidelines for the selection and training of sensory panel members. ASTM STP 758. American Society for Testing and Materials. p. 1-35.

ASTM. 1987. Standard practice for maintaining constant relative humidity by means of aqueous solutions. E104-85. p 32-34.

Baker GL, Cornell JA, Gorbet DW, O'Keefe SF, Sims CA, Talcott ST. 2003. Determination of pyrazine and flavor variations in peanut genotypes during roasting. J Food Sci. 68(1):394-400.

Baker GL, Sims CA, Gorbet DA, Sanders TH, O'Keefe SE. 2002. Storage water activity effect on oxidation and sensory properties of high-oleic peanuts. J Food Sci. 67(4):1600-1603.

Beavon R. 2002b. Q_{10}-the fact, not fiction. Available from: http://www.rod.beavon.clara.net/Q10.htm. Accessed Feb 11.

Bett KL, Vercellotti JR, Lovegren NV, Sanders TH, Hinsch RT, Rasmussen GK. 1994. A comparison of the flavor and compositional quality of peanuts from several origins, Food Chem. 51: 21-27.

Bett KL, Boylston TD. 1992. Effect of storage on roasted peanut quality: descriptive sensory analysis and gas chromatographic techniques. ACS Symposium series - American Chemical Society. 500:322-343.

Beuchat LR. 1981. Microbial stability as affected by water activity. Cereal foods world. 26(7):345-349.

Bishop JR, White CH. 1986. Assessment of dairy product quality and potential shelf-life - a review. J Food Prot. 49(9):739-753.

Bourne MC. 1982. Food texture and viscosity. New York: Academic Press. 325p.

Bourne MC. 1994. Converting from empirical to rheological tests on foods — it's a matter of time. Cereal Foods World 39(11):37-39.

Braddock JC, Sims CA, O'Keefe SF. 1995. Flavor and oxidative stability of roasted high oleic acid peanuts. J Food Sci. 60(3):489-493.

Bradley RL. 1998. Moisture and total solids analysis, In: *Food Analysis*., 2nd ed.(Nielsen, S.S., Ed.). Gaithersburg: Aspen Publishers, Inc., pp. 121-133.

Brannan GL, Koehler PE, Ware GO. 1999. Physico-chemical and sensory characteristics of defatted roasted peanuts during storage. Peanut Science 26(1):44-53.

Brene WM. 1975. Application of texture profile analysis to instrumental food texture evaluation. J Texture Stud. 6:53-82.

Broekel R. 1982. The great American candy bar book. Boston: Houghton Mifflin Co. 160 p.

Brown DF, Cater CM, Mattil KF, Darrock JG. 1975. Effect of variety, growing location and their interaction on the fatty acid composition of peanuts. J. Food Sci. 40:1055-1060.

Brunton NP, Cronin DA, Monahan FJ, Durcan R. 2000. A comparison of solid-phase microextraction (SPME) fibers for measurement of hexanal and pentanal in cooked turkey. Food Chem. 68(3):339-345.

Buckholz LL, Daun H. 1981. Instrumental and sensory characteristics of roasted peanut flavor volatiles. ACS symposium seriew. 170:163-181.

Buckholz LL, Duan H, Stier E, Trout R. 1980. Influence of roasting time on sensory attributes of fresh roasted peanuts. J. Food Sci. 45:547-554.

Burroni LV, Grosso NR, Guzman C. 1997. Principal volatile components of raw, roasted, fried Argentinean peanut flavors. J Agricultural and Food Chemistry. 45(8):3190-3192.

Cardelli C, Labuza TP. 2001. Application of Weibull hazard analysis to the determination of the shelf life of roasted and ground coffee. Lebensm.-Wiss. U.-Technol. 34:273-278.

Civille GV, Dus CA. 1992. Sensory evaluation of lipid oxidation in foods. In: St. Angelo AJ, editor. Lipid oxidation in food. Washington, DC: American Chemical Society. P 279-289.

Cobb WY, Johnson BR. 1973. In: Wilson CT, ed. Peanuts: Culture and Uses. Stillwater, Okla, USA: Amer Peanut Res Educ Assoc, Inc. pp. 209-256.

Collins JL, Sanchez JF. 1979. Effects of peanut shell flour on firmness, color and acceptance of peanut butter. J. Food Sci. 44: 944-945.

Crippen KL, Vercellotti JR, Lovegren NV, Sanders TH. 1992. Defining roasted peanut flavor quality. 2. Correlation of GC volatiles and sensory flavor attributes. Developments in Food Sci. 29:211-227.

Dethmers AE. 1979. Utilizing sensory evaluation to determine product shelf life. Food Technol. 33(9):40-42.

Dieckert JW, Morris NJ. 1958. Bitter principles of the peanut. J. Agr. Food Chem. 6:930-933.

Duyvesteyn WS, Shimoni E, Labuza TP. 2001. Determination of the end of shelf-life for milk using Weibull hazard method. Lebensm.-Wiss. U.-Technol. 34:143-148.

Felland Sl, Koehler PE. 1997. Sensory, chemical, and physical changes in increased water activity peanut butter products. J Food Quality 20(2):145-156.

Fisher CH. 1959. Highlights of peanut utilization research. Peanut J. Nut World 38(6):14,16,31-33.

Fontana Jr. AJ. 2000. Understanding the importance of water activity in food. Cereal Foods World 45(1):7-10.

Fore SP, Dupuy HP, Wadsworth JI. 1976. Correlation of volatile components of peanut products with flavor score. I. Shelf life studies on peanut butter. Peanut Sci 3(2):86-89.

Fore SP, Morris NJ, Freeman AF, Brickeford WF. 1953. Factors affecting the stability of crude oils of 16 varieties of peanuts. J. Amer. Oil Chem. Soc. 30: 298-301.

Frankel EN. 1980. Lipid Oxidation. Prog. Lipid Res. 19:1-22.

Freeman AF, Morris NJ, Willich RK. 1954. Peanut butter, U.S. Dept. Agr. AIC-370.

Fritsch CW, Gale TA. 1976. Hexanal as a measure of rancidity in low fat foods. J. Amer. Oil Chem. 54(6):225.

Gacula MC Jr, Kubala JJ. 1975. Statistical models for shelf life failures. J. Food Sci. 40(2):404-409.

Gacula MC Jr, Singh J. 1984. Statistical methods in food and consumer research. Orlando: Academic Press. 505 p.

Gacula MC Jr. 1997. Chp 1.1: Descriptive sensory analysis methods. In Gacula MC Jr, editor. Descriptive sensory analysis in practice. Food & Nutrition Press. p. 5-13.

Galvez FCF, Resurreccion AVA, Koehler PE. 1990. Optimization of procession of peanut beverage. J. Sensory Studies 5: 1-17.

Garthwaite, PH. 1994. An interpretation of Partial Least Squares. J American Statistical Assoc. 89(426):122-127.

Gills AG. 1998. Texture of unstabilized peanut butter and peanut butter stabilized with palm oil. M.S. Thesis, University of Georgia, Athens. 147 pp.

Gills LA, Resurreccion AVA. 2000. Sensory and physical properties of peanut butter treated with palm oil and hydrogenated vegetable oil to prevent oil separation. J Food Sci. 65(1):173-180.

Greenspan L. 1977. Humidity fixed points of binary saturated aqueous solutions. J Res of the National Bureau of Standards - A. Physics and Chemistry. 81(A):89-96.

Griffiths N. 1985. Sensory analysis in measuring shelf-life. Food, Flavours, Ingredients, Packaging and Processing. 7(9):47-48.

Grosso NR, Resurreccion AVA. 2002. Predicting consumer acceptance ratings of cracker coated and roasted peanuts from descriptive analysis and hexanal measurements. J Food Sci. 67(4): 1530-1537.

Harris NE, Westcott DE, Henick AS. 1972. Rancidity in almonds: shelf life studies. J Food Sci 37(6):824-827.

Hatcher L, Stepanski EJ. 1994. A step-by-step approach to using the SAS system for univariate and multivariate statistics. Chicheter; New York: John Wiley. Pp. 449-503.

Hodge JE. 1953. Dehydrated foods. Chemistry of browning reactions in model systems, *J. Agric. Food Chem.,* 1:928-943.

Hokes JC, MS Thesis University of Georgia, Athens, GA, 1977.

Holaday CE, Pearson JL. 1974. Effects of genotype and production area on the fatty acid composition, total oil and total protein in peanuts. J Food Sci 39(6):1206-1209.

Holt SD, Resurreccion AVA, McWatters KH. 1992. Formulation, evaluation and optimization of tortillas containing wheat, cowpea and peanut flours using mixture response surface methodology. J Food Sci. 57(1):121-127.

Hung YC, Chinnan MS. 1989. Mechanical texture measurement of whole and chopped peanuts. Peanut Sci. 16(2):32-37.

IFT. 1974. Shelf life of foods. Inst. Of Food Technologists Expert Panel on Food Safety and Nutrition. J. Food Sci. 39:861.

Ingham JL. 1976. 3,5,4'-trihydroxstilbene as a phytoalexin form groundnuts (*arachis hypogaea*). Phytochemistry. 15:1791-1793.

Jia M, Zhang H, Min DB. 1998. Optimization of solid-phase microextraction analysis for headspace flavor compounds of orange juice. J. Agric. Food Chem. 46(7):2744-2747.

Johnsen PB, Civille GV, Vercellotti JR, Sanders TH, Dus CA. 1988. Development of a lexicon for the description of peanut flavor. J Sensory Stud. 3:9-17.

Katz EE, Labuza TP. 1981. Effect of water activity on the sensory crispness and mechanical deformation of snack food products. J Food Sci 46(2):403-409.

Keen NT, Ingham JL. 1976. New stilbene phytoalexins from American cultivars of *Arachis hypogaea.* Phytochemisty 15: 1794-1795.

Koehler PE, Mason ME, Odell GV. 1971. Odor threshold levels of pyrazine compounds and assessment of their role in the flavor of roasted foods. J Food Sci. 36(5):816-818.

Koelsch CM. Downes TW, Labuza TP. 1991. Hexanal formation via lipid oxidation as a function of oxygen concentration: measurement and kinetics. J Food Sci. 56(3):816-820.

Kolsky JD. (2000) Using partial least squares regression in consumer research. Camo White Paper. Available at http://www.camo.com/PLSwhitepaper.PDF. Accessed August 2002.

Kritchevski D, Tepper SA, Vesselinovitch D, Wissler RW. Atherosclerosis 1971: 14-53.

Ku KL, Lee RS, Young CT, Chiou RYY. Roasted peanut flavor and related compositional characteristics of peanut kernels of spring and fall crops grown in Taiwan. J Agricultural and Food Chemistry. 46(8):3220-3224.

Labuza TP, Hyman CR. 1998. Moisture migration and control in multi-domain foods. Trends in Food Sci & Technol. 9(2):47-55.

Labuza TP, McNally L, Gallagher D, Hawkes J, Hurt F. 1972. Stability of intermediate moisture foods. 1. Lipid Oixidation. J. Food Sci 37(1):154-159.

Labuza TP, Riboh D. 1982. Theory and application of Arrhenius kinetics to the prediction of nutrient losses in foods. Food Technol. 36(10):66, 68, 70, 72, 74.

Labuza TP, Schmidl MK. 1985. Accelerated shelf-life testing of foods. Food Technol. 39(9):57-64, 134.

Labuza TP, Kaanane A, Chen JY. 1985. Effect of temperature on the moisture sorption isotherms and water activity shift of two dehydrated foods. J. Food Sci. 50: 385-391.

Labuza TP, Schmidl MK. 1988. Use of sensory data in the shelf life testing of foods: principles and graphical methods for evaluation. Cereal Foods World 33(2): 193-206

Labuza TP, Szybist LM. 1999. Playing the open dating game. Food Technol. 53(7):70-72, 74, 76, 78, 80, 85.

Labuza TP, Tannenbaum SR, Karel M. 1970. Water content and stability of low-moisture & intermediate-moisture foods. Food Technol. 24:543-548,550.

Labuza TP. 1971. Kinetics of lipid oxidation in foods. CRC Crit. Rev. in Food Tech. 2:355-394.

Labuza TP. 1980. The effect of water activity on reaction kinetics of food deterioration. Food Technol. 34(4):36-41,59.

Labuza TP. 1982. Moisture gain and loss in packaged foods. Food Technol. 36(4):92-94, 96-97.

Labuza TP. 1982. Shelf-Life Dating of Foods. Food and Nutrition Press, Westport, CT.

Labuza TP. 2001. Standard Desiccator Method for Isotherms. Available from: http://fscn1.fsci.umn.edu/ted_Labuza/awimages/Salt%20solutions%20FOR%20Isotherm.pdf. Accessed Jan 16.

Labuza TP. 2002. Topic 8: Design of accelerated shelf life tests. Available from http://courses.che.umn.edu/00fscn8334-1f/Topics_Folder/Topic%208%20%20ASLT%20and%20Sensory.pdf. Accessed Feb 18.

Langcake P, Pryce RJ. 1976. The production of resveratrol by Vitis vinifera and other members of the Vitaceae as a response to infection or injury. Physiological Plant Pathology 9:77-86.

Lee CM, Resurreccion AVA. 2001. Improved correlation between sensory and instrumental measurement of peanut butter texture. J Food Sci. 57(5): 1939-1949.

Lee SY, Trezza TA, Guinard, J.-X., Krochta, JM. 2002. Whey-protein-coated peanuts assessed by sensory evaluation and static headspace gas chromatography. In press.

Lund DB. 1977. Design of thermal processes for maximizing nutrient retention. Food Technol. 31(2):71-72, 74, 76-78.

Malundo TM, Resurreccion AVA. 1992. A comparison of performance of panels selected using analysis of variance and cluster analysis. J Sensory Stud. 7:63-75.

Mason ME, Johnson B, Hamming M. 1966. Flavor components of roasted peanuts. Some low molecular weight pyrazines and a pyrrole. J. Agric. Food Chem 14:454

Mate JL, Frankel EN, Krochta JM. 1996. Whey protein isolate edible coatings: effect on the rancidity process of dry roasted peanuts. J. Agric. Food Chem. 44:1736-1740.

Maxcy RB, Wallen SE. 1983. Heterogeneity of samples as a problem in shelf-life prediction. J Food Prot. 46:542-544.

McNeill KL, Sanders TH, Civille GV. 2002. Descriptive analysis of commercially available creamy style peanut butters. J Sensory Stud. 17:391-414.

McWatters KH. 1983. Diversified food uses for peanuts. In: Woodroof, J.G., Ed., *Peanuts: Production, Processing, Products.,* 3rd ed., Connecticut: AVI Publishing Company Inc. pp. 309-336.

Meilgaard M, Civille GV and Carr BT. 1991. Sensory Evaluation Techniques, 2nd ed. CRC Press, Boca Raton, FL. 354 p.

Minifie BW. 1999. Chocolate, cocoa, and confectionery: science and technology. 3rd ed. Maryland: Aspen Publishers. 904 pp.

Mitchell JH, Rosalind K, Malphrus RK. 1977. Lipid oxidation in Spanish peanuts: the effect of moist heat treatments. J. Food Sci. 42(6): 1457-1461.

Moskowitz HR. 1983. *Product Testing and Sensory Evaluation of Foods, Marketing and R&D Approaches*. Connecticut: Food & Nutrition Press, Inc. 605 p.

Moskowitz HR. 1997. Experts versus consumers: a comparison. J Sensory Stud. 12(1):155-168.

Muego-Gnanasekharan KF, Koehler PE, Resurreccion AVA. 1990. Effect of temperature, time and number of water extractions on the physicochemical and flavor characteristics of peanuts. J Food Sci 55(3):790-792.

Muego-Gnanasekharan KF, Resurreccion AVA, Garcia VV, del Rosario R. 1994. Consumer acceptance and storage stability of a cheese-flavored spread made from peanuts. Food Quality and Preference 4:111-117.

Mugendi JB, Sims CA, Gorbet DW, O'Keefe SF. 1998. Flavor stability of high-oleic peanuts stored at low humidity. J. Am. Oil Chem. Soc. 75(1):21-25.

Nawar WW. 1996. Chp 5: Lipids. In: Fennema O, editor. Food chemistry. 3rd ed. New York: Marcel Dekker. p 225-320.

Neucere NJ, Ory RL, Carney WB. 1969. Effect of roasting on the stability of peanut proteins. J. Agric. Food Chem. 17(1): 25-28.

Norden AJ, Gorbet DW, Knauft DA, Young CT. 1987. Variability in oil quality among peanut genotypes in the Florida breeding program. Peanut Science 14(1):7-11.

O'Mahony M, Thieme U, Goldstein LR. 1988. The warm-up effect as a means of increasing the discriminability of sensory difference tests. J. Food Sci. 53(6): 1848-1850.

Ory RL, St. Angelo AJ. 1982. Effects of lipid oxidation on proteins of oilseeds, In: Cherry, J.P., Ed., *Food Protein Deterioration Mechanisms and Functionality*, Washington, D.C.: American Chemical Society. 1982. pp. 55-67.

Pancholy SK, Deshpande AS, Krall S. 1978. Amino acids, oil and protein content of some selected peanut cultivars. Proc. Amer. Peanut Res. and Education Association 10: 30-37.

Pattee HE, Giesbrecht FG, Isleib TG. 1999. Sensory attribute variation in low-temperature-stored roasted peanut paste. J Agric. Food Chem. 47(6):2415-2420.

Pattee HE, Johns EB, Singleton JA, Sanders TH. 1974. Composition changes of peanut fruit parts during maturation. Peanut Sci 1:57-62.

Pattee HE, Purcell AE 1967. Carotenoid pigments of peanut oil. J. Amer. Oil Chem. Soc. 44:328-330.

Pattee, HE, Purcell AE, Johns EB. 1969. changes in carotenoid and oil content during maturation of peanut seeds. J. Amer. Oil chem. Soc. 46:629-631.

Pearce JH, Korth B, Warren CB. 1986. Evaluation of three scaling methods for hedonics. J Sensory Studies 1: 27-46.

Petersen MA, Tonder D. Poll L. 1998. Comparison of normal and accelerated storage of commercial orange juice - changes in flavour and content of volatile compounds. 9(1/2):43-51.

Pickett TA 1941. Vitamins in peanuts. Georgia Expt. A. Circ. 128.

Pickett TA, Holley KT. 1952. Peanut roasting studies. Georgia Agr. Expt. Sta. Tech. Bull. 1.

Plemmons LE, Resurreccion AVA. 1998. A warm-up sample improves reliability of responses in descriptive analysis. J Sensory Stud 13:359-376.

Prell PA. 1976. Preparation of reports and manuscripts which include sensory evaluation data. Food Technology 30(11):40-48.

Rainey BA. 1986. Importance of reference standards in training panelists, In: Gacula, M.C., *Descriptive Sensory Analysis in Practice,* Connecticut: Food & Nutrition Press, Inc. pp71-76.

Ramos AAT. 1995. Lipid Oxidation in roasted peanuts coated with edible films. M.S. Thesis, University of Georgia, Athens. p 14-68. 102 pp.

Reed KA, Sims CA, Gorbet DW, O'Keefe SF. 2002. Storage water activity affects flavor fade in high and normal oleic peanuts. Food Research International 35:769-774.

Ringe ML, Love MH. 1988. Kinetics of protein quality change in an extruded cowpea-corn flour blend under varied steady-state storage conditions. J Food Sci. 53(2):584-588.

Saguy I, Karel M. 1980. Modeling of quality deterioration during food processing and storage. Food Technol. 34(2):78-85.

Sahasrabubhe MR, Farn IG. 1964. Effect of heat on triglycerides of corn oil. J. Amer. Oil Chem. Soc. 41(4):264-267.

Sanders TH, Blankenship PD, Vercellotti JR, Crippen KL. 1990. Interaction of curing temperature and inherent maturity distributions on descriptive flavor of commercial grade sizes of florunner peanuts. Peanut Sci 17(2):85-89.

Sanders TH, Lansden JA, Greene RL, Drexler JS, Williams EJ. 1982. Oil Characteristics of Peanut Fruit Separated by a Nondestructive Maturity Classification Method. Peanut Sci. 9:20-23.

Sanders TH, McMichael RW, Hendrix KW. 2000. Occurrence of Resveratrol in Edible Peanuts. Journal of Agriculture and Food Chemistry 48:1243-1246.

Sanders TH, Vercellotti JR, Crippen KL, Civille GV. 1989. Effect of maturity on roast color and descriptive flavor of peanuts. J Food Sci 54(2):475-477.

Sanders TH, Vercellotti JR, Crippen KL, Hinsch RT, Rasmussen GK, Edwards, JH. 1992. Quality factors in exported peanuts from Argentina, china and the United States. J. Amer. Oil Chem. Soc. 69(10):1032-1035.

Sanders TH, Vercellotti JR, Grimm DT. 1993. Shelf life of peanuts and peanut products. Developments in Food Sci 33:289-309.

Sanders TH. 1982. Peanut Triacylglycerols: effect of season and production location. J. Amer. Oil Chem. Soc. 59(8):346-51.

Sanders TH. 1980. Fatty Acid Composition of Lipid Classes in Oils from Peanuts Differing in Variety and Maturity. J. Amer. Oil Chem. Soc. 57(1):12-15

Sanders TH. 1979. Varietal differences in peanut triacylglycerol structure. American Oil Chemists' Society. Lipids 14(7):630-633.

Sanders TH. 1983. The aflatoxin crisis. In: Woodroof, J.G., Ed., *Peanuts: Production, Processing, Products.,* 3rd ed. Connecticut: AVI Publishing Company, 151-162.

Santos BL, Resurreccion AVA. 1989. Effect of particle size on the quality of peanut pastes. J Food Quality 12:87-97.

Schaub J. 1990. The peanut program and its effects. FoodReview 13(1):37-40.

Seymour SK, Hamann DD. 1988. Crispness and crunchiness of selected low moisture foods. J. Text. Stud. 19:79-95.

Seymour SK, Hamann DD. 1988. Crispness and crunchiness of selected low moisture foods. J. Text. Stud. 19:79-95.

Shahidi F, Janitha PK, Wanasundara PD. 1992. Phenolic antioxidants, Crit. Rev. Food Sci. Nutr. 32(1): 67-103.

Shand PJ, Hawrysh ZJ, Hardin RT, Jeremiah LE. 1985. Descriptive sensory assessment of beef steaks by category scaling, line scaling and magnitude estimation. J. Food Sci. 50(2): 495-500.

Sheppard AJ, Rudolf TS. 1991. Analysis of peanuts and peanut products for total lipids, fatty acids and proximates. Peanut Sci 18:51-54.

Shewfelt AL, Young CT. 1977. Storage stability of peanut-based foods: a review. J Food Sci. 42(5):1148-1152.

Singh RP. 1996. Computer applications in food technology – use of spreadsheets in graphical, statistical, and process analysis. New York: Academic Press. 302 pp.

Singh RP. 2000. Chp. 1: Scientific principles of shelf-life evaluation. In: Man CMD, Jones AA, editors. Shelf-life evaluation of foods. 2nd ed. Gaithersburg: Aspen. P. 3-22.

Sobolev VS, Cole RJ. 1999. Trans-Resveratrol Content in Commercial peanuts and Peanut Products. Journal of Agriculture and Food Chemistry 47(4):1435-1439.

St. Angelo AJ, Kuck JC, Ory RL. 1977. Enzymes and oxidative stability of peanut products. In: Gould RF, editor. Enzymes in Food and Beverage Processing. Gould RF, ed. American Chemical Society, Washington, DC. pp. 229-243.

St. Angelo AJ, Ory RL. 1975. Effect of minor constituents and additives upon peroxidation of oil in peanut butter. J. Amer. Oil Chem. Soc. 2:38-40

St. Angelo AJ, Ory RL. Brown LE. 1972. A comparison of minor constituents in peanut butter as possible sources of fatty acid peroxidation. J. Amer. Peanut Res. And Educ. Assoc. 4(1):186-194.

St. Angelo AJ. 1996. Lipid oxidation in foods. Critical Reviews in Food Science and Nutrition 36(3):175-224.

St. Angelo, A. J., Kuck, J. C., and Ory, R. L., Enzymes and oxidative stability of peanut products, in Enzymes in food and Beverage Processing, Ory, R.L. and St. Angelo, A.J., Eds., ACS Symposium Ser. 47. American Chemical Society, Washington, D.C., 1977, 229.

St. Angelo, A. J., Kuck, J. C., and Ory, R. L., Role of lipoxygenase and lipid oxidation in quality of oilseeds. J. Agric. Food Chem., 27, 229, 1979.

Stansbury MT, Field ET, Guthrie JD. 1950. The tannin and related pigments in the red skins (testa) of peanut kernels. J. Am. Oil. Chemists' Soc. 27:317-321.

Stone H., Sidel JL. 1993. Sensory Evaluation Practices. 2nd ed. San Diego: Academic Press. 338 p.

Szczesniak AS, Brandt MA, Friedman HH. 1963. Development of standard rating scales for mechanical parameters of texture and correlation between the objective and the sensory methods of texture evaluation. J Food Sci (28):397-403.

Taoukis P, Labuza TP. 1996. Chp. 17: Summary: Integrative Concepts. In: Fennema OR. Editor. Food Chemistry. 3rd ed. New York: Marcel Dekker. P. 1013-1042.

Thybo AK, Martens M. 2000. Analysis of sensory assessors in texture profiling of potatoes by multivariate modeling. Food Quality & Preference 11:283-288.

Tobias RD. 1997. *An introduction to partial least squares regression*. Cary, NC: SAS Institute.

Vickers ZM. 1984. Crispness and crunchiness - a difference in pitch? J Texture Stud. 15(1):157-163.

Vivar ER de, Brennan JG. 1980. Instrumental textural measurement - a brief study on peanuts. IFST Proceedings 13(3):213-218.Warner KJH, Dimick PS, Ziegler GR, Mumma RO, Hollender R. 1996. 'Flavor-fade' and off-flavors in ground roasted peanuts as related to selected pyrazines and aldehydes. J Food Sci 61(2):469-472.

Warner KJH, Dimick PS, Ziegler GR, Mumma RO, Hollender R. 1996. 'Flavor-fade' and off-flavors in ground roasted peanuts as related to selected pyrazines and aldehydes. J Food Sci 61(2):469-472.

Woodroof JG. 1983. Peanuts production, processing, products, 3rd Ed. Westport: The AVI Publishing Co., Inc.

Young CT, Hammons RO. 1973. Variations in the protein levels of a wide range of peanut genotypes. Oleagineux 28:293-297.

Young CT, Hovis AR. 1990. A method for rapid analysis of headspace volatiles of raw and roasted peanuts. J. Food Sci 55(1):279-280.

Young CT, Worthington RE, Hammons RO, Matlock RS, Waller GR, Morrison RD. 1974. Fatty acid composition of Spanish peanut oils as influenced by planting location, soil moisture conditions, variety, and season. J Am Oil Chem Soc 51(7):312-315.

TABLE 2.1
Proximate Composition of Peanuts

Constituents	Percentage
Moisture	5.0%
Protein	28.5%
Lipids	47.5%
Crude fiber	2.8%
Nitrogen-free extract	13.3%
Ash	2.9%
Reducing sugars	0.2%
Disaccharide sugar	4.5%
Starch	4.0%
Pentosans	2.5%

From Freeman and others 1954

TABLE 2.2
Fatty Acid Composition of Peanuts

Constituents	Percentage of Total Fatty Acids
Palmitic (16:0)	9.0-12.2%
Stearic (18:0)	1.3-3.2%
Oleic (18:1)	41.1-61.7%
Linoleic (18:2)	23.4-41.9%
Arachidic (20:0)	0.8-2.0%
Eicosenoic (20:1)	0.7-2.2%
Behenic (22:0)	1.5-3.1%

From Brown and others 1975

Table 2.3
Amino Acids Composition of Peanuts

Constituents	Percent of total Amino acids
Lysine	3.53%
Histidine	2.44%
Arginine	9.19%
Aspartic acid	10.18%
Threonine	4.16%
Serine	4.24%
Glutamic acid	20.12%
Proline	3.91%
Glycine	5.13%
Alanine	3.91%
Valine	3.70%
Methionine	0.79%
Isoleucine	3.04%
Leucine	5.92%
Tyrosine	3.70%
Phenylalanine	5.06%
Tryptophan	0.88%

From Pancholy and others 1980

Table 2.4
Moisture Content of Peanuts and Peanut Products

Product	Range
Freshly dug peanuts	30-39
Cured peanuts in stacks	5-10
Water blanched peanuts	5-8
Unshelled peanuts in warehouse	5-7
Shelled peanuts in warehouse	5-6
Dry-blanched peanuts	3-4
Peanut flour	4.5-7.3
Unshelled roasted peanuts	0.5-1.0
Shelled, roasted, salted peanuts	0.5-2.0
Peanut butter	0.5-2.0
Peanut brittle	1.5-2.5
Peanut roll, peanuts exposed	5.5-6.5
Chocolate covered bar, fondant center with whole or crushed peanuts	4.0-5.0
Chocolate covered bar, crisp candy center with ground peanuts	1.0-2.0
Hard candy coat	1.0-2.0
Peanut butter	1.0-2.0
Ground peanuts in candy center	1.0-2.0
Peanuts individually coated with sugar, hard candy, or chocolate	1.5-2.5
Uncoated peanut roll	5.9
Chocolate covered peanuts	0.9
Chocolate coated nut roll	5.1

From Woodroof 1983.

TABLE 2.5
Inorganic Constituents of Peanut Kernels

Constituents	Range (mg/100 g)
Potassium	680-890
Sodium	Trace
Calcium	20-80
Magnesium	90-340
Phosphorus	250-660
Sulfur	190-240
Chlorine	Trace
Silica Dioxide	80
Zinc	1.7-80
Manganese	0.8-50
Iron	1.8-100
Cobalt	0.03
Copper	0.7-30
Boron	2.6-50
Fluorine	0.14
Iodine	0.02
Strontium	0.8-5
Barium	8-30
Vanadium	10-50
Chromium	1-30
Aluminum	100
Nickel	3-8
Titanium	30-80
Molybdenum	0.8-3
Tin	0-5
Lead	0-50

From Freeman and others 1954

Table 2.6
Lexicon of Roasted Peanut Descriptors

Descriptor	Definition
AROMATICS	
Roasted peanutty	The aromatic associated with medium-roast peanuts (about 3-4 on USDA color chips) and having fragrant character such as methyl pyrazine
Raw bean/peanutty	The aromatic associated with light-roast peanuts (about 1-2) on USDA color chips) and having legume-like character (specify beans or pea if possible.)
Dark roasted peanut	The aromatic associated with dark-roasted peanuts (4+ on USDA color chips) and having very browned or toasted character.
Sweet aromatic	The aromatics associated with sweet material such as caramel, vanilla, molasses, fruit (specify type).
Woody/hulls/skins	The aromatics associated with base peanut character (absence of fragrant top notes) and related to dry wood, peanut hull, and skins.
Cardboard	The aromatic associated with somewhat oxidized fats and oils and reminiscent of cardboard.
Painty	The aromatic associated with linseed oil, oil based paint.
Burnt	The aromatic associated with very dark roast, burnt starches, and carbohydrates, (burnt toast or espresso coffee).
Green	The aromatic associated with uncooked vegetables, grasstwigs, *cis*-3-hexanal.
Earthy	The aromatic associated with wet dirt and mulch.
Grainy	The aromatic associated with raw grain (bran, starch, corn, sorghum).
Fishy	The aromatic associated with trimethylamine, cod liver oil, or old fish.
Chemical/plastic	The aromatic associated with plastic and burnt plastics.
Skunky/mercaptan	The aromatic associated with sulfur compounds, such as mercaptan, which exhibit skunk-like character.
TASTES	
Sweet	The taste on the tongue associated with sugars.
Sour	The taste on the tongue associated with acids.
Salty	The taste on the tongue associated with sodium ions
Bitter	The taste on the tongue associated with bitter agents such as caffeine or quinine
CHEMICAL FEELING FACTORS	
Astringent	The chemical feeling factor on the tongue, described as puckering/dry and associated with tannins or alum.
Metallic	The chemical feeling factor on the tongue described as flat, metallic and associated with iron and copper.

(Johnsen and others 1988)

Table 2.7
Lexicon of Peanut Butter Descriptors – Appearance and Flavor

Descriptor	Definition
Color	
Description	The actual color name or hue, such as red, blue, etc.
Intensity	The intensity or strength of the color from light to dark.
Chroma	The chroma or purity of the color, ranging from dull, muddled to pure, bright color.
Gloss	Amount of light reflected from the product's surface.
Visible Particles	The amount of particles in the surface.
Aromatics	
Roasted Peanutty	The aromatic associated with medium-roast and having fragrant character such as methyl pyrazine.
Raw Bean	The aromatic associated with light-roast peanuts and having legume-like character.
Dark Roast	The aromatic associated with dark-roasted peanuts and having very browned or toasted character.
Sweet Aromatic	The aromatics associated with sweet material such as caramel, vanilla, molasses, and fruit.
Woody/Hulls/Skins	The aromatics associated with base peanut character (absence of fragrant top notes) and related to dry wood, peanut hull, and skins.
Fruity-fermented	The aromatics characterized by fermentation (alcohol) and/or reminiscent of fruit.
Phenolic	The aromatic associated with plastic and burnt plastic.
Cardboardy	The aromatic associated with somewhat oxidized fats and oils and reminiscent of cardboard.
Burnt	The aromatic associated with very dark roast, burnt starches, and carbohydrates.
Mustry	The aromatic associated with wet dirt and mulch.
Green	The aromatic associated with uncooked vegetables, grass and twigs.
Painty	The aromatic associated with linseed oil and oil based paint.
Soy	The aromatic associated with raw or cooked soybean.
Basic Tastes	
Sweet	The taste on the tongue associated with sugars.
Sour	The taste on the tongue associated with acids.
Salty	The taste on the tongue associated with sodium ions
Bitter	The taste on the tongue associated with bitter agents such as caffeine or quinine
Chemical Feeling Factors	
Astringent	The chemical feeling factor on the tongue, described as puckering/dry and associated with tannins or alum.
Heat/Burn	The burning sensation in the mouth caused by certain substances, such as capsacin from red to piterin from black peppers; mild heat or warmth is caused by some brown spices

(McNeill and others 2002)

Table 2.8
Lexicon of Peanut Butter Descriptors – Oral Texture

Descriptor	Definition
Surface	***Hold ¼ tsp on spoon; feel surface with lips and evaluate for***[a]
Stickiness to lips[a,b]	The amount of which sample adheres to lips
Oiliness[a,b]	Amount of oiliness/moistness on surface
Roughness[a,b,c]	Amount of particles in surface
First Compression	***Place ¼ tsp of peanut butter in mouth and compress between tongue and patate; evaluate for***[a]
Firmness[a,b,c]	Force to compress sample.
Cohesiveness[a,b,c]	Amount of sample deforms rather than shears/cuts.
Slipperiness[a,b,c]	Amount which products slides across tongue
Denseness[c]	Compactness of the cross section
Adhesiveness (palate)[a,b,c]	Amount of force to remove sample from roof of mouth.
Stickiness[a,b]	Amount of product that adheres to all oral surfaces
Breakdown	***Manipulate between tongue and palate 7 times; evaluate for***[a]
Mixes with Saliva[c]	Amount of saliva which mixes with sample
Adhesiveness of Mass[a,b,c]	Degree sample sticks to palate; force to remove from palate.
Cohesiveness of Mass[a,b,c]	Degree mass holds together.
Roughness of Mass[b]	Amount of particles on the surface of the mass.
Residual	***Manipulate between tongue and palate until before swallowing, evaluate for***[a]
Cohesiveness of mass[a,b,c]	Degree to which a substance is compressed between the teeth after manipulating between tongue and palate 7 times, or its ability to stick to itself after 7 chews.
Adhesiveness of mass[a,b,c]	Force required to remove the material that adheres to the mouth (palate, teeth) after 7 chews.
Loose Particles[c]	Amount of particles left on mouth surface.
Oil Film[c]	Amount of oil film on oral surfaces.
Chalky Film[c]	Amount of chalk film on oral surfaces.
Swallow	***Feel mouth surface and teeth with tongue after product is expectorated; evaluate for***[a]
Oiliness[a,d]	Amount of oil film on oral surfaces
Adhesiveness to teeth[a,b]	Amount of product left on the teeth before you are ready to expectorate

[a]Lee and Resurreccion, 2001.
[b]Meilgaard and others 1991
[c]McNeill and others 2002
[d]Gills, 1998.

TABLE 2.9
Shelf Life of Roasted Peanuts Determined Using Sensory and Instrumental Methods

Type of Test	Temperature (°C)	Relative Humidity(%)	Exposure to Atmosphere	Shelf life (days)	Criteria for Shelf Life Determination	Notes
Sensory	25	12	Open	70[2]	Cardboardy>5.0 on 10-point scale Painty>5.0 on 10-point scale	High Oleic Peanuts
	25	40	Open	47[3]	Peanutty<6.0 on 15-point scale	
	25	52	Open	70[2]	Painty>5.0 on 10-point scale	High Oleic Peanuts
	25	67	Open	70[2]	Cardboardy>5.0 on 10-point scale Painty>5.0 on 10-point scale	High Oleic Peanuts
	38	n/a	Open	14[1]	n/a	
	40	n/a	Closed	21[4]	Regression of descriptive ratings on oxidized, painty with consumer rating<6.0	
Survey	10	60	Closed	90[5]	n/a	
	n/a	n/a	Closed	84[6]	n/a	
Instrumental	25	40	Open	32[3]	Peroxide value >10	
	25	29-38	Open	136[8]	Change from initiation to propagation, Arrhenius-hexanal level	
	40	29-38	Open	70[8]	Change from initiation to propagation, Arrhenius-hexanal level	
	50	29-38	Open	47[8]	Change from initiation to propagation, Arrhenius-hexanal level	
	30	n/a	n/a	177.1[7]	Hexanal level>15ppm	
	40	n/a	Closed	28[4]	Regression of hexanal measurement with consumer rating<6.0	
Unknown	23	n/a	n/a	21[9]	Salted peanuts	

[1]Baker and others, 2002
[2]Braddock and others 1995
[3]Grosso and Resurreccion, 2002
[4]Anon., 1978
[5]Anon., 1971
[6]Ramos, 1995
[7]Lee and others, 2002.
[8]Shewfelt & Young, 1977

Table 2.10
Temperature Dependence of Water Activity of Selected Saturated Salt Slurries

	Water activity at		
Saturated salt	**23ºC**	**30ºC**	**40ºC**
Potassium carbonate[1]	0.44	0.44	0.43
Magnesium nitrate[1]	0.54	0.53	0.51
Sodium bromide[2]	0.58	0.56	0.53
Sodium nitrate[1]	0.67	0.64	0.61
Potassium iodide[2]	0.69	0.68	0.66
Sodium chloride[1]	0.77	0.75	0.73
Ammonium sulfate[2]	0.81	0.81	0.80

[1]Estimated from regression equations from Labuza and others (1985)
[2]From Greenspan (1977)

TABLE 2.11
Volatile Compounds Identified as Influential on the Quality of Fresh and Stored Roasted Peanut

Compounds	References
1-hexanol	Burroni and others 1997
1-methylpyrrole	Brannan and others 1999; Burroni and others 1997
2,3,5-trimethylpyrazine[2]	Warner and others 1996; Baker and others 2003
2,3-dihydrobenzofuran	Braddock and others 1995
2,3-dimethylpyrazine	Braddock and others 1995 ; Baker and others 2003
2,5-dimethylpyrazine	Braddock and others 1995; Brannan and others 1999 ; Baker and others 2003
2,6-dimethylpyrazine[2]	Burroni and others 1997
2-ethyl-3-methylpyrazine[2]	Buckholz and others 1980; Braddock and others 1995; Warner and others 1996.
2-ethyl 3,6-dimethylpyrazine	Buckholz and others 1980
2-ethyl-5-methypyrazine	Braddock and others 1995
2-ethyl-6-methylpyrazine	Buckholz and others 1980; Buckholz & Daun 1981
2-methylpyrazine[2]	Brannan and others 1999 ; Baker and other 2003
2-octanone (2-octanone)	Bett & Boylston 1992
2-vinyl-3,6(5)-dimethyl pyrazine	Buckholz and others 1980
3-ethyl-2,5-dimethylpyrazine	Braddock and others 1995
3-methylpyridine	Braddock and others 1995
4-ethyl-2,5-dimethyl-isoxazolidine	Burroni and others 1997
Acetic acid	Burroni and others 1997; Braddock and others 1995
Benzaldehyde	Braddock and others 1995
Benzeneacetaldehyde	Braddock and others 1995
Benzothiazole	Braddock and others 1995
Dimethylpyrazine	Koehler and others 1971
Ethanol	Brannan and others 1999
Ethylpyrazine	Braddock and others 1995
Heptanal (heptaldehyde) [1]	Warner and others 1996
Hexanal (caproaldehyde) [1]	Bett & Boylston 1992; Brannan and others 1999
(capronaldehyde)	Buckholz and others 1980; Burroni and others 1997 Ramos 1995; Warner and others 1996
Isovaleraldehyde	Buckholz and others 1980
Methylbutanal	Crippen and others 1992
Methylpropanal	Crippen and others 1992
Methylpyrazine	Braddock and others 1995
n-methypyrrole	Crippen and others 1992; Young and Hovis 1990
Nonanal (nonylaldehyde) [1]	Warner and others 1996
Octanal (capryladehyde) [1]	Bett & Boylston 1992; Warner and others 1996
Pentanal (valeraldehyde) [1]	Buckholz & Daun 1981
Phenyl acetaldehyde	Buckholz and others 1980
Pyridine	Brannan and others 1999

[1]Compounds identified as related to roasted peanut oxidative aroma (Warner and others 1996). In addition, there were 5 unknown compounds listed by Warner and others (1996).
[2]Compounds identified as related to roasted peanut aroma (Warner and others 1996). In addition, there were 4 unknown compounds listed by Warner and others (1996).

FIGURE 2.1
SPREADSHEET FOR CALCULATION OF EXPECTED ACCELERATED SHELF LIFE AT A HIGHER WATER ACTIVITY (Adapted from Singh, 2000)

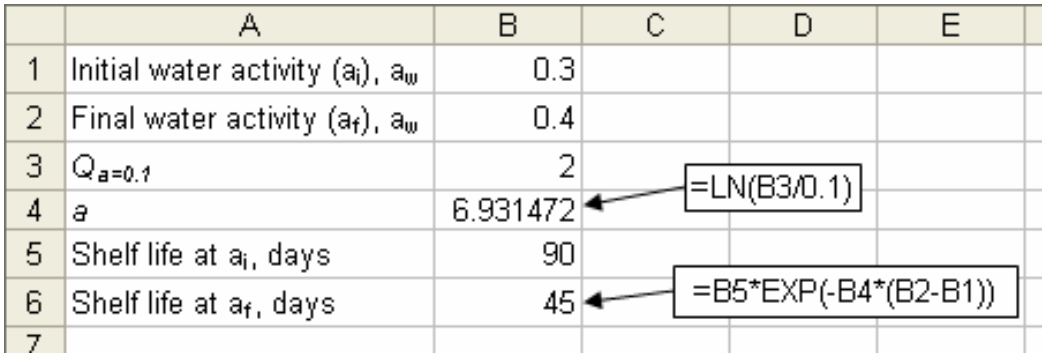

A
B
C
D
E
1 Initial water activity (a_i), a_w 0.3
2 Final water activity (a_f), a_w 0.4
3 $Q_{a=0.1}$ 2
4 a 6.931472
5 Shelf life at a_i, days 90
6 Shelf life at a_f, days 45
=LN(B3/0.1)
=B5*EXP(-B4*(B2-B1))

FIGURE 2.2
DECISION TREE FOR THE CONDUCTING THE WEIBULL HAZARD METHOD OF SHELF LIFE STUDY

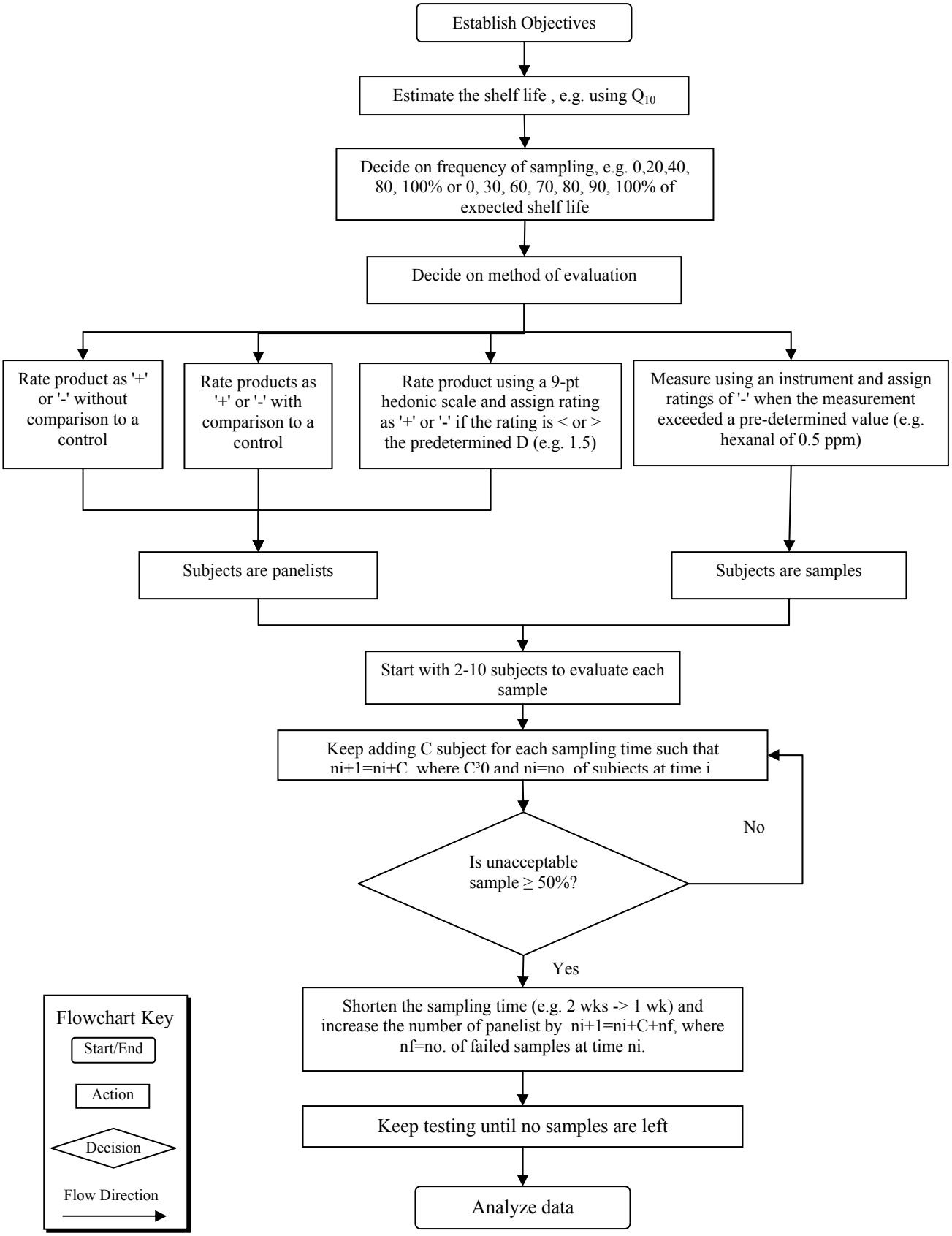

Establish Objectives
Estimate the shelf life , e.g. using Q_{10}
Decide on frequency of sampling, e.g. 0,20,40, 80, 100% or 0, 30, 60, 70, 80, 90, 100% of expected shelf life
Decide on method of evaluation
Rate product as '+' or '-' without comparison to a control
Rate products as '+' or '-' with comparison to a control
Rate product using a 9-pt hedonic scale and assign rating as '+' or '-' if the rating is < or > the predetermined D (e.g. 1.5)
Measure using an instrument and assign ratings of '-' when the measurement exceeded a pre-determined value (e.g. hexanal of 0.5 ppm)
Subjects are panelists
Subjects are samples
Start with 2-10 subjects to evaluate each sample
Keep adding C subject for each sampling time such that ni+1=ni+C, where C≥0 and ni=no. of subjects at time i
Is unacceptable sample ≥ 50%?
No
Yes
Shorten the sampling time (e.g. 2 wks -> 1 wk) and increase the number of panelist by ni+1=ni+C+nf, where nf=no. of failed samples at time ni.
Keep testing until no samples are left
Analyze data
Flowchart Key
Start/End
Action
Decision
Flow Direction

FIGURE 2.3
DECISION TREE FOR THE CALCULATIONS OF WEIBULL HAZARD METHOD DATA

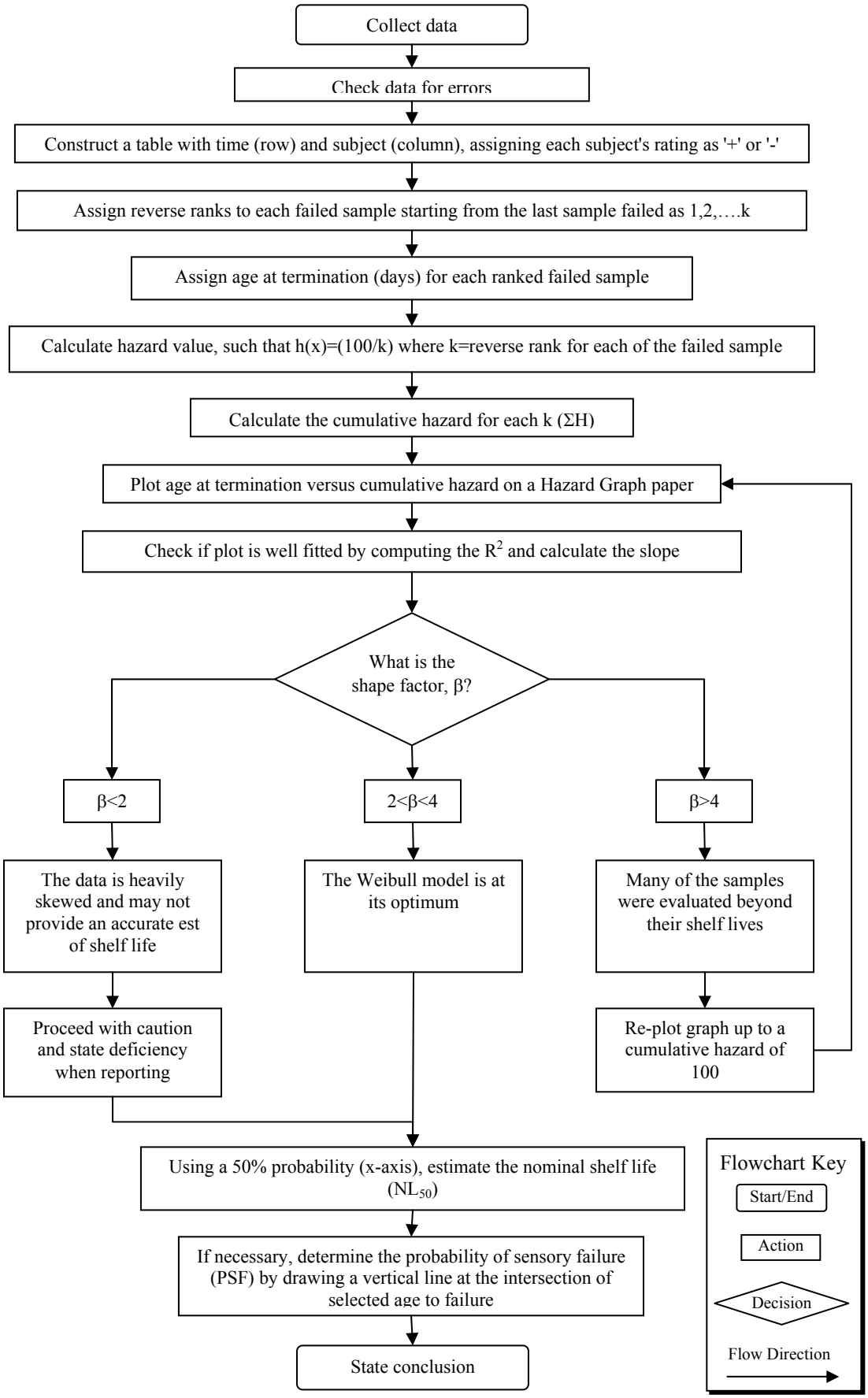
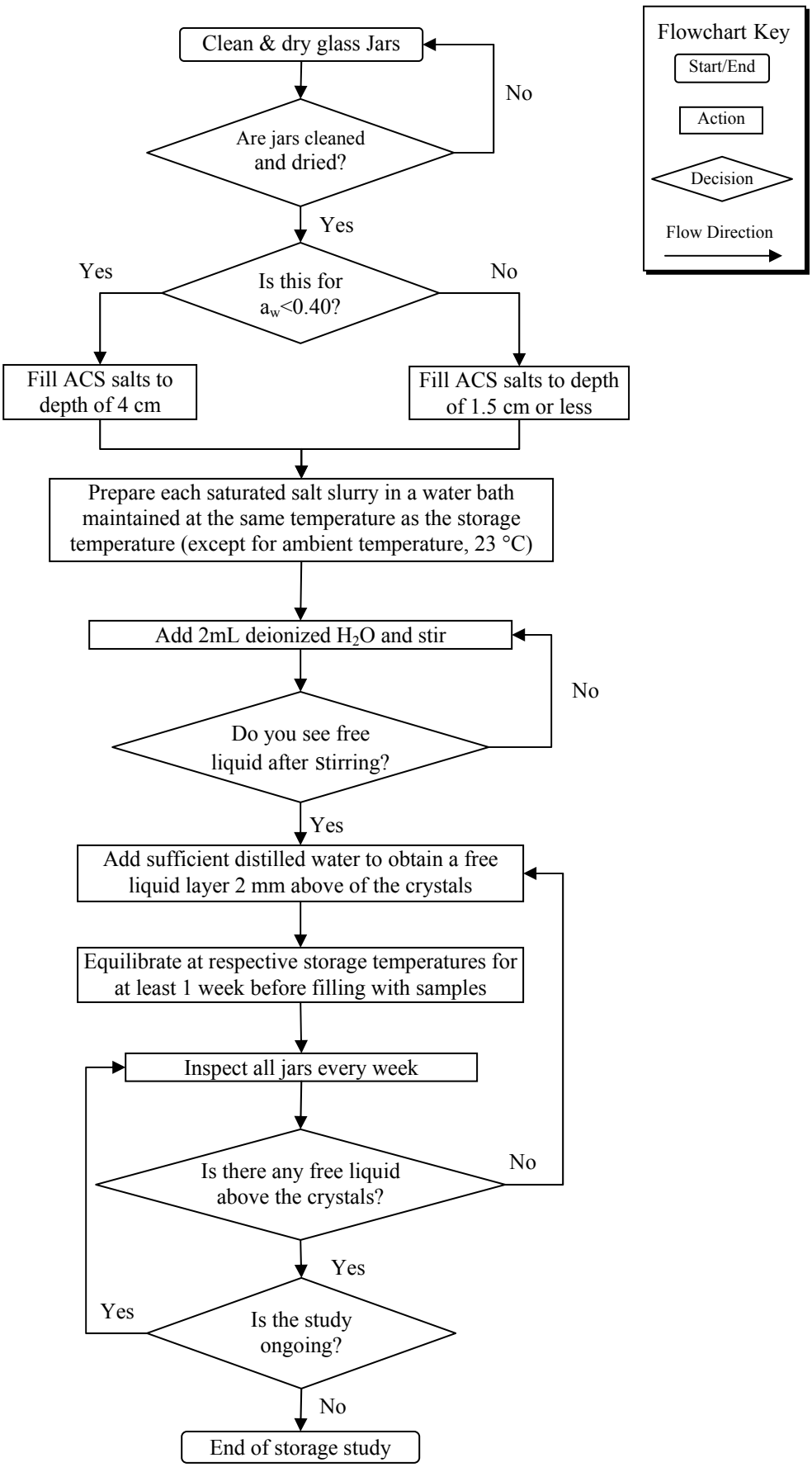

Collect data
Check data for errors
Construct a table with time (row) and subject (column), assigning each subject's rating as '+' or '-'
Assign reverse ranks to each failed sample starting from the last sample failed as 1,2,….k
Assign age at termination (days) for each ranked failed sample
Calculate hazard value, such that h(x)=(100/k) where k=reverse rank for each of the failed sample
Calculate the cumulative hazard for each k (ΣH)
Plot age at termination versus cumulative hazard on a Hazard Graph paper
Check if plot is well fitted by computing the R2 and calculate the slope
What is the shape factor, β?
β<2
2<β<4
β>4
The data is heavily skewed and may not provide an accurate est of shelf life
The Weibull model is at its optimum
Many of the samples were evaluated beyond their shelf lives
Proceed with caution and state deficiency when reporting
Re-plot graph up to a cumulative hazard of 100
Using a 50% probability (x-axis), estimate the nominal shelf life (NL50)
If necessary, determine the probability of sensory failure (PSF) by drawing a vertical line at the intersection of selected age to failure
State conclusion
Flowchart Key
Start/End
Action
Decision
Flow Direction

FIGURE 2.4
DECISION TREE FOR PREPARATION OF SATURATED SALT SLURRIES IN MASON JARS


Flowchart Key
Start/End
Action
Decision
Flow Direction
Clean & dry glass Jars
Are jars cleaned and dried?
No
Yes
Is this for a_w<0.40?
Yes
No
Fill ACS salts to depth of 4 cm
Fill ACS salts to depth of 1.5 cm or less
Prepare each saturated salt slurry in a water bath maintained at the same temperature as the storage temperature (except for ambient temperature, 23 °C)
Add 2mL deionized H_2O and stir
Do you see free liquid after Stirring?
No
Yes
Add sufficient distilled water to obtain a free liquid layer 2 mm above of the crystals
Equilibrate at respective storage temperatures for at least 1 week before filling with samples
Inspect all jars every week
Is there any free liquid above the crystals?
No
Yes
Is the study ongoing?
Yes
No
End of storage study

SECTION III

DESCRIPTIVE PROFILES OF ROASTED PEANUTS STORED AT VARYING TEMPERATURES AND HUMIDITY CONDITIONS[1]

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[1] Lee, C.M. and A. V. A. Resurreccion. Accepted by *J. Sensory Studies*.

ABSTRACT

Roasted peanuts were stored at 20 treatment combinations of water activities (0.33, 0.44, 0.54, 0.67, 0.75) and temperatures (23, 30, 35, 40 °C), and evaluated after storing for 0, 20, 40, 60, 80, 100, and 110% of estimated shelf life, ranging from 0 to 91 d. Regression models indicated that increasing storage time and storage water activity resulted in decreasing crispness, crunchiness, hardness, roasted peanutty, sweet aromatic, salty, bitter and sweet attributes, and increasing fracturability, chewiness, tooth packing, and cardboard flavor. Storage temperature did not contribute to regression models of textural properties of roasted peanuts. However, increasing storage temperature resulted in faster rate of decrease for roasted peanutty and faster rate of increase of cardboard flavor. Roasted peanuts stored between 0.33 and 0.41 a_w at 23 °C are predicted to have the least change in sensory properties after 68 and 91 d, respectively.

INTRODUCTION

The keeping quality of roasted peanuts is related to its storage conditions, including factors such as temperature, time, and relative humidity (water activity, a_w). In intermediate moisture foods containing peanuts, the effect of water activity is critical due to moisture transfer that occurs into the peanut until equilibrium moisture is reached between the nutmeat and the surrounding food. Roasted peanut loses freshness and crispness if brought into contact with an environment or ingredients with more than 6% moisture, developing a soggy nut aroma and flavor (Woodroof, 1983).

Critical water activity (a_c) is a_w at which crisp products, including potato chips, corn curl, saltines and popcorn, lose their acceptance. This usually occurs between 0.35 and 0.50 a_w (Quast and Karel, 1972; Katz and Labuza, 1981). Similarly, Evranuz (1993) concluded that the a_c for crispness of salted roasted peanuts is approximately 0.40 a_w. Recently, Baker *et al.* (2002) found that a storage a_w between 0.33 and 0.44 is the most favorable condition to maintain crunchiness and reduce oxidation in roasted high-oleic peanuts. Using both sensory and instrumental methods to evaluate texture of whole roasted peanut stored at 6 different a_w between 0.12 and 0.76, Hung and Chinnan (1989) found that the textural properties changed significantly between 0.5 and 0.76 a_w.

Among the flavor properties of roasted peanuts, roasted peanutty, cardboard, rancid/oxidized, painty flavor have been studied extensively in storage research (Braddock *et al.*, 1995; Warner *et al.*, 1996; Mugendi *et al.*, 1998; Brannan *et al.*, 1999; Baker *et al.*, 2002). Both painty and cardboard flavor intensity of roasted peanuts increased with storage time (Braddock *et al*., 1995; Mugendi *et al*., 1998). Braddock *et al.* (1995) concluded that cardboardy flavor intensity in normal peanut increased to twice as high as in high oleic peanuts stored at 25 °C and

40 % a_w, whereas Mugendi *et al*. (1998) found that painty was twice as high in runner peanuts than in high oleic peanuts. However, Mugendi *et al*. (1998) stored the peanuts at 40 °C and 0.18 a_w. Comparing fresh and oxidized peanut paste made from the same peanut source, oxidized peanut paste was found to have lower roasted peanutty, sweet aromatic and sweet taste, but higher cardboard and painty intensities (Civille & Dus, 1992). However, most previous research used a single temperature and research that model sensory properties of roasted peanuts as influenced by varying storage temperature and a_w simultaneously is lacking.

A storage environment close to the water monolayer of a product results in a protective condition due to the water molecules surrounding the food surface, thereby isolating oxygen from the lipid resulting in reduced rate of lipid oxidation (Labuza, 1971). The monolayer water content of salted roasted peanuts was identified as 2.1% moisture or around 0.30 a_w (Evranuz, 1993). When stored at a_w above or below its monolayer, the rate of flavor change increases with increasing difference between the storage a_w and monolayer a_w (Evranuz, 1993; Mate *et al.*, 1996). Using peroxide value as the end point of quality, the accelerating factor (Q_{10}) of salted, roasted, unblanched peanuts was estimated to be 1.60 (Evranuz, 1993). This suggests that every 10 °C increase in temperature will result in a 60% increase in reaction rate. For high oleic peanuts stored at water activities of 0.12, 0.33, 0.44, 0.52 and 0.67, changes in flavor due to oxidation were more predominant at 0.12, 0.52 and 0.67 a_w; whereas at 0.33 and 0.44 a_w, near the monolayer of peanuts, the oxidation rate was the lowest (Baker *et al.,* 2002).

The objective of this study was to investigate changes in descriptive profiles of roasted peanuts as affected by various storage conditions, including temperature, time, and a_w. The specific objectives were (a) to establish a descriptive profile of roasted peanuts stored at various conditions encompassing a spectrum of temperature, time and surrounding a_w, and (b) to model

the effect of storage temperature, time and a_w on color, flavor and texture attributes of roasted peanuts.

MATERIALS AND METHODS

Sampling scheme

A scheme was determined to obtain samples from peanuts stored at different temperatures and water activities representing intervals at 20% of the expected shelf life, up to 100% (Anon., 1993). A survey among retailers concluded that the shelf life of roasted peanuts stored at ambient (23 °C) is approximately 90 d (Anon., 1971). The following equation (Labuza & Schmidl, 1985) was used to estimate the shelf life of peanuts stored at an accelerated temperature of T_2:

$$\theta_{T_2} = \theta_{T_1} \times Q_{10}^{\Delta/10}$$

where θ = shelf life, $T_1<T_2$,$\Delta = T_1 - T_2$. Assuming a Q_{10} of 1.5, a 90 d shelf life of peanuts at 23 °C was projected to be 68, 55 and 45 d at 30, 35 and 40 °C, respectively. In order to estimate the shelf life of roasted peanuts stored at different water activities, the equation was revised to reflect change in a_w instead of temperature:

$$\theta_{a_w''} = \theta_{a_w'} \times Q_a^{-|\Delta|/0.1}$$

where θ = shelf life, a_w' = water activity 1, a_w'' = water activity 2, $\Delta = a_w' - a_w''$, and Q_a=accelerating factor due to a 0.1 change in a_w. The revised equation was used to calculate "estimated shelf life" (ESL) of roasted peanuts stored at each water activity using an assumed Q_a of 1.3. A sampling scheme, using the ESL in days, was constructed such that samples were to be removed from storage after 20, 40, 60, 80, 100 and 110% of ESL (Table 3.1).

Experimental Design

A 4x5 factorial design consisting of 4 storage temperatures of 23, 30, 35, 40 °C and 5 water activity levels of 0.33, 0.44, 0.54, 0.67 and 0.75 were evaluated over storage time between 2 to 91 d. The experiment was replicated twice resulting in a total of 40 samples. For each treatment combination of temperature and water activity, samples were drawn from storage at 6 different times after 20, 40, 60, 80, 100 and 110% of ESL as calculated above (Table 3.1). Control samples, consisting of peanuts belonging to the same batch of roasted peanuts used in the study, were packaged immediately in 0.075mm (3-mil.) polyethylene bags (Koch Supplies, Kansas City, MO) after roasting and cooling and flushed with 99% nitrogen then stored at 4 °C. Similarly, samples removed from storage were packaged and held until needed. This was to ensure minimum changes in all samples. The sensory properties of 40 stored roasted peanut samples were evaluated by a descriptive panel (n=12) over 2 sessions for each of the 6 sampling times.

Controlled Humidity Jar Set-up

Chemical salts such as magnesium chloride (Fisher Scientific, Yongers, NY), potassium carbonate (Mallinckrodt Baker, Inc., Phillipsburg, NJ), magnesium nitrate (Mallinckrodt Baker, Inc., Phillipsburg, NJ), sodium bromide (Mallinckrodt Baker, Inc., Phillipsburg, NJ), sodium nitrite (Mallinckrodt Baker, Inc., Phillipsburg, NJ), potassium iodide (Mallinckrodt Baker, Inc., Phillipsburg, NJ) and sodium chloride (Morton International, Inc., Chicago, IL) were used to maintain relative humidity levels of 0.33, 0.44, 0.54, 0.67 and 0.75, respectively (Table 3.2). The water activity of each temperature-chemical combination was estimated according to published equations shown in Table 3.2 (Labuza, 2001; Webb & Labuza., 2002). To allow for

variability of water activity of salts at different temperatures, different chemicals were selected for treatments so that the effect of variability was minimized (Table 3.2). To obtain a water activity of 0.54, magnesium nitrate was used for jars stored at 23 and 30°C, and sodium bromide for jars stored at 35 and 40 °C (Table 3.2). Similarly to obtain a water activity of 0.67, sodium nitrite was used for jars stored at 23°C, whereas potassium iodide was used for jars intended for 30, 35 and 40 °C (Table 3.2). Slurries of salts were prepared according to a procedure described later. A set-up was designed to allow maximum exposure of the samples to the surrounding humidity while protecting it from contact with the saturated salt slurries (Fig. 3.1). Each controlled humidity jar was maintained at its specified water activity and temperature.

Half-gallon wide mouth Mason jars (Ball Corp., Broomfield, CO), saturated salt slurries and a plastic net, with 0.5 cm holes were used. The plastic net was formed into a cylindrical shape with a plastic coil (Magic Spring, Dolgencorp, Inc., Goodlettsville, TN) by threading the coil through the net (Fig. 1). To avoid interference with the equilibrium relative humidity from materials such as wood and cotton, only materials made of plastic were used inside the jar. Salts were weighed and added to empty Mason jars. The saturated salt slurries were prepared in the jars at ambient temperature of 23 °C or inside a water bath (Model 220A, Napco Inc., Portland, OR) maintained at 30, 35 or 40 °C to obtain water activities from 0.33 to 0.75 (AOAC, 1995).

Mason jars were cleaned and dried prior to use. Saturated salt slurries of lower water activity (a_w<0.40) and higher water activity (a_w≥0.40) were prepared by filling the jars with the respective salt up to 4 cm and 1.5 cm in depth, respectively (AOAC, 1995). In each jar, 2 mL of double-deionized water was added and stirred without splashing onto the inside wall of the jar. This was repeated until no more salts could be dissolved by stirring (AOAC, 1995). Sufficient

water was added to obtain approximately 2 mm of liquid above the salts when necessary (Labuza, 2001).

Sample jars prepared with saturated salt slurries were stored at their respective storage temperatures (23, 30, 35 or 40 °C) for at least one week to equilibrate (Labuza, 2001). The water activity within each controlled humidity jar was collected using the Safe Storage Monitor (Decagon Devices, Inc., Pullman, WA) by monitoring the equilibrium relative humidity of the jar without sample, using a probe, for 2 weeks. To verify the water activity over the 2 wk period, data collected was transferred to a personal computer using the SafeLink software (Decagon Devices, Inc., Pullman, WA) provided with the Safe Storage Monitor. The actual water activity was approximately equal to the calculated water activity (Table 3.2). During storage, the jars were inspected every week and distilled water or salt was added to the jar to maintain the slurry (2 mm liquid layer above salt).

Two rubber bands were used outside the jar to suspend the plastic net cylinder at least 5 cm above the slurry. The plastic net cylinders were filled with peanuts, the jars were capped, sealed tightly and were held in storage for the pre-determined ESL (Table 3.1). Jars stored at 23 °C were stored in corrugated paperboard boxes to exclude light similar to dark conditions of samples at accelerated temperatures.

Sample Preparation

Shelled, raw medium Georgia Green peanut kernels (2001 crop, McCleskey Mills, Smithville, GA) were used in this study. Peanuts were sorted for defective kernels and foreign material then stored at 4 °C (Nor-Lake, Inc., Hudson, WI) for up to two weeks. They were equilibrated to 23 °C at least 12 h before processing. Sorted raw kernels were heated in 4 kg

batches to 190 °C for 6 min in a rotary gas roaster (Model L5, Probat Inc., Memphis, TN) to a medium roast with a color Lightness (L) value of 50 ± 1.0 (Johnsen *et al.,* 1988).

A Gardner XL-800 colorimeter (Pacific Scientific, Bethesda, MD) was standardized using a yellow reference tile (L=79.56, a=-6.17, b=22.98). Color of the roasted peanuts was measured by filling the colorimeter sample cup to a depth of 1 cm and four readings were obtained for each sample. After roasting, peanuts were allowed to cool for 3 min in a 64 cm diameter circular perforated stainless steel tray equipped with a cooling fan and a rotating brush that combs the peanuts around the circle (Model L5, Probat Inc., Memphis, TN). They were then blanched using a dry peanut blancher (Model EX, Ashton Food Machinery Co. Inc., Newark, NJ). Blanched peanuts were sorted manually, wearing plastic gloves and were rejected if they were discolored, damaged or had any remaining testa. Since it took 10 to 20 roasting batches to completely roast all the peanuts, all batches were combined in a rotating coating pan (Stokes Equipment Inc., OH) with no heating to mix the different batches and cool to 23 °C before packaging. Three hundred and fifty grams of sample were placed in each of controlled humidity jar. The jars, filled with samples, were moved to storage incubators maintained at 30 °C (Model 3107, The Electric Hotpack Company, Inc., Philadelphia, PA), 35 °C (American Instrument Co., Silver Spring, MD), 40 °C (Model 645 Treas, Precision Scientific, Winchester, VA), or in a room maintained at 23 °C. Control samples were stored in 0.075mm (3-mil.) polyethylene bags (Koch Supplies, Kansas City, MO), flushed with 99% nitrogen, vacuum packaged, and stored at 4 °C.

Sampling Procedure

On the day of sampling, sample jars were equilibrated to room temperature (23 °C) for 4 h prior to opening to prevent sudden condensation of moisture onto the samples (Labuza, 2001). Samples removed from their storage conditions were packaged under conditions similar to control. Drawn samples, packaged as described above, were accumulated for sensory test until all 20 treatments representing the same percent-ESL were obtained.

Descriptive Analysis

Samples were evaluated by a descriptive panel trained using a hybrid (Einstein, 1991) of the Spectrum, Quantitative Descriptive Analysis (QDA) and Texture Profile Analysis. Panelists were recruited, screened, trained as described in the following paragraphs.

Panel. Twelve panelists were recruited, trained and calibrated on descriptive analysis of roasted peanuts. All panelists were recruited on the basis of the following criteria: 1) between the age of 18-64 years old, 2) non-smokers, 3) not allergic to peanuts, 4) eat peanuts, 5) available to attend all training and testing sessions, 6) interest in participating, and 7) able to verbally communicate about the product (Plemmons and Resurreccion, 1998). Potential panelists were screened to test their ability to recognize and distinguish between different tastes and aromatic compounds (Plemmons and Resurreccion, 1998). Recruited panelists had 3 mo to 20 y of experience on descriptive analysis. Prior to the screening and training sessions, panelists signed a consent form approved by the University of Georgia Institutional Review Board. They were paid cash for their participation.

Training. Panelists who were not previously trained in descriptive analysis were required to participate in one additional day of training prior to the training sessions. Panelists

were trained on descriptive analysis test procedures adapted from Meilgaard *et al.* (1991). Each training session lasted 2 h and a total of three sessions were conducted over three days before the panelists were trained and calibrated. During training, panelists were presented with samples of peanuts previously stored under different moisture conditions. A lexicon of descriptive terms was used to characterize the sensory profiles of the roasted peanut (Szczesniak *et al.*1963; Johnsen *et al.*1980; Meilgaard *et al.*1991; Muego-Gnanasekharan and Resurreccion, 1992; Ward, 1995; Civille and Lyon, 1996; Divino *et al*., 1996; Plemmons and Resurreccion, 1998; Gills and Resurreccion, 2000; Grosso and Resurreccion, 2002). The final list of attributes, definitions, evaluating instructions and external references used to rate each attribute was decided or modified by panel consensus (Table 3.3). Panelists used 150-mm unstructured line scales with anchors at the 12.5 and 137.5 mm, corresponding to weak and strong, respectively. Standard references and a control were provided and their intensities (Table 3.3 & 3.4) were included on the paper and computer ballots used.

Ballot. The ballot developed by the panel consisted of 23 attributes describing the appearance, texture, flavor, taste and aftertaste of stored roasted peanuts. The paper ballot used during calibration was identical to the computer ballot (Compusense *five*, version 4.2, Compusense, Inc., Guelph, Ontario, Canada) used during testing. Monadic presentation was built into the computer ballot such that panelists were not allowed to move back or forward between samples. However, they were allowed to move back and forth among the attributes belonging to the same sample. Instructions, definitions, references, control and reference intensities were provided on both the paper and computer ballots. The arrangement of the attributes in the ballot was in the order of perception during normal consumption of peanuts,

except that texture attributes were presented before flavor attribute due to their importance in roasted peanut characteristics.

Calibration. Prior to each of the testing sessions, a 1 hr calibration session was held during which the panelists were asked to calibrate themselves with the four basic taste solutions, evaluate references and control samples, and their respective attribute intensities. A warm-up sample was evaluated during calibration and the reliability of panelist responses was monitored by the use of a blind duplicate sample evaluated in the booth. Panelists were calibrated by obtaining an average panel rating for each attribute and panelists not rating within 10% of the mean rating were asked to re-evaluate the sample and adjust their ratings until a consensus was reached. Panelists evaluated the warm-up sample using paper ballots during calibration and used computerized ballots when evaluating samples in 10 individually partitioned booths. Each booth was equipped with a computer and panelists used a computer mouse for rapid and accurate entry of ratings.

Test Conditions. All screening, training and testing were performed at the Department of Food Science & Technology, University of Georgia in Griffin, GA. Samples were evaluated in environmentally controlled partitioned booths illuminated with two 50 W white incandescent bulbs providing 738 lx of light.

Test Procedure. At least 1 h prior to testing, 10 g of each sample was removed from their original containers and was placed into 28.57-g plastic cups with lids (Solo Cup Co., Highland, IL). Twenty samples of roasted peanut and one control sample were evaluated during each session with mandatory breaks of 5 min each after the fifth, tenth, and fifteenth samples to reduce panelist fatigue. Samples were coded with three-digit random numbers and served at ambient temperature (23 °C) on a stainless steel tray lined with white paper. Evaluation

sequence was based on a randomized complete block design and controlled by Compusense® *five*. Panelists expectorated all samples and rinsed with water and saltine crackers between samples. Testing sessions were conducted between 10 am and 12 pm of each day, for a total of 13 d.

Statistical Analyses

Statistical analyses were performed using SAS (Version 8.0e, SAS Institute Inc., Cary, NC). Results of descriptive analysis were first analyzed by cluster analysis using the PROC VARCLUS procedure to identify any outliers for each sampling time (Malundo and Resurreccion, 1992). In addition, raw data of panelists' ratings were plotted for each sample to identify panelists who did not perform consistently with the panel. Two panelists were identified as outliers and their data were removed the data set. Results from the remaining 10 panelists who were not outliers were used in the remaining statistical analyses.

Regression analysis (PROC REG) was used to relate mean ratings of each descriptive attribute to storage a_w, temperature and time, their square terms, and their interactions. The full model is a second order polynomial regression model with 3 linear terms, including storage time (x_1), storage water activity (x_2), and storage temperature (x_3); their squared terms; and all possible cross products as shown:

$$Y=\beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3+\beta_{11}x_1^2+\beta_{22}x_2^2+\beta_{33}x_3^2+\beta_{12}x_1x_2+\beta_{13}x_1x_3+\beta_{23}x_2x_3+\beta_{123}x_1x_2x_3+\varepsilon$$

where Y is the rating of the descriptive attribute; β_0 is the intercept when x_1, x_2 and x_3 equal 0; β_1, β_2 and β_3 are parameter estimates of storage time (x_1), water activity(x_2), and temperature(x_3) respectively; β_{11}, β_{22} and β_{33} are the parameter estimates of their square terms x_1^2, x_2^2 and x_3^2;

and β_{12}, β_{13}, β_{23}, and β_{123} are the parameter estimates of their cross product terms, x_1x_2, x_1x_3, x_2x_3, and $x_1x_2x_3$.

For each attribute, reduced models with 1 to 10 terms and having adjusted $R^2 \geq 0.70$ were retained (Bourne, 1982). Models with the equal number of terms were examined for their adjusted-R^2 and Mallow's C_p value (Rothman, 1997). Models with the highest adjusted-R^2 and optimum Mallow's C_p value that approximate the number of terms in the model including the intercept (Rothman, 1997), were selected and tested against the full model using the partial F-statistics (Cornell, 1982):

$$F = \frac{\left[\frac{(SSE_{reduced} - SSE_{full})}{(df_{reduced} - df_{full})}\right]}{MSE_{full}}$$

where *SSE* is the sum of squares of error, *MSE* is the mean square error and *df* is the degrees of freedom. Models that were not significantly different ($p>0.05$) from the full model were used to create contour plots using Statistica® (Version 6.0, Statsoft, Inc., Tulsa, OK). Contour plots were constructed for each of the descriptive attributes using regression models. If storage temperature is present in the final regression model, individual contour plots were constructed for each of the storage temperatures, 23, 30, 35 and 40 °C. Since this was a shelf life study and the storage days for each treatment combination are different, part of the contour plot is not applicable to this discussion. Shaded portions of the contour plots indicates a region that was not studied and no further conclusions were made regarding these conditions

RESULTS AND DISCUSSION

Significant regression equations based on the mean panel data (n=60), with $R^2>0.70$ (Malundo and Resurreccion, 1992) are shown in Table 3.5. The resulting contour plots for the

selected attributes that could be predicted are shown in Figures 3.2 to 3.4. Although the models for sweet aromatic, woody/hulls/skins, salty, bitter and sweet were significant, no further discussion was included in this paper because these attributes were rated 14 or less, indicating low intensities.

Texture

Among the regression models of all texture attributes, storage temperature (x_3) was not significant and was eliminated from models for crispness, fracturability, crunchiness, hardness, chewiness and tooth packing (Table 5). Therefore, contour plots for all texture attributes (Fig. 3.2) are applicable to temperatures between 23 and 40 °C.

Crispness of roasted peanut decreased with increasing storage water activity (Fig. 3.2A). The control sample was rated at 29 on a 150-mm scale (Table 3.4). When stored between 0.33 and 0.41 a_w, the crispness remained high around 29 throughout the storage period (Fig. 3.2A). However, as storage a_w increased beyond 0.41, crispness decreased with storage time and storage a_w (Fig. 3.2A). Peanuts stored at 0.75 a_w had the lowest crispness rating of less than 14 after storing for 28 d (Fig. 3.2A). A large difference between the storage water activity (0.75 a_w) and the roasted peanut (0.39 a_w) yielded a sample that absorbed more moisture from the surrounding environment.

Fracturability is defined as the force with which the sample breaks. The descriptive panel was trained to evaluate fracturability according to Ward (1995). With increasing moisture presence in the peanut, the sample did not break until more force was applied, thus accounting for the increase in fracturability with increasing storage time and water activity (Fig. 3.2B). The fracturability of samples stored at 0.33 to 0.41 a_w remained between 52 and 54 with increasing storage time (Fig. 3.2B). Samples stored at 0.33 a_w were rated around 52 and similar to the

control samples at 50, indicating that water activity at 0.33 had little effect on the fracturability of roasted peanuts (Fig. 3.2B). With increasing water activity above 0.41, the peanut kernel absorbed more moisture and resulted in a sample that required more force to bite into before it breaks. Compared with a control fracturability rating of 50, the panel rated these samples as high as 64 (Fig. 3.2B). The definition of fracturability used in this study was found to be incomplete and should be revised as "the force required on the surface of a sample that causes it to shatter". After storage at high water activities, samples would no longer shatter and any force applied resulted in a cutting action. Thus, panelists were rating the cutting force, rather than true fracturability.

Crunchiness of roasted peanuts decreased with increasing storage time and water activity, from 60 to a low of 10 (Fig. 3.2C). This agrees with the findings of Baker *et al.* (2002). Compared to a control rating of 60 (Table 3.4), samples stored at 0.47 a_w or less remained crunchy with ratings of 50 to 60 when stored between 60 to 91 d. Increasing the water activity beyond 0.47 resulted in samples that are rated less than 50 on crunchiness towards the end of the study (Fig. 3.2C). As the storage water activity increases beyond 0.60, roasted peanuts were rated less than 50 in crunchiness after less than 50% of the storage time evaluated (Fig. 3.2C). Samples stored at 0.70 or more were rated less than 50 in crunchiness, indicating that a relative humidity of 0.70 has an immediate and deleterious effect on the crunchiness of roasted peanuts (Fig. 3.2C).

The effect of storage water activity on hardness was similar to crunchiness, such that hardness decreased with increasing storage water activity and time, from 85 to less than 60 (Fig. 3.2D). Compared to a control rating of 85 (Table 3.4), samples stored at a water activity of 0.53 or less were rated at 75 or more at the end of storage (Fig. 3.2D). Increasing water activity

beyond 0.53 resulted in samples that were rated less than 75 in hardness (Fig. 3.2D). At a water activity of 0.65 or above, samples were rated less than 75 after storing for about 50% of the storage time tested, or less than 18 d (Fig. 3.2D).

Chewy increases with increasing storage water activity and storage time. The chewy rating for the control sample was 15 (Table 3.4) and that of stored samples reached as high as 32 (Fig. 3.2E). For samples stored between 0.33 and 0.50 a_w, chewy intensity remained similar to the control with storage time, with ratings of 20 or less (Fig. 3.2E). However, samples stored in 0.50 a_w or above were rated more than 20 in chewy at the end of the storage study (Fig. 3.2E). After storing for 50% or less of the storage time, sample chewiness was rated more than 20 if stored at 0.60 a_w and above (Fig. 3.2E). In particular, samples stored at 0.70 a_w and above were rated 20 and above in chewy within a day of storage (Fig. 3.2E).

Panelists did not detect a drastic change in tooth packing, which ranged from 67 to 76 (Fig. 3.2F). Tooth packing increased with increasing storage time and water activity (Fig. 3.2F). Control samples were rated at 67 for tooth packing intensity. At the end of the study, samples stored at 0.62 a_w or below were rated between 67 and 72 in tooth packing throughout the study, or within a 5-point range of the control (Fig. 3.2F). However, with increasing water activity beyond 0.62, samples were rated higher than 72 in tooth packing intensity by the end of the study (Fig. 3.2F). Samples stored at 0.68 a_w and above were rated higher than 72 in tooth packing after approximately 50% of their storage time (Fig. 3.2F).

Flavor

Roasted peanutty is a desirable flavor attribute of roasted peanut (Crippen *et al.,* 1992). Roasted peanutty decreased with increasing storage time, water activity and temperature (Fig. 3.3). Compared with a control intensity of 74 (Table 3.4), only samples stored at 23 and 30 °C

had similar intensity ratings between 70 and 75 (Fig. 3.3A and 3.3B). Samples stored at 23 °C remained higher in roasted peanutty intensity (>70) for a longer period of time than those stored at 30 °C (Fig. 3.3A and 3.3B). At water activities of 0.54 or above, samples are predicted to decrease drastically in roasted peanutty to as low as 0 by the end of their storage times (Fig. 3.3). At accelerated temperatures (30 to 40 °C) and at 0.54 a_w, roasted peanutty flavor decreased to 65 or less after 9 d of storage (Fig. 3.3B, 3.3C, and 3.3D). Roasted peanutty flavor is a product of roasting and is due primarily to the pyrazines present after roasting at high temperature (Maga, 1982). Increasing storage water activity above the water monolayer and increasing temperature accelerated the rate of flavor loss, possibly due to increasing lower molecular weight compounds such as hexanal that hinder the roasted peanutty flavor (Warner *et al.,* 1996). The decrease in roasted peanutty flavor can also be attributed to the degradation of lipid radicals (Bett & Boylston, 1992). In trail mixes where peanuts are present with raisins, roasted peanuts are exposed to a water activity of 0.51 to 0.53 (Anon., 2004). Data from this study suggests that the roasted peanutty flavor of peanuts in trail mixes was reduced from 75 to 65 within 15 to 20 d of storage at 23 °C. In a system such as jelly whereby water activity is as high as 0.74 (Felland & Koehler, 1997), results from this study indicated that the roasted peanutty flavor can be dissipated as early as day 0.

Cardboard flavor is associated with slightly oxidized fats and oils and is found in oxidized products in its earlier stage of oxidation. Control peanut samples had a cardboard flavor intensity of 0 and treatments had intial ratings of around 0 (Fig. 3.4). Compared with samples stored at 23 °C, increasing storage temperature from 30 to 40 °C resulted in samples that are more than 10 in cardboard flavor intensity after storing for an increasingly shorter time (Fig. 3.4). The rate of change was higher for samples stored at higher temperature, as indicated by

closer contours for graphs depicting higher temperatures (Fig. 3.4B, 3.4C, and 3.4D) compared to the changes at ambient temperature (Fig. 3.4A). Similarly, samples stored at higher water activity conditions develops higher cardboard flavor compared with those stored at lower water activity and after storing for the same amount of time (Fig. 3.4) and this is in agreement with Baker *et al.* (2002) and are indicated by closer contours on each of the graphs at higher water activity levels (Fig. 3.4A, 3.4B, 3.4C, or 3.4D).

Regression models indicated that increasing storage time and storage water activity resulted in decreasing crispness, crunchiness, hardness, roasted peanutty, sweet aromatic, salty, bitter and sweet attributes, and increasing sensory fracturability, chewiness, tooth packing and cardboard flavor of roasted peanut. Storage temperature did not contribute to the regression models of textural properties. Increasing temperature of storage resulted in increased rate of change for roasted peanutty and cardboard flavors. For a minimal effect due to storage on the sensory properties of roasted peanuts, it is best for roasted peanuts samples to be stored at 23 °C and exposing only to a water activity condition between 0.33 and 0.41.

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REFERENCES

ANONYMOUS. 1971. Food stability survey, Vol II. Rutgers University Dept. of Food Science, for the State of new jersey Dept. of Health and the U.S. Dept. of Agriculture/Economic Research Service. pp. 57. U.S. Government Printing Office, Washington D.C.

ANONYMOUS. 1993. Shelf life of foods - guidelines for its determination and prediction. pp 55. Institute of Food Science & Technology, London, U.K.

ANONYMOUS. 2004. Water activities of selected solutions and foods. Available from: http://food.oregonstate.edu/water/aw.html. Accessed Jan 15.

AOAC, INTERNATIONAL. 1995. Water activity of canned vegetables. Method No. 978.18. Official methods of analysis, 16th ed. Chapter 42. pp 1-2. Association of Official Analytical Chemists, Arlington, VA.

BAKER, G.L., SIMS, C.A., GORBET, D.A., SANDERS, T.H. and O'KEEFE, S.E. 2002. Storage water activity effect on oxidation and sensory properties of high-oleic peanuts. J Food Sci. *67*, 1600-1603.

BETT, K.L., and BOYLSTON, T.D. 1992. Effect of storage on roasted peanut quality. **In**: Lipid oxidation of foods. pp. 322-343. St. Angelo, A.J., Ed., American Chemical Society, Washington DC.

BOURNE, M.C. 1982. Food texture and viscosity. pp. 289. Academic Press, New York.

BRADDOCK, J.C., SIMS, C.A., and O'KEEFE, S.F. 1995. Flavor and oxidative stability of roasted high oleic acid peanuts. J Food Sci. *60*:489-493.

BRANNAN, G.L., KOEHLER, P.E., and WARE, G.O. 1999. Physico-chemical and sensory characteristics of defatted roasted peanuts during storage. Peanut Science *26*:44-53.

CIVILLE, G.V. and DUS, C.A. 1992. Sensory evaluation of lipid oxidation in foods. In *Lipid oxidation in food*. (St. Angelo AJ, ed.). pp. 279-289. American Chemical Society, Washington, D.C.

CIVILLE, G.V. and LYON, G.V. 1996. Aroma and flavor lexicon for sensory evaluation: terms, definitions, references, and examples. ASTM Data Series Publication DS 66. pp. 74.

CORNELL, J.A. 1982. *How to Run Mixture Experiments for Product Quality*, Vol. 5. pp. 1-60, American Society Quality for Control, Milwaukee, Wisconsin.

CRIPPEN, K.L., VERCELLOTTI, J.R., LOVEGREN, N.V. and SANDERS, T.H. 1992. Defining roasted peanut flavor quality. 2. Correlation of GC volatiles and sensory flavor attributes. Developments in Food Sci. *29*, 211-227.

DIVINO, G.L., KOEHLER, P.E. and AKOH, C.C. 1996. Enzymatic and autoxidation of defatted peanuts. J Food Sci. *61*:112-115, 120.

EINSTEIN, M.A. 1991. Descriptive techniques and their hybridization. In: *Sensory science theory and applications in food* (LAWLESS, H.T. and KLEIN, B.T., eds.). pp. 317-338, Marcel Dekker, Inc., New York, New York.

EVRANUZ, E.O. 1993. The effects of temperature and moisture content on lipid peroxidation during storage of unblanched salted roasted peanuts: shelf life studies for unblanched salted roasted peanuts. International J Food Sci & Technol. *28*, 193-199.

FELLAND S.L. and KOEHLER, P.E. 1997. Sensory, chemical, and physical changes in increased water activity peanut butter products. J Food Quality *20*(2):145-156.

GILLS, L.A. and RESURRECCION, A.V.A. 2000. Sensory and physical properties of peanut butter treated with palm oil and hydrogenated vegetable oil to prevent oil separation. J Food Sci. *65*, 173-180.

HUNG, Y.-C. and CHINNAN, M.S. 1989. Mechanical texture measurement of whole and chopped peanuts. Peanut Sci. *16*, 32-37.

GROSSO, N.R., and RESURRECCION, A.V.A. 2002. Predicting consumer acceptance ratings of cracker-coated and roasted peanuts from descriptive analysis and hexanal measurements. *J Food Sci*. *67*: 1530-1537.

JOHNSEN, P.B., CIVILLE, G.V., VERCELLOTTI, J.R., SANDERS, T.H. and DUS, C.A. 1988. Development of a lexicon for the description of peanut flavor. J Sensory Stud. *3*, 9-17.

KATZ, E.E. and LABUZA, T.P. 1981. Effect of water activity on the sensory crispness and mechanical deformation of snack food products. J Food Sci *46*, 403-409.

LABUZA, T.P. 2001. Standard Desiccator Method for Isotherms. Available from: http://fscn1.fsci.umn.edu/ted_Labuza/awimages/Salt%20solutions%20FOR%20Isotherm.pdf. Accessed Jan 16.

LABUZA, T.P. 1971. Kinetics of lipid oxidation in foods. CRC Crit. Rev. in Food Tech. *2*, 355-394.

LABUZA, T.P. and SCHMIDL, M.K. 1985. Accelerated shelf-life testing of foods. Food Technol. *39*, 57-62, 64, 134.

MAGA, J.A. and SIZER, C.E. 1982. Pyrazines in foods: A Review. J Agr. Food Chem. *21*, 22-30.

MALUNDO, T.M.M. and RESURRECCION, A.V.A. 1992. A comparison of performance of panels selected using analysis of variance and cluster analysis. J Sensory Stud. *7,* 63-75.

MATE, J.I., SALTVEIT, M.E. and KROCHTA, J.M. 1996. Peanut and walnut rancidity: effects of oxygen concentration and relative humidity. J Food Sci. *61*, 465-468, 472.

MEILGAARD, M., CIVILLE, G.V. and CARR, B.T. 1991. Sensory Evaluation Techniques, 2nd ed. pp 142-150, 260-261. CRC Press, Boca Raton, FL.

MUEGO-GNANASEKHARAN, K.F. and RESURRECCION, A.V.A. 1992. Physicochemical and sensory characteristics of peanut paste stored at different temperatures. J Food Sci. *57*, 1385-1389.

MUGENDI, J.B., SIMS, C.A., GORBET, D.W., and O'KEEFE, S.F. 1998. Flavor stability of high-oleic peanuts stored at low humidity. J. Am. Oil Chem. Soc. *75*:21-25.

PLEMMONS, L.E. and RESURRECCION, A.V.A. 1998. A warm-up sample improves reliability of responses in descriptive analysis. J Sensory Stud. *13*, 359-376.

QUAST, D.G. and KAREL, M. 1972. Effects of environmental factors on the oxidation of potato chips. J Food Sci. *37*, 584-588.

ROTHMAN, L. 1997. Relationship between consumer responses and analytical measurements. In: Relating consumer, descriptive, and laboratory data to better understand consumer responses. (Munoz, A.M., ed.). pp. 62-77. American Society for Testing and Materials, West Conshocken, PA.

SAS Institute Inc. 2002. SAS/STAT Guide for personal computers. 8th ed. Cary, N.C.: SAS Institute Inc.

SZCZESNIAK, A.S., BRANDT, M.A. and FRIEDMAN, H.H. 1963. Development of standard rating scales for mechanical parameters of texture and correlation between the objective and the sensory methods of texture evaluation. J. Food Sci. *28*, 397-403.

WARD, C.D.W. 1995. Effects of physicochemical and sensory properties on functionality and consumer acceptance of snack chips formulated with cowpea, corn, and wheat flour mixtures. Ph.D. Dissertation. University of Georgia, Athens. pp. 69-70.

WARNER, K.J.H., DIMICK, P.S., ZIEGLER, G.R., MUMMA, R.O. and HOLLENDER, R. 1996. 'Flavor-fade' and off-flavors in ground roasted peanuts as related to selected pyrazines and aldehydes. J Food Sci *61*, 469-472.

WEBB, R. and LABUZA, T.P. 2002. Water activity of saturated salt solutions. Available from: http://www.users.bigpond.com/webbtech/salt.html. Accessed March 25.

WOODROOF, J.G. 1983. Peanut confections. In *Peanuts: Production, Processing, Products*. 3rd ed. (Woodroof, J.G., Ed.) pp.265-292. AVI Publishing Company Inc., Westport, CT.

TABLE 3.1.
STORAGE TIMES (DAYS) FOR ROASTED PEANUTS STORED AT EACH TEMPERATURE AND WATER ACTIVITY LEVEL

Treatment		Storage Days Representing Estimated Shelf Life (%)					
Temperature	**Water Activity**	**20**	**40**	**60**	**80**	**100**	**110**
23 °C	0.33	17	33	50	66	83	91
	0.44	12	25	37	50	62	68
	0.54	10	19	29	38	48	53
	0.67	7	14	20	27	34	37
	0.75	6	11	17	22	28	31
30 °C	0.33	13	25	38	50	63	69
	0.44	9	19	28	38	47	52
	0.54	7	14	22	29	36	40
	0.67	5	10	16	21	26	29
	0.75	4	8	13	17	21	23
35 °C	0.33	10	20	30	40	51	56
	0.44	8	15	23	30	38	42
	0.54	6	12	17	23	29	32
	0.67	4	8	13	17	21	23
	0.75	3	7	10	14	17	19
40 °C	0.33	8	17	25	33	41	46
	0.44	6	12	19	25	31	34
	0.54	5	10	14	19	24	26
	0.67	3	6	8	11	14	15
	0.75	2	5	7	10	12	13

TABLE 3.2.
CALCULATED AND MEASURED WATER ACTIVITY OF SATURATED SALTS USED TO MAINTAIN THE WATER ACTIVITY OF CONTROLLED HUMDITIY JARS AT VARIOUS TEMPERATURES

Water activity	Temperature	Saturated salt	Calculated water activity	Measured water activity[a]
0.33	23 C	Magnesium chloride	0.33[b]	0.32
	30 C	Magnesium chloride	0.33[b]	0.31
	35 C	Magnesium chloride	0.32[b]	0.30
	40 C	Magnesium chloride	0.32[b]	0.30
0.44	23 C	Potassium carbonate	0.43[c]	0.42
	30 C	Potassium carbonate	0.43[c]	0.45
	35 C	Potassium carbonate	0.43[c]	0.44
	40 C	Potassium carbonate	0.43[c]	0.41
0.54	23 C	Magnesium nitrate	0.54[d]	0.53
	30 C	Magnesium nitrate	0.53[d]	0.52
	35 C	Sodium bromide	0.55[e]	0.55
	40 C	Sodium bromide	0.53[e]	0.51
0.67	23 C	Sodium nitrite	0.67[f]	0.63
	30 C	Potassium iodide	0.68[g]	0.69
	35 C	Potassium iodide	0.67[g]	0.66
	40 C	Potassium iodide	0.66[g]	0.66
0.75	23 C	Sodium chloride	0.77[h]	0.77
	30 C	Sodium chloride	0.75[h]	0.76
	35 C	Sodium chloride	0.74[h]	0.72
	40 C	Sodium chloride	0.73[h]	0.79

[a]Water activity was measured using a Decagon Safe Storage Monitor (Decagon Devices, Inc., Pullman, WA)
[b]Using the equation: $\ln(a_w) = (151.0652/T)-1.6271$, where T= temperature in °K (Webb & Labuza, 2002)
[c]Using the equation: $\ln(a_w) = (-3.0240/T)-0.8300$, where T= temperature in °K (Webb & Labuza, 2002)
[d]Using the equation: $\ln(a_w) = (484.6993/T)-2.2670$, where T= temperature in °K (Webb & Labuza, 2002)
[e]Using the equation: $\ln(a_w) = (447.8054/T)-2.0575$, where T= temperature in °K (Webb & Labuza, 2002)
[f]Using the equation: $\ln(a_w) = (435.96/T)-1.88$, where T= temperature in °K (Labuza, 2002b)
[g]Using the equation: $\ln(a_w) = (258.1545/T)-1.2388$, where T= temperature in °K (Webb & Labuza, 2002)
[h]Using the equation: $\ln(a_w) = (23.1092/T)-0.3607$), where T= temperature in °K (Anon., 2002)
[a]Water activity was measured using a Decagon Safe Storage Monitor (Decagon Devices, Inc., Pullman, WA)

TABLE 3.3.
DESCRIPTIVE ATTRIBUTES AND THEIR DEFINITIONS USED IN THE DESCRIPTIVE ANALYSIS OF ROASTED PEANUTS

Attributes[a]	Definition	References	Intensity[b]
APPEARANCE			
Brown color[c,d]	The intensity of strength of brown color from light to dark brown[d]	white paper[b] (L=91.42, a=-0.22,b=0.04) dry cardboard[k] (L=49.71, a=5.77, b=16.01)	0 30
Moist	Amount of wetness on surface	wet cardboard	100
TEXTURE			
Crispness[h]	Amount of force needed and intensity of sound (high pitch) generated from chewing a sample with incisors[h]	corn chips[h] (Frito Lay, Plano, TX)	70
Fracturability[h]	The force with which the sample breaks[h]	corn chips (Frito Lay, Plano, TX)	53
Crunchiness[c,h]	The force needed and intensity of sound (low pitch) generated from chewing a sample with molar teeth[c,h]	corn chips[h,k] (Frito Lay, Plano, TX)	75
Hardness[d,h]	Amount of force needed to compress a food between molar teeth[d]	corn chips (Frito Lay, Plano, TX)	80
Chewvy[h,i]	The length of time in seconds required to masticate a sample at the rate of one chew per second in order to reduce it to a consistency satisfactory for swallowing[i]	raw peanuts	33
Tooth packing[c,h]	The degree to which product sticks on the surface of molars[c]	raw peanuts	80
FLAVOR			
Roasted peanutty[c,d,e]	The aromatic associated with medium-roast peanuts[c,d,e,h]	dark roasted peanuts (L=45.0±1.0)	84
Raw beany[c,e,f]	The aromatic associated with raw peanuts[c,d,f]	raw peanuts[b,k]	41
Oxidized[c,d,f]	The flavor associated with rancid fats and oils[c]	old vegetable oil[b,l] (Hunt-Wesson, Inc., Fullerton, CA)	37

(Continued on next page)

TABLE 3.3 (cont.)
DESCRIPTIVE ATTRIBUTES AND THEIR DEFINITIONS USED IN THE DESCRIPTIVE ANALYSIS OF ROASTED PEANUTS

Attributes[a]	Definition	References	Intensity[b]
Sweet aromatic[e]	The aromatics associated with sweet material such as caramel, vanilla, molasses, fruit[e]	caramel candy (Hershey Food Corporation, Hershey, PA)	60
Woody/hulls/skins[e]	The aromatics associated with base peanut character (absence of fragrant top notes) and related to dry wood, peanut hull, and skins[e]	peanut skins[k]	35
Cardboard[e,f]	The aromatic associated with somewhat oxidized fats and oils and reminiscent of wet cardboard[e,j]	wet cardboard[k]	24
Painty[e]	The aromatic associated with linseed oil, oil based paint[e]	boiled linseed oil[k] (Klean Strip, W. M. Barr & Co., Inc., Memphis, TN)	115
Burnt[e]	The aromatic associated with very dark roast, burnt starches, and carbohydrates, (burnt toast or espresso coffee)[e]	burnt peanuts[b,k] (lightness value L=40±1.0)	35
Earthy[e]	The aromatic associated with wet dirt and mulch[e]	wet soil[k] (Schultz Co., St. Louis, MO)	50
Fishy[e]	The aromatic associated with trimethylamine, cod liver oil, or old fish[e]	cod liver oil (E.R. Squibb & Sons, Inc., Princeton, NJ)	79
TASTES			
Salty[c,d,e]	The taste on the tongue associated with sodium chloride[c,d,e]	0.2% sodium chloride solution 0.35% sodium chloride solution 0.5% sodium chloride solution	25 50 85
Sour[e,g]	The taste on the tongue associated with citric acids[e,g]	0.05% citric acid solution 0.08% citric acid solution 0.15 % citric acid solution	20 50 100
Bitter[b,c,d,f,g]	The taste on the tongue associated with caffeine[b,c,d,f,g]	0.05% caffeine solution 0.08% caffeine solution 0.15% caffeine solution	20 50 100

(Continued on next page)

TABLE 3.3 (cont.)
DESCRIPTIVE ATTRIBUTES AND THEIR DEFINITIONS USED IN THE DESCRIPTIVE ANALYSIS OF ROASTED PEANUTS

Attributes[a]	Definition	References	Intensity[b]
Sweet[c,d,e,f]	The taste on the tongue associated with sugars[c,d,e,f]	2.0% sucrose solution	20
		5.0% sucrose solution	50
		10.0% sucrose solution	100
		15.0% sucrose solution	150
CHEMICAL FEELING FACTOR			
Astringency	The puckering of drying sensation of the mouth or tongue surface	grape juice (Welch's, Concord, MA)[f]	65

[a]Attributes are listed in the order perceived by the panelists
[b]Intensity ratings are based on 150 mm unstructured line scales
[c]Plemmons and Resurreccion (1998)
[d]Gills and Resurreccion (2000)
[e]Johnsen *et al.*(1980)
[f]Muego-Gnanasekharan and Resurreccion (1992)
[g]Meilgaard *et al.*(1991)
[h]Ward (1995)
[i]Szenesniak *et al.*(1963)
[j]Civille and Lyon (1996)
[k]Grosso and Resurreccion (2002)
[l]Divino *et al.* (1996)

TABLE 3.4.
INTENSITY RATINGS OF CONTROL SAMPLES[a] USED IN THE DESCRIPTIVE ANALYSIS OF ROASTED PEANUTS

Attributes	Intensity[b]
APPEARANCE	
Brown color	23
Moist	0
TEXTURE	
Crispness	29
Fracturability	50
Crunchiness	60
Hardness	85
Chewy	15
Tooth packing	67
FLAVOR	
Roasted peanutty	74
Raw beany	0
Oxidized	0
Sweet aromatic	14
Woody/hulls/skins	12.5
Cardboard	0
Painty	0
Burnt	0
Earthy	5
Fishy	0
TASTES	
Sweet	12
Sour	0
Salty	12
Bitter	12
FEELING FACTOR	
Astringent	15

[a]Medium roasted Georgia Green medium runner peanuts (L=50.0 ± 1.0)
[b]Intensity ratings are based on 150 mm unstructured line scales

TABLE 3.5.
PREDICTION EQUATIONS AND THEIR RESPECTIVE R^2 RELATING DESCRIPTIVE ATTRIBUTES TO STORAGE TIME (x_1), STORAGE WATER ACTIVITY (x_2), AND STORAGE TEMPERATURE (x_3)[a,b]

Attribute	Intercept	Parameter estimates for								R^2
		x_1	x_2	x_3	x_1^2	x_2^2	x_1x_2	x_1x_3	$x_1x_2x_3$	
TEXTURE										
Cripsness	-5.7514	0.3216	149.2675	--[c]	--	149.6844	-0.8613	--	--	0.80
Fracturability	73.7918	-0.2084	-101.3370	--	--	105.4783	0.5612	--	--	0.79
Crunchiness	-50.8692	1.0585	472.4999	--	--	-469.7338	-2.8440	--	--	0.81
Hardness	21.6508	0.6031	270.3118	--	--	-268.2215	-1.6589	--	--	0.71
Chewy	52.6825	-0.3529	-159.8555	--	--	161.2446	0.9459	--	--	0.83
Tooth packing	84.3376	-0.1324	-74.4686	--	--	78.5412	0.3668	--	--	0.77
FLAVOR										
Roasted peanutty	31.4099	0.9228	294.4414	-0.8364	--	-319.6853	-3.3962	--	--	0.85
Sweet Aromatic	1.5586	-0.0080	58.1573	-0.0556	--	-55.1176	--	0.0071	-0.0241	0.84
Woody/hulls/ Skins	-1.8119	0.1196	50.7700	0.0291	-0.0008	-43.7399	--	0.0056	-0.0236	0.76
Cardboard	37.0167	0.0698	-174.7779	0.1830	--	156.7565	--	-0.0280	0.0817	0.82
TASTES										
Salty	2.8719	0.0869	34.4812	0.0166	-0.0006	-30.2226	--	0.0035	-0.0154	0.78
Bitter	5.2266	0.1719	24.0013	0.0216	-0.0007	-20.7703	-0.1587	--	-0.0080	0.72
Sweet	-0.6823	0.1448	45.5111	0.0300	-0.0010	-38.2908	--	-0.0048	-0.0229	0.79

[a]Regressions based on 60 points (4 temperatures X 5 a_w X 6 sampling times), all values presented are significant at α=0.05
[b]Storage times (x_1) were between 2 to 91 days depending on treatments, storage water activities (x_2) were 033, 0.44, 0.54, 0.67 and 0.75 a_w and storage temperatures (x_3) were 23, 30, 35 and 40 °C
[c]"—" indicates that the variable is not significant in the model at α=0.05

FIG. 3.1. CONTROLLED HUMIDITY JAR USED IN THE STUDY OF ROASTED PEANUTS STORED AT DIFFERENT WATER ACTIVITY CONDITIONS

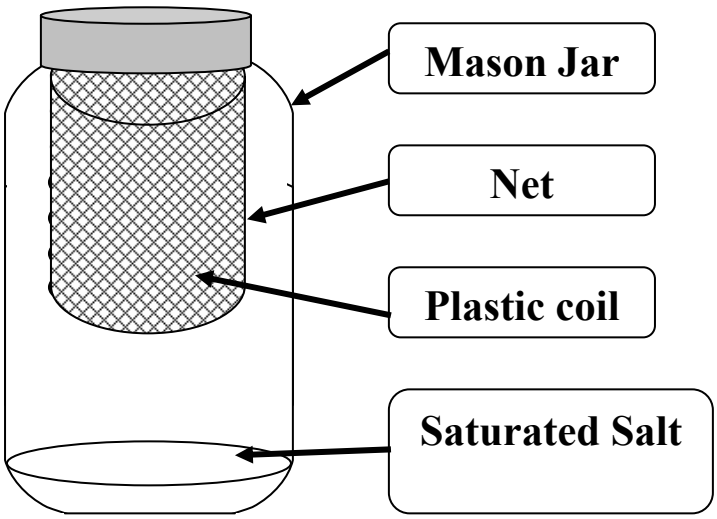

Mason Jar
Net
Plastic coil
Saturated Salt

FIG. 3.2. CONTOUR PLOTS ILLUSTRATING THE EFFECTS OF STORAGE TIME (DAYS) AND STORAGE WATER ACTIVITY ON THE CRISPNESS (A), FRACTURABILITY (B), CRUNCHINESS (C), HARDNESS (D), CHEWINESS (E) AND TOOTH PACKING (F) OF STORED ROASTED PEANUTS. SHADED AREAS (□) REPRESENT STORAGE CONDITIONS AND TIME THAT WERE NOT INCLUDED IN THE EXPERIMENTAL DESIGN.

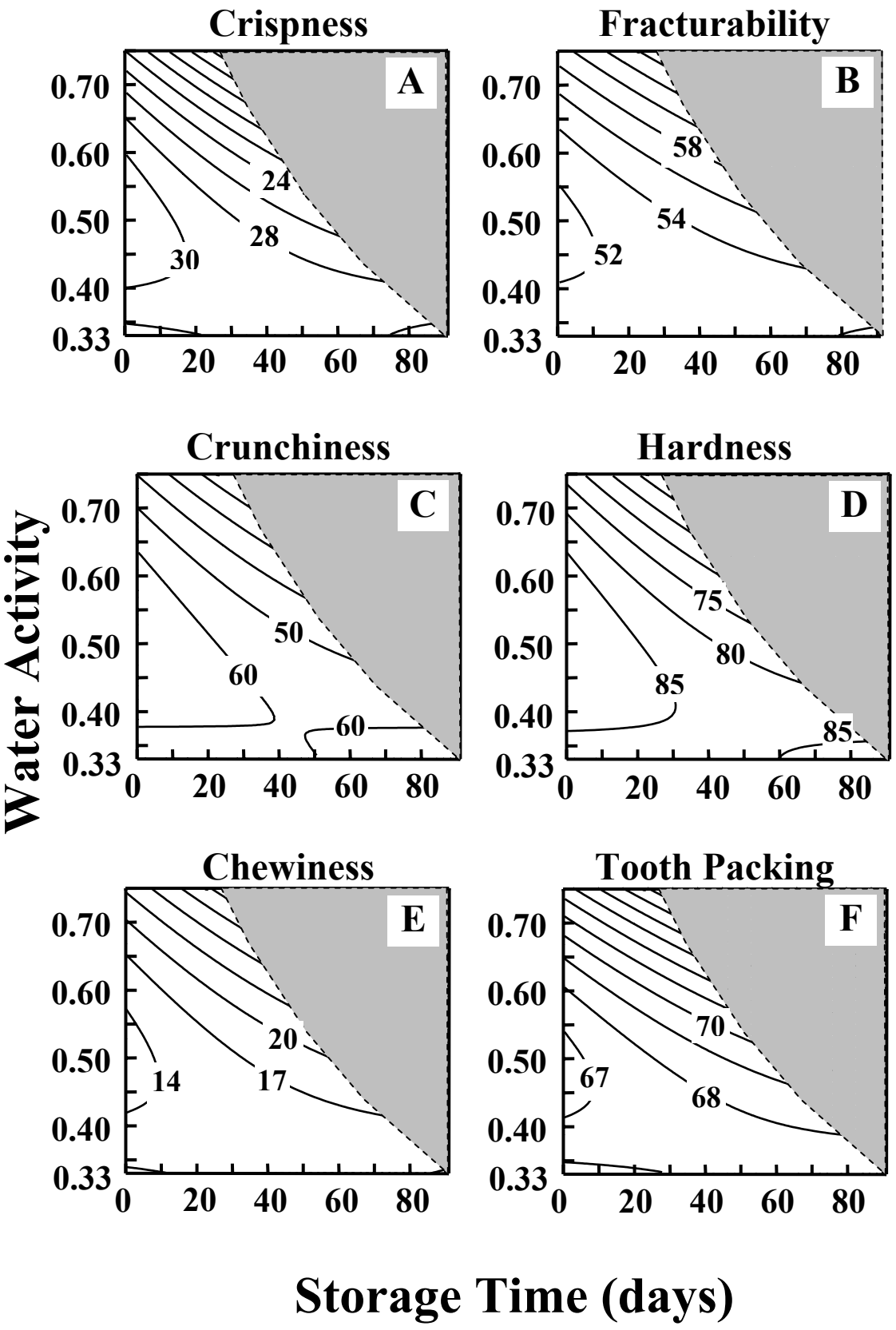

Crispness
A
0.70
0.60
0.50
0.40
0.33
0
20
40
60
80
24
28
30
Fracturability
B
58
54
52
Crunchiness
C
50
60
60
Hardness
D
75
80
85
85
Chewiness
E
20
17
14
Tooth Packing
F
70
67
68
Water Activity
Storage Time (days)

FIG. 3.3. CONTOUR PLOTS ILLUSTRATING THE EFFECTS OF STORAGE TIME (DAYS) AND STORAGE WATER ACTIVITY ON THE ROASTED PEANUTTY FLAVOR OF ROASTED PEANUTS STORED AT 23 (A), 30 (B), 35 (C), AND 40 °C (D). SHADED AREAS (□) REPRESENT STORAGE CONDITIONS AND TIME THAT WERE NOT INCLUDED IN THE EXPERIMENTAL DESIGN.

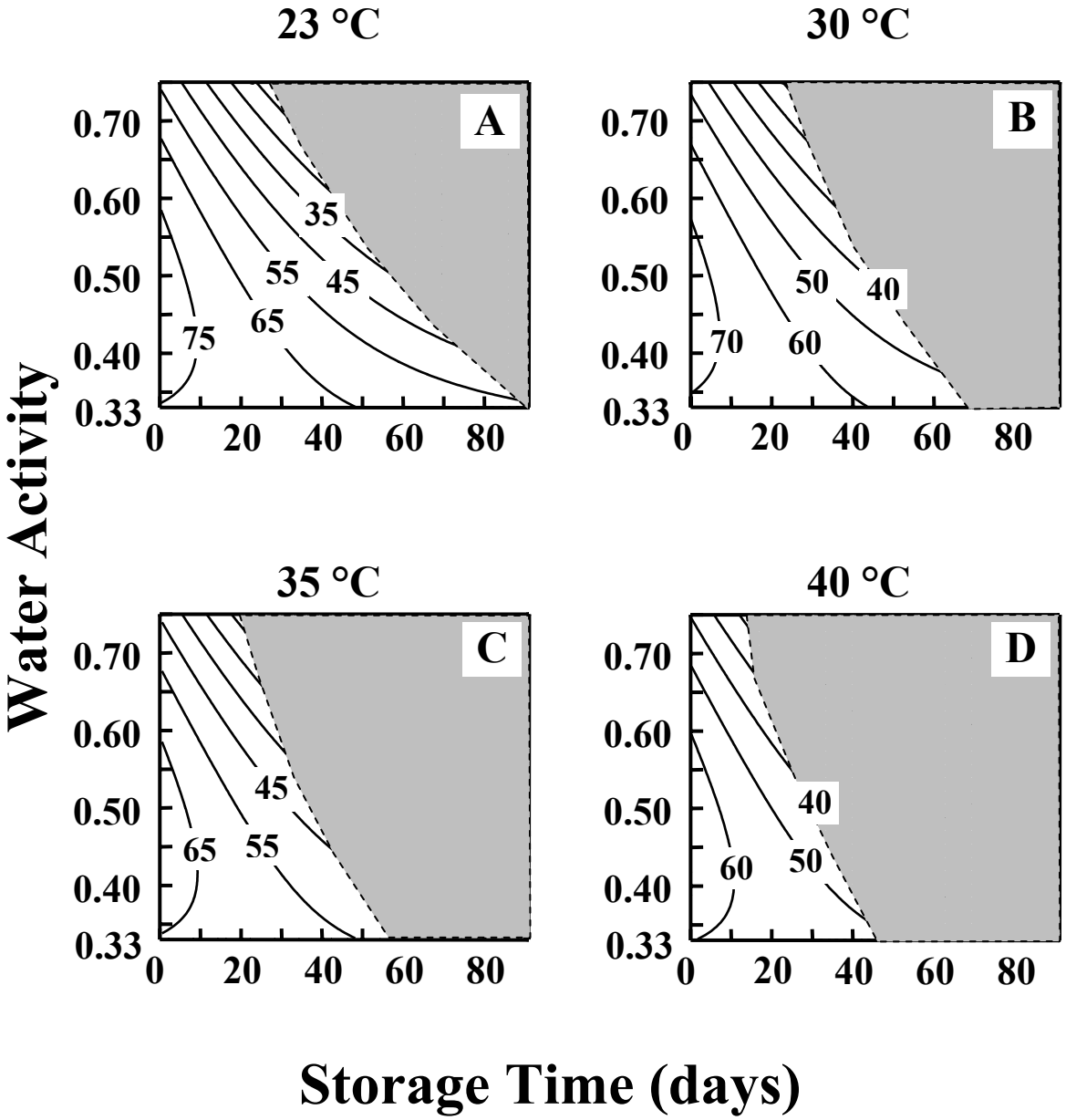
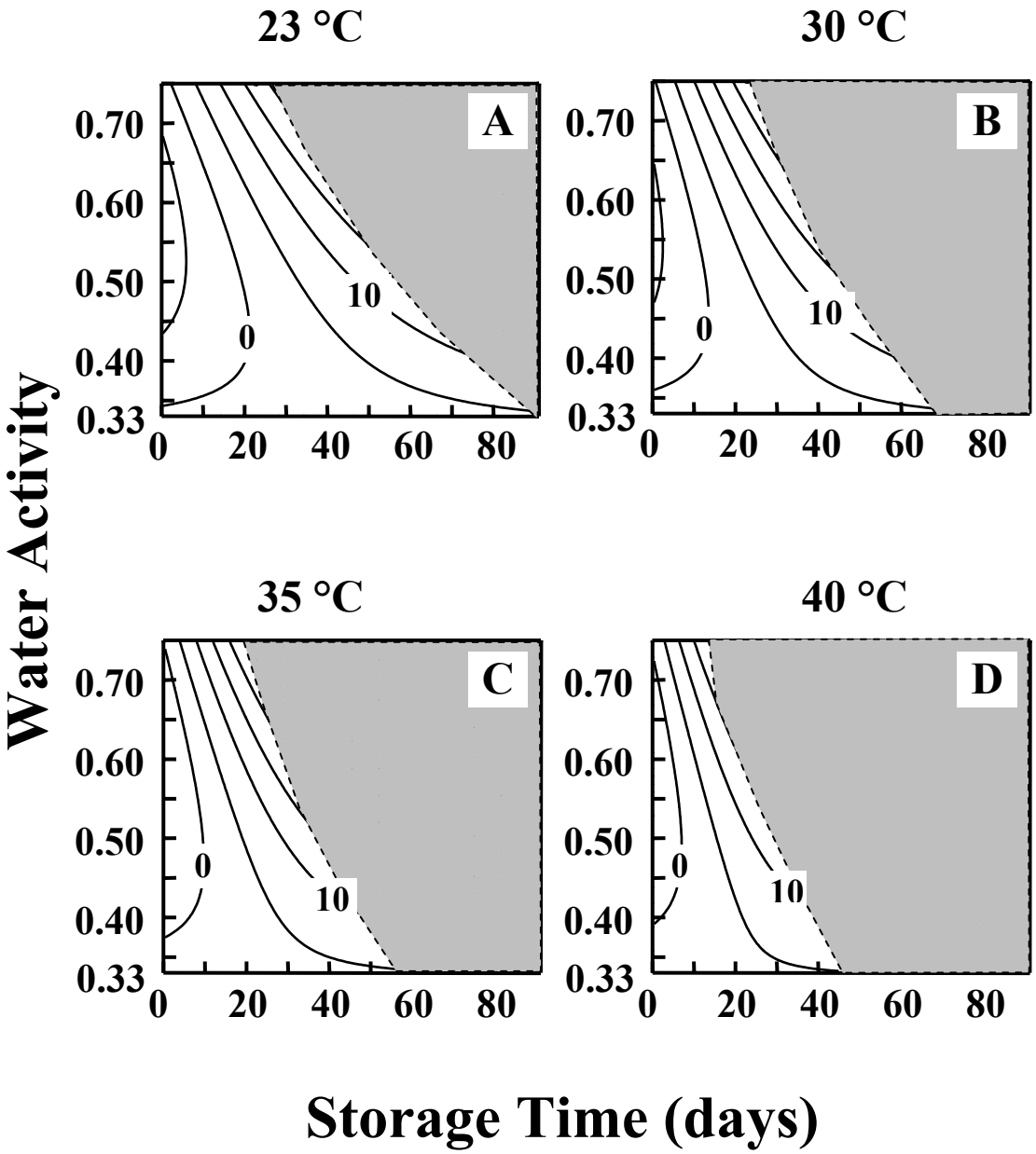

23 °C
30 °C
35 °C
40 °C
A
B
C
D
Water Activity
Storage Time (days)
0.70
0.60
0.50
0.40
0.33
0
20
40
60
80
75
65
55
45
35
70
60
50
40

FIG. 3.4. CONTOUR PLOTS ILLUSTRATING THE EFFECTS OF STORAGE TIME (DAYS) AND STORAGE WATER ACTIVITY ON THE CARDBOARD FLAVOR OF ROASTED PEANUTS STORED AT 23 (A), 30 (B), 35 (C), AND 40 °C (D). SHADED AREAS (▒) REPRESENT STORAGE CONDITIONS AND TIME THAT WERE NOT INCLUDED IN THE EXPERIMENTAL DESIGN.


23 °C
30 °C
35 °C
40 °C
A
B
C
D
0
10
0.70
0.60
0.50
0.40
0.33
0
20
40
60
80
Water Activity
Storage Time (days)

SECTION IV

CONSUMER ACCEPTANCE OF ROASTED PEANUTS AFFECTED BY STORAGE TEMPERATURE AND HUMIDITY CONDITIONS[3]

[3] Lee, C.M. and A. V. A. Resurreccion. To be submitted to *LWT Food Science and Technology*.

ABSTRACT

Consumer acceptance and intensity ratings of roasted peanuts stored at temperatures of 23, 30, 35, and 40°C, and water activities of 0.33, 0.44, 0.54, 0.67 and 0.75 were determined over time. Consumer acceptance ratings, including overall, appearance, color, and texture, were not affected by storage water activity but not storage temperature. Similarly, consumer intensity ratings of crunchiness were affected by storage water activity and time, but not storage temperature. However, aroma acceptance, flavor acceptance, and crunchiness and stale/oxidized/rancid intensity ratings of roasted peanuts were dependent on storage temperature.

At 23 °C, the shelf life (consumer acceptance >5.0) of roasted peanuts stored between 0.33 and 0.75 a_w was determined by overall acceptance and decreased by approximately 50% with a 0.1 increase in water activity. At accelerated temperatures of 30, 35 and 40 °C, shelf life of roasted peanuts was predominantly limited by flavor acceptance (>5.0), and to a lesser extent, by aroma and overall acceptance. The shelf life of roasted peanuts stored at accelerated temperatures decreased by 50% or more with a 0.1 increase in water activity.

INTRODUCTION

Shelf life of roasted peanuts is determined by various storage conditions, including temperature, time, and surrounding relative humidity (RH). Compared with the effects of temperature and time, changes in surrounding water activity (a_w = %RH/100) usually result in more complex reactions. When exposed to an environment with a_w different from its original state, moisture transfer occurs between the food and the environment until an equilibrium a_w is reached. Generally, the accelerating factor due to a change in 0.1 a_w (Q_a) is 2 or 3 for the rate of enzymatic and chemical reactions (Labuza 1982). In a study on the shelf life of roasted and ground coffee, an increase of 0.1 in water activity resulted in a 60% increase in deterioration rate, whereas an increase of 10 °C only resulted in a 20% increase in deterioration (Cardelli and Labuza 2001). Roasted peanuts lose freshness and crispness if brought into contact with ingredients of more than 6% moisture, and develop a soggy nut aroma and flavor (Woodroof 1983). It is crucial that the critical water activity (a_c) at which the product is unacceptable is known in order to estimate shelf life of a product (Labuza and Schmidl, 1985).

Shelf life refers to the end of consumer quality, and is the time at which a percentage of consumers are displeased by the product (Labuza & Schmidl 1988). According to Labuza & Schmidl (1988), hedonic testing is of limited use in shelf life evaluation but is commonly used. While trained panelists are more sensitive to changes, affective sensory tests are conducted to better understand the correlations between sensory changes and consumer acceptance (Dethmers 1979). In a study by Peryam (1964) on fish fingers and beef burgers, consumers were sensitive to small changes in quality, reflecting differences in trained panel ratings. Significant changes in descriptive rating does not necessary translate to significant difference in acceptability, suggesting a conflict between statistical and commercial significance (Griffiths 1985).

Shelled, blanched and roasted peanuts absorb moisture much more rapidly than other forms of peanuts (Woodroof and others 1945). Peanut flavor in candy is improved if the peanuts are first roasted to a light brown color with a moisture content of less than 3% (Woodroof 1983). Roasted peanuts stored at 48-50 °F and at a humidity of <60% were shelf stable for 90 days (Anon. 1978). Using an arbitrary end point of 6 on a 15-point descriptive scale for peanut flavor intensity, the shelf life of roasted Florunner peanuts stored at 25 °C at 40% relative humidity was predicted to have a shelf life of 47 days (Braddock and others 1995).

Comparing control and oxidized peanut pastes made from the same peanut source, oxidized peanut paste was found to have lower roasted peanutty, sweet aromatic and sweet, and higher cardboard and painty intensity (Civille and Dus 1992). The a_c of potato chips was found to be 0.40 a_w (Quast and Karel 1972), and for products such as potato chips, popcorn, puffed corn curls and saltines, were in the range of 0.35 to 0.50 a_w (Katz and Labuza 1981). When roasted high oleic peanuts were stored at water activities between 0.12 and 0.67, it was found that samples stored between 0.33 and 0.44 showed the least oxidation, loss of crunchiness and maintenance of desirable flavor (Baker and others 2002).

The objective of this study was to investigate the changes in color, flavor, and texture of roasted peanuts as affected by storage time, temperature, and water activity between 0.3 and 0.7 (low to intermediate moisture). The specific objectives are to determine the consumer acceptance of roasted peanuts as affected by storage time, temperature, and water activity using consumer tests; to model the effects of storage time, temperature and water activity on consumer acceptance and intensity ratings; and to identify attributes that are the limiting factors in consumer acceptance of stored roasted peanuts.

MATERIALS & METHODS

Sampling scheme

A scheme was determined to obtain samples from peanuts stored at different temperatures and water activities representing 40 and 110% of estimated shelf life (ESL). A survey among retailers concluded that the shelf life of roasted peanuts stored at ambient condition is approximately 90 d (Anon., 1971). Using the following equation (Labuza & Schmidl, 1985), the ESL of peanuts stored at an accelerated temperature of T_2 was calculated:

$$\theta_{T_2} = \theta_{T_1} \times Q_{10}^{\Delta/10}$$

where θ = shelf life, $T_1<T_2$, $\Delta = T_1 - T_2$. By applying an assumed Q_{10} of 1.5, the shelf life (100% ESL) of peanuts at 23 °C of 90 d was projected to be 68, 55 and 45 d at 30, 35 and 40 °C, respectively. The equation was adapted to reflect a change in water activity such that the shelf life at different water activity can be projected:

$$\theta_{a_w''} = \theta_{a_w'} \times Q_a^{-|\Delta|/0.1}$$

where θ = shelf life, a_w' = water activity 1, a_w'' = water activity 2, $\Delta = a_w' - a_w''$, and Q_a=accelerating factor due to a 0.1 change in a_w. Using an assumed Q_a of 1.3, the new equation was applied in calculating the ESL of each treatment. A sampling scheme was determined (Table 4.1) and samples were stored and removed after storing for the number of days corresponding to 40 and 110% ESL.

Experimental Design

The experimental design consisted of four storage temperatures of 23, 30, 35, and 40 °C and five storage a_w of 0.33, 0.44, 0.54, 0.67 and 0.75 evaluated over storage time (Table 4.1). Depending on the treatment condition, samples were stored for 5 to 91 d shown in Table 4.1. A

total of 20 samples per ESL were collected, representing 20 different treatment conditions. Control samples and samples that were not evaluated immediately were packaged after sampling in 0.075 mm (3-mil) polyethylene bags (Koch Supplies, Kansas City, Mo., U.S.A.), flushed with 99% nitrogen, and stored at 4°C. For each ESL, consumers (n=50) evaluated 10 treatment samples per day for a total of 4 days.

Controlled Humidity Chambers

Saturated salts including magnesium chloride (Fisher Scientific, Yonkers, N.Y., U.S.A.), potassium carbonate (Mallinckrodt Baker, Inc., Phillipsburg, N.J., U.S.A.), magnesium nitrate (Mallinckrodt Baker, Inc., Phillipsburg, N.J., U.S.A.), sodium bromide (Mallinckrodt Baker, Inc., Phillipsburg, N.J., U.S.A.), sodium nitrite (Mallinckrodt Baker, Inc., Phillipsburg, N.J., U.S.A.), potassium iodide (Mallinckrodt Baker, Inc., Phillipsburg, N.J., U.S.A.) and sodium chloride (Morton International, Inc., Chicago, Ill., U.S.A.) were used to maintain various equilibrium humidity of 0.33, 0.44, 0.54, 0.67 and 0.75 (Greenspan, 1977). To counteract the effect of temperature on the equilibrium humidity of the saturated salts used to maintain 0.54 and 0.67 a_w, two different chemicals were used (Table 4.2). To attain storage water activity of 0.54, magnesium nitrate was used for chambers stored at 23 and 30°C, and sodium bromide for chambers stored at 35 and 40 °C (Table 4.2). Similarly, for a water activity of 0.67, sodium nitrite was used for chambers stored at 23°C, whereas potassium iodide was used for chambers intended for 30, 35 and 40 °C (Table 4.2).

The storage chamber was designed so that the samples were exposed to the surrounding humidity and were not in contact with the saturated salt slurries (Fig. 4.1). Half-gallon wide mouth Mason jars (Ball Corp., Broomfield, Colo., U.S.A.), saturated salt slurries and a plastic

net with 0.5 cm holes maintained in a cylindrical form with a plastic coil (Magic Spring, Dolgencorp, Inc., Goodlettsville, Tenn., U.S.A.) were used (Fig. 4.1). The plastic coil was threaded around and through the plastic net to provide a cylindrical shape to be filled with samples and suspended inside the jar (Fig. 4.1).

Saturated salts slurries were prepared in Mason jars at an ambient temperature of 23 °C or inside a water bath (Model 220A, Napco Inc., Portland, Ore., U.S.A) maintained at 30, 35 or 40 °C to obtain water activities from 0.33 to 0.75 (AOAC 1995). Saturated salts were added to the jar and sufficient deionized water was added to form slurry (AOAC 1995). Sufficient salts or deionized water were added to form slurry with approximately 2 mm of liquid layer above the crystals (Labuza 2001). The cylindrical shape plastic net was inserted into the jar and the jar was closed and stored at its respective temperature for a week to attain an equilibrium relative humidity between the saturated salt slurry and the interior atmosphere (Labuza 2001).

Before adding the roasted peanuts, two rubber bands were used to secure the plastic net around the outside neck of each jar so that the peanuts would not drop to the bottom of the jar during filling (Fig. 4.1). After adding the roasted peanuts (350 g), the storage chambers were closed and sealed tightly, and were held in storage for their respective ESL shown in Table 4.1.

The water activity of the atmosphere inside the storage chambers were monitored using a Safe Storage Monitor (Decagon Devices, Inc., Pullman, Wash., U.S.A.) for two weeks. Data collected on the monitor were transferred using SafeLink software ((Decagon Devices, Inc., Pullman, Wash., U.S.A.). The storage chambers were inspected every week and more saturated salty or deionized water was added if necessary.

Sample Preparation

Shelled medium Georgia Green peanuts (2001 crop, McCleskey Mills, Smithville, Ga., U.S.A.) were purchased and stored at 4°C (Nor-Lake, Inc., Hudson, Wis., Ga., U.S.A.). Peanuts were sorted for defective kernels and foreign objects, and were stored for up to two weeks prior to roasting. Sorted peanuts were equilibrated to 23°C for at least 12 h before roasting in 4 kg batches. The peanuts were roasted at 190° for 6 min in a rotary gas roaster (Model L5, Probat Inc., Memphis, Tenn., U.S.A.) to attain a medium roast, or a color Lightness (L) value of 50 ± 1.0 (Johnsen and others 1988). Roasted peanuts were cooled for 3 min, then blanched using a dry blancher (Model EX, Ashton Food Machinery Co. Inc., Newark, N.J., U.S.A.). After blanching, peanuts were sorted and rejected if they had any remaining testa, were discolored or were damaged. A total of 30 roasting batches were needed to roast 135 kg of raw peanuts. Roasted and blanched peanuts were mixed in a rotating coating pan (Stokes Equipment Inc., Ohio, U.S.A.), cooled to 23°C, packaged in polyethylene bags that were flushed with 99% nitrogen, and stored at 4°C.

Sampling Procedure

After storing for their respective ESL (Table 4.1), storage chambers were removed from the incubators and equilibrated to ambient temperature (23°C) for 4 h prior to opening. This was to prevent sudden condensation of moisture (Labuza 2001). Samples were removed and packaged as previously described, and were accumulated until all twenty treatments representing the same ESL were collected.

Consumer Test

Fifty untrained consumers, consisting of employees, students and faculty members, were recruited from the University of Georgia Griffin Campus for the consumer test. Panelists were recruited if (a) they are not allergic to peanuts, (b) their ages are between 19 to 65 years, and (c) they eat peanut or peanut products at least once a month. Four consumer tests, each with 50 panelists, were conducted to completely evaluate samples of 40 and 110%ESL. Consumers who participated in one of the consumer tests did not necessarily participate in another test.

Test Location. The consumer tests were conducted at the Department of Food Science and Technology, Griffin Campus in nine hourly sessions between 9 and 11pm, and between 2 and 7 pm on each day. The test was conducted in a laboratory setting of partitioned booths illuminated with two 50 W white incandescent bulbs providing 738 lx of light.

Test material. Roasted peanuts, as previously described, were evaluated by the consumer panels. In addition to the twenty treatment samples, the control sample was also evaluated. At least one hour prior to testing, 5 g of each sample was removed from the original packaging and placed into 28.57-g plastic cups with lids (Solo Cup Co., Highland, Ill., U.S.A.). Samples were coded with three-digit random numbers and served at ambient temperature (23 °C) on a stainless steel tray lined with white paper.

Test procedure. Ten samples, plus a control sample, of roasted peanut were evaluated in a monadic sequential order during each day, with a mandatory break of 5 min after the 4^{th} and 8^{th} samples to reduce panelist fatigue. A total of 4 d of testing was conducted to completely test all 40 treatment samples. During the break, panelists filled out a computerized demographics questionnaire regarding their age, gender, marital status, occupation, educational background,

income and eating habits. The evaluation sequence was based on a randomized complete block design, controlled by Compusense® *five*.

Ballot. Consumers recorded their answers on computer ballots consisting of acceptance and intensity questions. Panelists rated stored roasted peanuts in terms of overall acceptance, as well as acceptance of appearance, color, aroma, flavor, and texture, using a 9-point hedonic scale, with 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely (Peryam 1964). For overall, flavor and texture acceptance, panelists were instructed to eat two pieces of roasted peanut to evaluate the attributes. In addition, panelists also rated the intensities of crunchiness, roasted peanutty flavor and stale/oxidized/rancid flavor using a 9-point intensity scale anchored at the two ends of the scale. For crunchiness intensity, the anchor words were 'not crunchy at all' and 'very crunchy', representing the 1- and 9-point on the scale. The anchor words for roasted peanutty flavor and stale/oxidized/rancid flavor were 'none' and 'high' for the 1- and 9-point ratings. Panelists were instructed to eat three pieces of the samples to evaluate all three intensity attributes. For each panelist, unsalted saltine crackers and deionized water were provided for rinsing, and cups with lids were provided for expectoration.

Statistical Analysis

Results from the experiment were analyzed using the SAS (Ver. 8.0e, SAS Institute Inc., Csry, N.C., U.S.A.). Regression analysis (PROC REG) was used to construct the relationships of mean consumer ratings and storage time, water activity and temperature. Prediction models that are significant ($p<0.05$) were determined for each attribute. Reduced models with adjusted $R^2 \geq 0.65$, having the highest adjusted R^2 and lowest mean square error (MSE) and Mallow's C_p value, and that were not significantly different ($p>0.05$) from its full model were selected for the

prediction model. The partial F-statistic employed in the determination of significance difference between the reduced model and the full model is as follow:

$$F = \frac{(SSE_{reduced} - SSE_{full})}{(df_{reduced} - df_{full})}$$

where *SSE* is the sum of squares of error, *MSE* is the mean square error and *df* is the degrees of freedom. The full model selected is a second order polynomial regression model with 3 linear terms, including storage time (x_1), storage water activity (x_2), and storage temperature (x_3); their squared terms; and all possible cross products as shown:

$$Y=\beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3+\beta_{11}x_1^2+\beta_{22}x_2^2+\beta_{33}x_3^2+\beta_{12}x_1x_2+\beta_{13}x_1x_3+\beta_{23}x_2x_3+\beta_{123}x_1x_2x_3+\varepsilon$$

where Y is the rating of the descriptive attribute; β_0 is the intercept when x_1, x_2 and x_3 equal 0; β_1, β_2 and β_3 are parameter estimates of x_1, x_2 and x_3, representing storage time, temperature and water activity respectively; β_{11}, β_{22} and β_{33} are the parameter estimates of their square terms x_1^2, x_2^2 and x_3^2; and β_{12}, β_{13}, β_{23}, and β_{123} are the parameter estimates of their cross product terms, x_1x_2, x_1x_3, x_2x_3, and $x_1x_2x_3$. Contour plots for each significant model of the descriptive attributes were constructed using Statistica® (Ver. 6.0, Statsoft, Inc., Tulsa, Okla., U.S.A.).

RESULTS & DISCUSSION

Significant regression models with adjusted R^2>0.65, lowest Mallow's C_p value and lowest mean square error, that were not different from the full model as determined by the F-test,

are shown in Table 4.3. Storage temperature was not a significant regressing variable in some models, and these include overall acceptance, as well as acceptance of appearance, color and texture, and crunchiness intensity ratings (Table 4.3). Reduced models had an R^2 ranging from 0.60 to 0.75 (Table 4.3). Contour plots were constructed to depict the effect of storage time and water activity of each attribute, and are presented in Fig. 4.2 to 4.7. Since this was a storage study, the shaded areas indicate that the samples were not subjected to storage beyond their ESL, and no further implications were made on those points inside the shaded areas (Fig. 4.2 to 4.7).

Overall acceptance. Overall acceptance was affected by storage time and water activity, but not temperature (Fig. 4.2A). Control samples were rated at 6.51 on the 9-point scale for overall acceptance. At day 0, only roasted peanuts stored at 0.73 or more are predicted to be unacceptable, or less than 5 on a 9-point scale (Fig. 4.2A). Roasted peanuts are predicted to have lower overall acceptance score with increasing storage time and water activity (Fig. 4.2A). Samples stored at a water activity of 0.33 to 0.39 are predicted to be acceptable (>5.0) for about 80 d (Fig. 4.2A). For example, if roasted peanuts were added to cookies with a water activity of 0.3 to 0.4, the shelf life is thus limited to approximately 3 months. Increasing the water activity of an ingredient surrounding roasted peanut to 0.5 will result in roasted peanuts that remain acceptable (>5.0) for only 40 d (Fig. 4.2A). Thus, roasted peanuts exposed to raisins of 0.5 a_w in trail mixes are predicted to be acceptable (>5.0) for about 40 d. Using overall acceptance as the determining factor, the shelf lives of roasted peanuts stored at 0.33, 0.44, 0.54, 0.67 and 0.75 a_w are calculated using the regression equation (Table 4.3) and estimated as 151, 55, 32, 10 and 0 days.

Appearance and color acceptance. Appearance and color acceptance were rated similarly by the consumers (Fig. 4.2B and 4.2C). Control samples were rated 5.42 and 5.52 on

appearance and color, respectively. The roasting process resulted in peanuts that had black speckles and were not desirable. Samples stored at 0.55 a_w or less were rated more than 5 (neither like nor dislike) on appearance and color acceptance for at least 50 days. Increasing the storage time and water activity resulted in decreasing acceptance of appearance and color (Fig. 4.2B and 4.2C). Samples stored at 0.55 a_w and above were rated (<5.0) unacceptable in appearance prior to the end of the experiment for the respective treatments, such as those stored at 0.67 and 0.75 (Fig. 4.2B). Similarly, samples stored at 0.58 a_w and above were rated unacceptable (<5.0) prior to the end of the study (Fig. 4.2C). The authors observed that samples stored at higher water activity were darker, thus displeasing consumers because of unusual color.

Texture acceptance. Texture acceptance is one of the most important criteria in consumer acceptance of roasted peanut. The effect of storage time and water activity was greater compared to that of appearance and color, as shown by closer contour lines that indicate rapid decrease in acceptance ratings. Control samples were rated 7.39 on texture acceptance, higher than ratings for overall acceptance (6.51). Increasing storage time and water activity resulted in samples that were rated lower in texture acceptance (Fig. 4.3D). Samples stored at 0.50 a_w or below were rated at least 5.0 on texture acceptance at the end of the study, or between 60 to 91 days (Fig. 4.2D). Knowing that the water activity of intermediate water activity ingredients such as caramel is between 0.60 and 0.65 (Beuchat, 1981), the texture of roasted peanut in such ingredient will remain acceptable (>5.0) for between 30 to 40 days (Fig 2D). Based on the regression model of texture acceptance (Table 4.3) and an acceptable rating of 5.0 or more, the shelf life of peanuts stored at 0.33, 0.44, 0.54, 0.67 and 0.75 a_w was predicted to be 226, 149, 95, 13 and 0 days.

Aroma acceptance. Temperature was a significant regressor in the models relating consumer aroma acceptance to storage variables (Table 4.3). Contour plots depicting the effect of storage time and water activity at each of the storage temperatures, 23, 30, 35 and 40 °C, are shown in Figure 4.3A, 4.3.B, 4.3C and 4.3D, respectively. The aroma acceptance rating of the control samples was 6.60. Increasing the storage temperature from 23 to 40 °C resulted in a decrease in decreasing aroma acceptance, and the change was much more rapid at 35 and 40 °C, as indicated by the closer contours at higher temperatures. At higher temperatures such as 30, 35 and 40 °C, all samples were rated less than 5 at the end of the study (Fig. 4.3B, 4.3C and 4.3D), indicating that none of the samples were acceptable to the consumer in terms of aroma. Increasing storage time or water activity also resulted in lower aroma acceptance ratings. This was indicated by bigger and smaller spaces between contours at higher and lower water activities, respectively. The model of consumer aroma acceptance has the highest R^2 (Table 4.3), and shelf life of roasted peanuts at different temperatures can be calculated from the model. Using a rating of 5 as the minimum for aroma acceptance, the shelf life of roasted peanuts stored at 23 °C and at 0.33, 0.44, 0.54, 0.67, and 0.75 a_w are estimated to be 145, 85, 57, 29 and 13 days, respectively.

Flavor acceptance. In contrast with aroma acceptance, the effect of storage on flavor acceptance was more critical, and this indicates that more samples were rated unacceptable (<5.0) with increasing storage time, water activity and temperature (Fig. 4.4). Control samples were rated 6.76 on flavor acceptance, and this decreases with increasing storage temperature, time, or water activity. Samples stored at elevated temperatures of 30, 35 and 40 °C were rated less than 5.0 in flavor acceptance by the end of the study, and the rates of change was faster than 23 °C, as indicated by closer contours at higher temperatures (Fig. 4.4B, 4.4C and 4.4D).

Increasing water activity from 0.33 to 0.75 resulted in roasted peanuts that were rated less acceptable in flavor. Only samples stored at 23 °C and between 0.33 and 0.43 a_w had a shelf life of at least 65 days, as indicated by a flavor acceptance of 5 or more (Fig. 4.4A). With the exception of samples stored at 23 °C and at 0.33 and 0.44 a_w, all samples were rated unacceptable (<5.0) at the end of storage (Fig. 4.4).

Roasted peanutty flavor intensity. Consumers detected a similar trend in the loss of roasted peanutty flavor intensity as with the flavor acceptance. Temperature was a significant variable in predicting roasted peanutty intensity, and contour plots were constructed for each of 23, 30, 35 and 40 °C, and are shown in Fig. 4.5. Control samples had a rating of 7.1 on roasted peanutty flavor intensity. Only samples stored at a water activity of 0.45 or below are predicted to have a rating of 7.1 within 10 days of storage (Fig. 4.5). Roasted peanutty flavor was predicted to decrease with increasing storage temperature, water activity, and time (Fig. 4.5). At each temperature, increasing water activity resulted in a higher rate of decrease of roasted peanutty flavor (Fig. 4.5). Increasing the storage temperature resulted in a more rapid rate of change, as indicated by contours that are closer-spaced at higher temperatures (Fig. 4.5). Samples that were stored at 30 °C or above were rated less than 5.0 on roasted peanutty intensity by the end of the study (Fig. 4.5B, 4.5C, and 4.5D).

Crunchiness intensity. Crunchiness intensity was not affected by storage temperature (Table 4.3), and a contour plot illustrating predicted crunchiness intensity is shown in Fig. 4.6. Crunchiness intensity was predicted to decrease with increasing storage water activity and time (Fig .6). The rate of decrease for crunchiness intensity increases with increasing storage water activity (Fig. 4.6). Samples stored between 0.33 and 0.48 a_w are predicted to have a crunchiness intensity of 5.0 or above for at least 60 days (Fig. 4.6).

Stale/rancid/oxidized flavor intensity. Consumers rated stale/rancid/oxidized flavor intensity that is commonly associated with peanuts stored beyond their shelf life. Since temperature was a significant regressor in the prediction model, four different graphs were constructed to represent the predicted changes in stale/rancid/oxidized flavor intensity at 23, 30, 35 and 40 °C (Fig. 4.7). Control samples were rated 2.80 on stale/rancid/oxidized flavor intensity. As storage temperature increases, stale/rancid/oxidized flavor intensity increases more rapidly and this was indicated by the closer contours in graphs representing higher temperatures of 35 and 40 °C (Fig. 4.7C and 4.7D) as compared to those at 23 and 30 °C (Fig. 4.7A and 4.7B). With the exception of samples stored at 23 °C, panelists rated all samples higher than 5.0 in stale/rancid/oxidized flavor intensity by the end of the study (Fig. 4.7). Similarly, stale/rancid/oxidized flavor intensity increased with increasing storage days for all samples. Within the same storage temperature, the rate of increase in stale/rancid/oxidized flavor intensity increases with increasing storage water activity, which was indicated by contours that are closer at higher water activity (Fig. 4.7).

Shelf life prediction using multiple consumer acceptance attributes. Using 5.0 as the limit for overall acceptance and acceptance for appearance, color, aroma, texture and flavor, contour plots were overlaid to identify the estimated shelf life when roasted peanuts are stored at 23, 30, 35 and 40 °C (Fig. 4.8A, 4.8B, 4.9A, and 4.9B). At 23 °C, overall acceptance was the only limiting factor, and samples that are rated less than 5.0 on overall acceptance are considered acceptable (Fig. 4.8A). The shape of the curve corresponding to a 5.0 in overall acceptance indicates that the Q_a of roasted peanuts was approximately 2 between 0.45 and 0.75 a_w, such that an increase of 0.1 a_w reduced its shelf life (>5.0 in overall acceptance) by 50%. The effect of

water activity on the shelf life of roasted peanut was lowest between 0.33 and 0.45 a_w, as indicated by a flatter curve.

In addition to overall acceptance, the shelf life of samples stored at 30, 35 and 40 °C are also limited by aroma, flavor, and overall acceptance (Fig. 4.8B, 4.9A and 4.9B). For the most part, the limiting effect of flavor acceptance superceded that of overall acceptance, while aroma acceptance was the least important factor among the three (Fig. 4.8B, 4.9A and 4.9B). The upward sloping shape of the optimum region (>5.0 in consumer acceptance) indicated that the Q_a of roasted peanut at 30 and 35 increased with increasing storage water activity between 0.33 and 0.75 (Fig. 4.8B and 4.9A). However, consumer acceptance (>5.0) of roasted peanuts stored at 40°C indicated two different constant Q_a's between 0.33 and 0.62, and between 0.62 and 0.75 (Fig. 4.9B). The rate of decrease in shelf life of roasted peanuts stored at 30, 35 and 40°C increased with increasing storage temperatures (Fig. 4.8A, 4.8B, 4.9A and 4.9B).

Shelf life of roasted peanut was affected by storage time, water activity and temperature. At 23 °C, the shelf life of roasted peanut stored at different water activity conditions was predicted by overall acceptance. At elevated temperatures of 30, 35 and 40 °C, shelf life of roasted peanuts was predominantly predicted by a flavor acceptance, and to a lesser extent, by aroma and overall acceptance. The Q_a of roasted peanuts stored at 23°C remains approximately constant at 2 between 0.33 and 0.75 a_w. However, increasing the temperatures to 30, 35 and 40°C resulted in an increasing Q_a between 0.33 and 0.75 a_w.

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REFERENCES

Anonymous. (1978). Roasted peanuts stay fresh one year. Food engineering 50(12):95.

Anonymous. (1971). Food stability survey, Vol II. Rutgers University Dept. of Food Science, for the State of new jersey Dept. of Health and the U.S. Dept. of Agriculture/Economic Research Service. pp. 57. U.S. Government Printing Office, Washington D.C.

AOAC, International. (1995). Chp. 42: Water activity of canned vegetables. Method No. 978.18. Official methods of analysis, 16th ed. (pp 1-2). Arlington, VA: Association of Official Analytical Chemists.

Baker, G.L., Sims C.A., Gorbet D.A., Sanders T.H., & O'Keefe SF. (2002). Storage water activity effect on oxidation and sensory properties of high-oleic peanuts. J. Food Sci. 67(5), 1600-1603.

Beuchat, L.R. (1981). Microbial stability as affected by water activity. Cereal Foods World. 26(7), 345-349.

Braddock, J.C., Sims, C.A., & O'Keefe, S.F. (1995). Flavor and oxidative stability of roasted high oleic acid peanuts. J. Food Sci. 60(3), 489-493.

Cardelli, C. & Labuza, T.P. (2001). Application of Weibull Hazard analysis to the determination of the shelf life of roasted and ground coffee. Lebensm.-Wiss. U.-Technol. 34(5), 273-278.

Civille, G.V. & Dus, C.A. (1992). Sensory evaluation of lipid oxidation in foods. In: St. Angelo AJ, editor. Lipid oxidation in food. ACS Symposium Series. (pp. 279-289). Washington, DC: American Chemical Society.

Dethmers, A.E. (1979). Utilizing sensory evaluation to determine product shelf life. Food Technol. 33(9), 40-42.

Greenspan, L. (1977). Humidity fixed points of binary saturated aqueous solutions. J. Res. of the National Bureau of Standards - A. Physics and Chemistry. 81(A), 89-96.

Griffiths, N. (1985). Sensory analysis in measuring shelf-life. Food, Flavours, Ingredients, Packaging and Processing. 7(9), 47-48.

Johnsen, P.B., Civille, G.V., Vercellotti, J.R., Sanders, T.H., & Dus, C.A. (1988). Development of a lexicon for the description of peanut flavor. J. Sensory Stud. 3, 9-17.

Katz, E.E. & Labuza, T.P. (1981). Effect of water activity on the sensory crispness and mechanical deformation of snack food products. J. Food Sci. 46(2), 403-409.

Labuza, T.P. & Schmidl, M.K. (1988). Use of sensory data in the shelf life testing of foods: principles and graphical methods for evaluation. Cereal Foods World 33(2), 193-206.

Labuza, T.P. & Schmidl, M.K. (1985). Accelerated shelf-life testing of foods. Food Technol. 39(9), 57-64, 134.

Labuza, T.P. (1982). Moisture gain and loss in packaged foods. Food Technol. 36(4), 92-94, 96-97.

Labuza, T.P., Kaanane, A., and Chen J.Y. (1985). Effect of temperature on the moisture sorption isotherms and water activity shift of two dehydrated foods. J. Food Sci. 50, 385-391.

Labuza, T.P. (2001). Standard Desiccator Method for Isotherms. Available from: http://fscn1.fsci.umn.edu/ted_Labuza/awimages/Salt%20solutions%20FOR%20Isotherm.pdf. Accessed Jan 16.

Peryam, D.M. (1964). Consumer preference evaluation of the storage stability of foods. Food Technol. 18, 1460-1463.

Quast, D.G. & Karel, M. (1972). Effects of environmental factors on the oxidation of potato chips. J. Food Sci. 37(4), 584-588.

Woodroof, J.G., Cecil, S.R., & Thompson, H.H. (1945). The effects of moisture on peanuts and peanut products. Georgia Agr. Expt. Sta. Bull. No. 241.

Woodroof, J.G. (1983). Peanuts; production, processing, products, 3rd Ed. Westport: The AVI Publishing Co., Inc. 414 p.

Table 4.1 ─ Storage time (days) for roasted peanuts maintained at different temperature and water activity treatment combinations

Treatment Combination		Storage time (days)[a]	
Temperature	**Water Activity**	**40% ESL**	**110% ESL**
23 °C	0.33	33	91
	0.44	25	68
	0.54	19	53
	0.67	14	37
	0.75	11	31
30 °C	0.33	25	69
	0.44	19	52
	0.54	14	40
	0.67	10	29
	0.75	8	23
35 °C	0.33	20	56
	0.44	15	42
	0.54	12	32
	0.67	8	23
	0.75	7	19
40 °C	0.33	17	46
	0.44	12	34
	0.54	10	26
	0.67	6	15
	0.75	5	13

[a]Storage days representing 40 and 110% of estimated shelf life (ESL) for each treatment, respectively.

Table 4.2 ─ Estimated and measured water activity of saturated salts used to maintain the water activity at various temperatures

Water activity	Temperature	Saturated salt	Estimated water activity[a]	Measured water activity[b]
0.33	23 °C	Magnesium chloride	0.33	0.32
	30 °C	Magnesium chloride	0.33	0.31
	35 °C	Magnesium chloride	0.32	0.30
	40 °C	Magnesium chloride	0.32	0.30
0.44	23 °C	Potassium carbonate	0.43	0.42
	30 °C	Potassium carbonate	0.43	0.45
	35 °C	Potassium carbonate	0.43	0.44
	40 °C	Potassium carbonate	0.43	0.41
0.54	23 °C	Magnesium nitrate	0.54	0.53
	30 °C	Magnesium nitrate	0.53	0.52
	35 °C	Sodium bromide	0.55	0.55
	40 °C	Sodium bromide	0.53	0.51
0.67	23 °C	Sodium nitrite	0.67	0.63
	30 °C	Potassium iodide	0.68	0.69
	35 °C	Potassium iodide	0.67	0.66
	40 °C	Potassium iodide	0.66	0.66
0.75	23 °C	Sodium chloride	0.77	0.77
	30 °C	Sodium chloride	0.75	0.76
	35 °C	Sodium chloride	0.74	0.72
	40 °C	Sodium chloride	0.73	0.79

[a]Calculated using established equations (Labuza *et al.*, 1985)
[b]Water activity was measured using the Decagon Safe Storage Monitor (Decagon Devices, Inc., Pullman, WA, U.S.A.)

Table 4.3 ─ Prediction equations and their respective multiple coefficient of determination[a] (R^2) relating consumer attributes to storage time (x_1), storage water activity (x_2), and storage temperature (x_3)

Attribute	Intercept	Parameter estimates[b] for								
		X_1	X_2	X_3	X_1^2	X_2^2	X_1X_2	X_1X_3	$X_1X_2X_3$	R^2
ACCEPTANCE										
Overall	-0.5852	0.0716	30.9856	─	─	-31.7925	-0.2406	─	─	0.67
Aroma	3.4193	0.0218	14.0339	0.0004	─	-14.6593	─	─	-0.0042	0.75
Flavor	8.7662	0.0249	-3.8221	-0.0121	─	-	─	─	-0.0052	0.60
Appearance	1.5449	0.0383	16.8728	─	─	-16.6991	-0.0970	─	─	0.70
Color	2.0307	0.0339	15.1563	─	─	-14.9774	-0.0887	─	─	0.67
Texture	-1.5893	0.1139	37.9296	─	─	-38.7567	-0.3223	─	─	0.70
INTENSITY										
Roasted Peanutty	8.4186	0.0343	-3.5152	0.0011	─	─	─	─	-0.0061	0.61
Crunchiness	-2.1091	0.1243	41.2904	─	─	-42.4737	-0.3588	─	─	0.69
Oxidized	1.3903	-0.0048	2.4564	0.0135	─	─	─	─	0.0031	0.60

[a] Based on 60 observations

[b] '─' denotes that the parameter estimate was not different from 0 (α=0.05).

Figure 4.1 ─ Storage chamber used in the study of roasted peanuts stored at different water activity conditions.

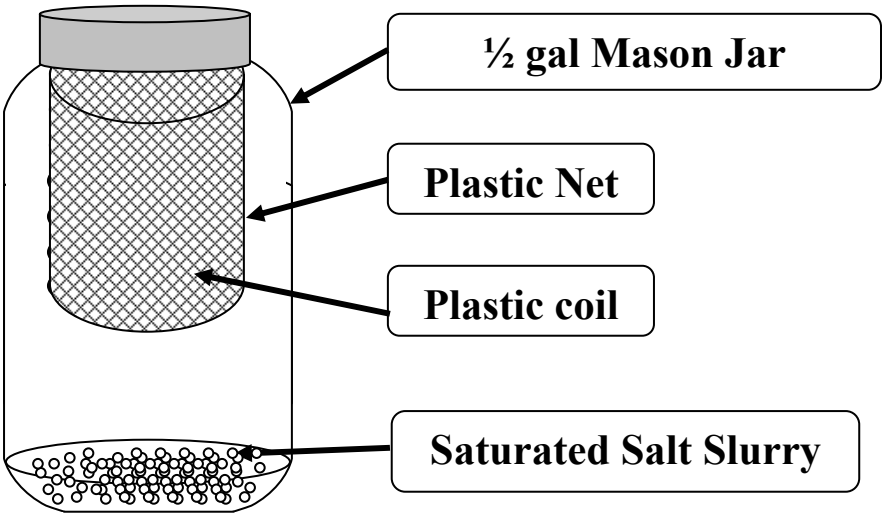

½ gal Mason Jar
Plastic Net
Plastic coil
Saturated Salt Slurry

Figure 4.2 – Contour plots illustrating the effects of storage time (days) and storage water activity on the consumer overall (A), appearance (B), color (C), and texture acceptance (D) of roasted peanuts. Shaded areas (▢) represent storage conditions and time that were not included in the experimental design.

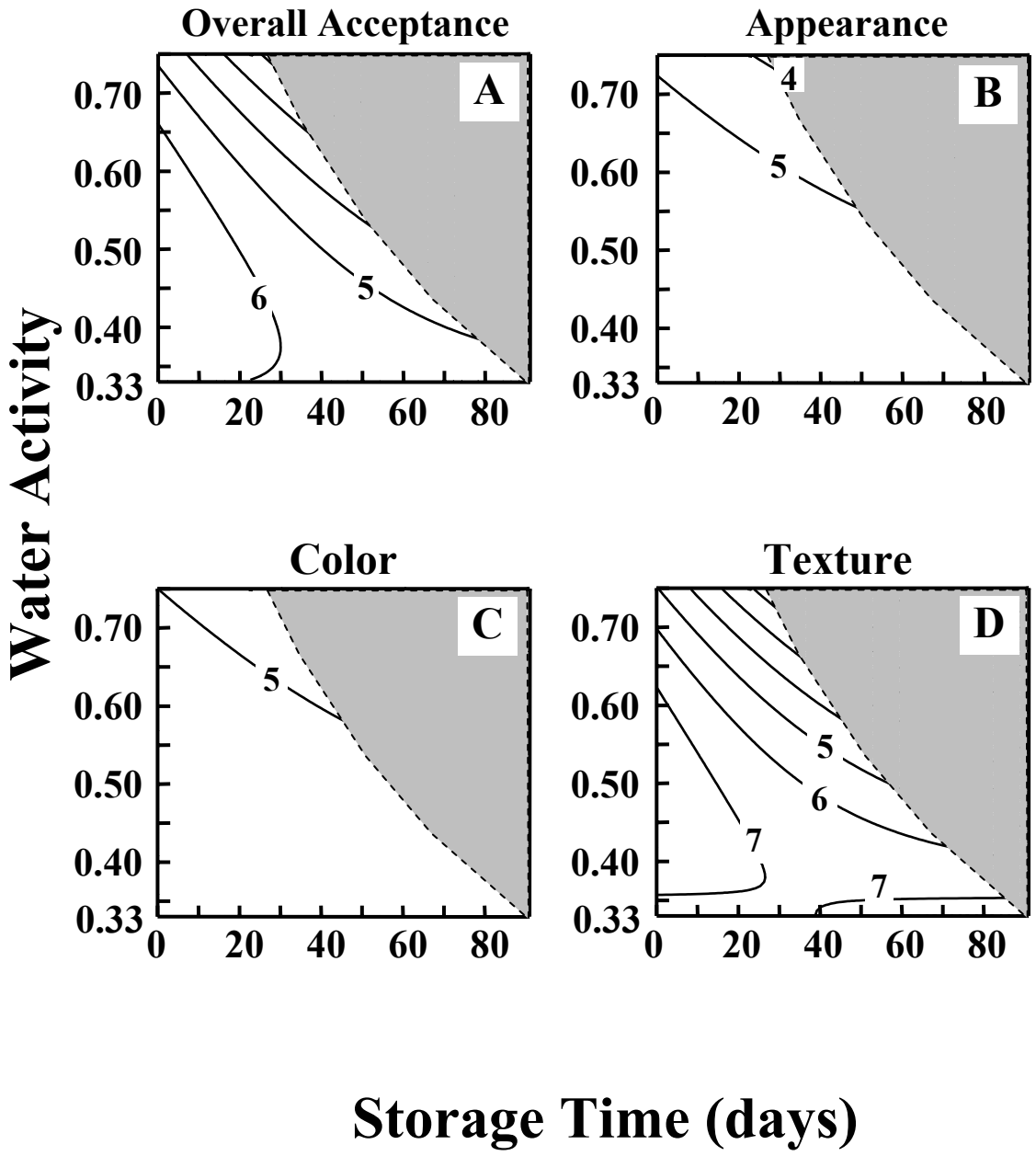

Overall Acceptance
A
Appearance
B
Color
C
Texture
D
Water Activity
0.70
0.60
0.50
0.40
0.33
0
20
40
60
80
4
5
6
7
Storage Time (days)

Figure 4.3 – Contour plots illustrating the effects of storage time (days) and storage water activity on the consumer aroma acceptance of roasted peanuts stored at 23 (A), 30 (B), 35 (C), and 40 °C (D). Shaded areas (▒) represent storage conditions and time that were not included in the experimental design.

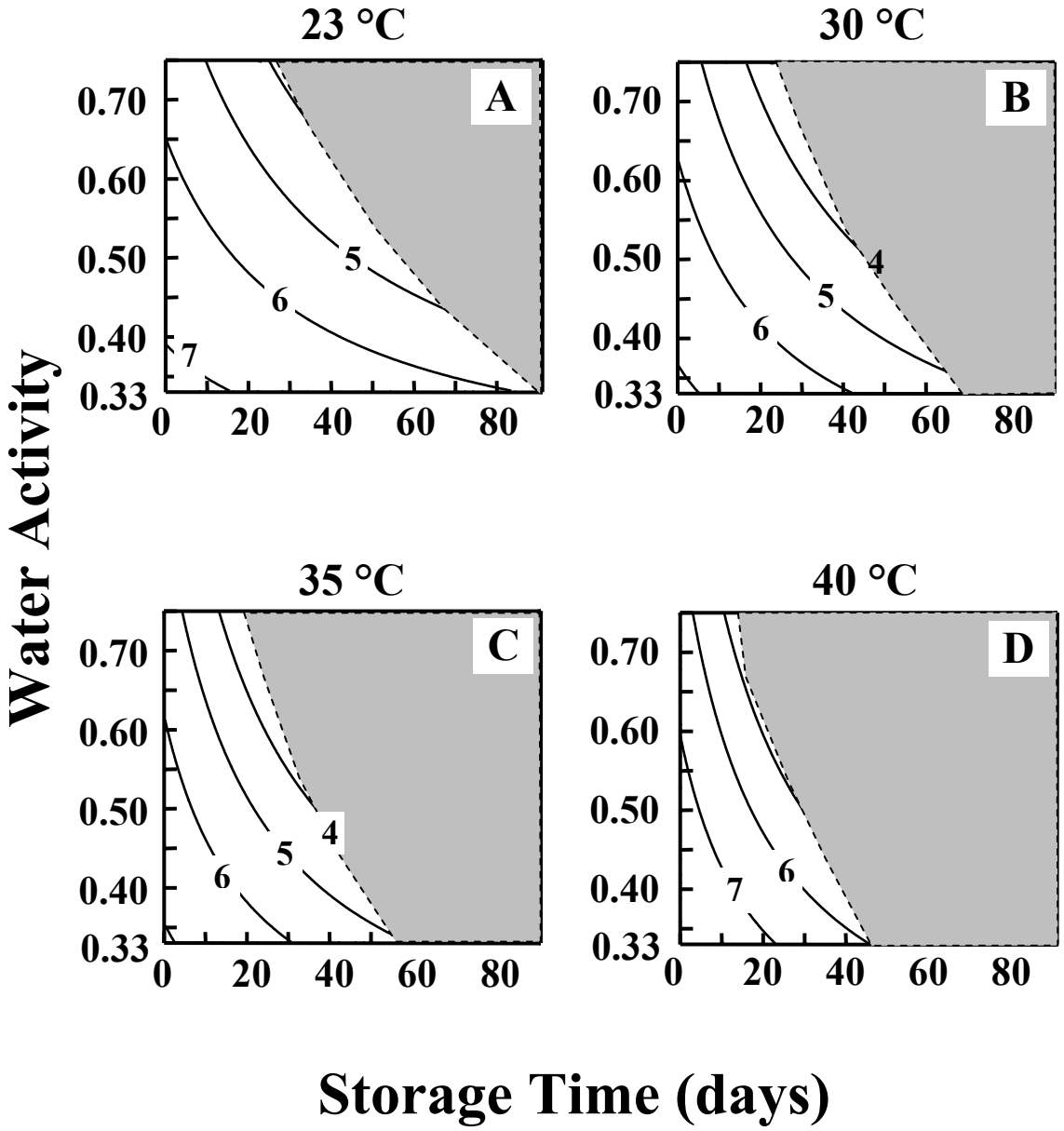

23 °C
30 °C
35 °C
40 °C
A
B
C
D
Water Activity
Storage Time (days)
0.70
0.60
0.50
0.40
0.33
0
20
40
60
80
4
5
6
7

Figure 4.4 ─ Contour plots illustrating the effects of storage time (days) and storage water activity on the consumer flavor acceptance of roasted peanuts stored at 23 (A), 30 (B), 35 (C), and 40 °C (D). Shaded areas (□) represent storage conditions and time that were not included in the experimental design.

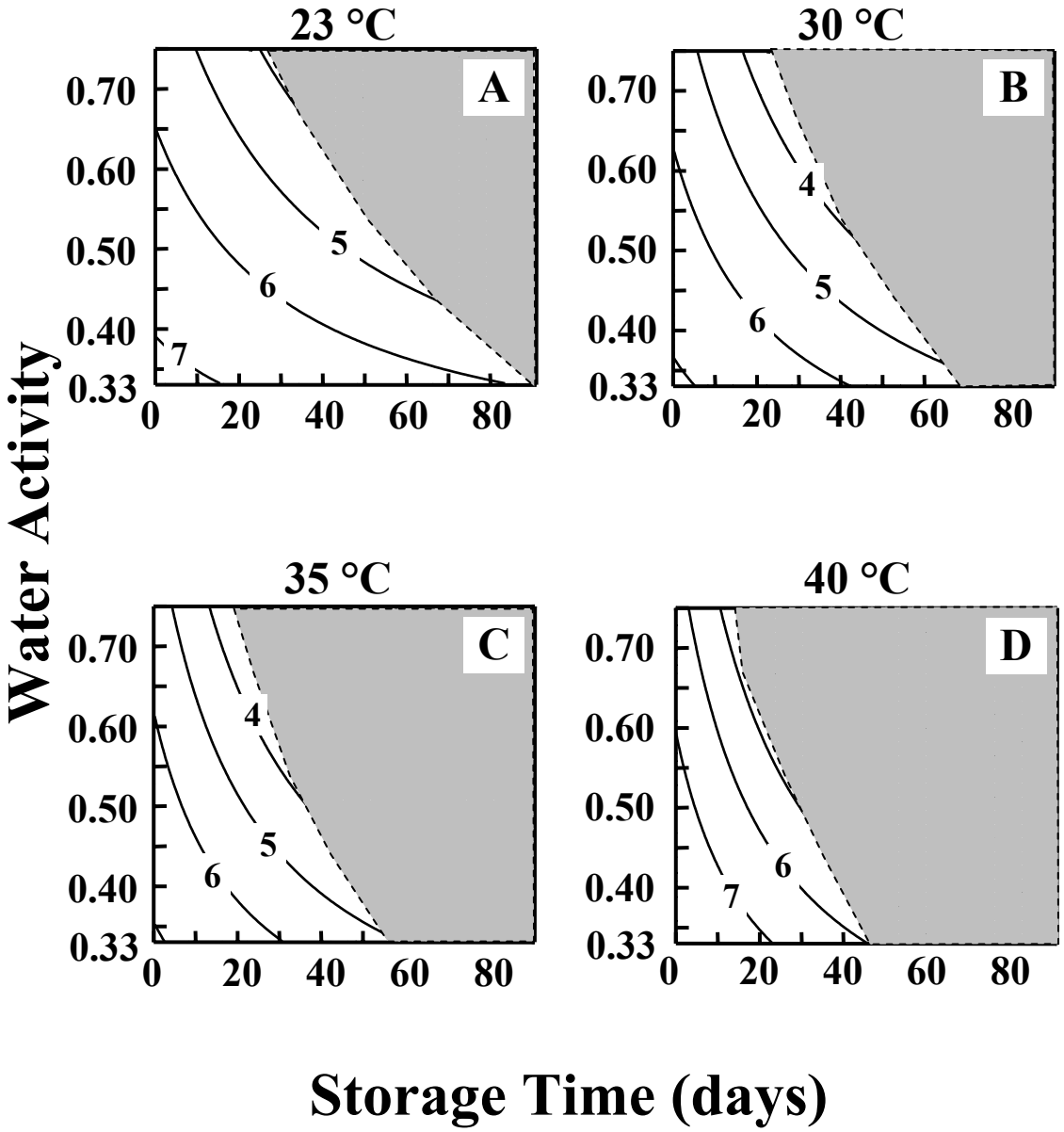

23 °C
30 °C
35 °C
40 °C
A
B
C
D
Water Activity
Storage Time (days)
0.70
0.60
0.50
0.40
0.33
0
20
40
60
80
4
5
6
7

Figure 4.5 ─ Contour plots illustrating the effects of storage time (days) and storage water activity on the consumer roasted peanutty intensity ratings of roasted peanuts stored at 23 (A), 30 (B), 35 (C), and 40 °C (D). Shaded areas (▒) represent storage conditions and time that were not included in the experimental design.

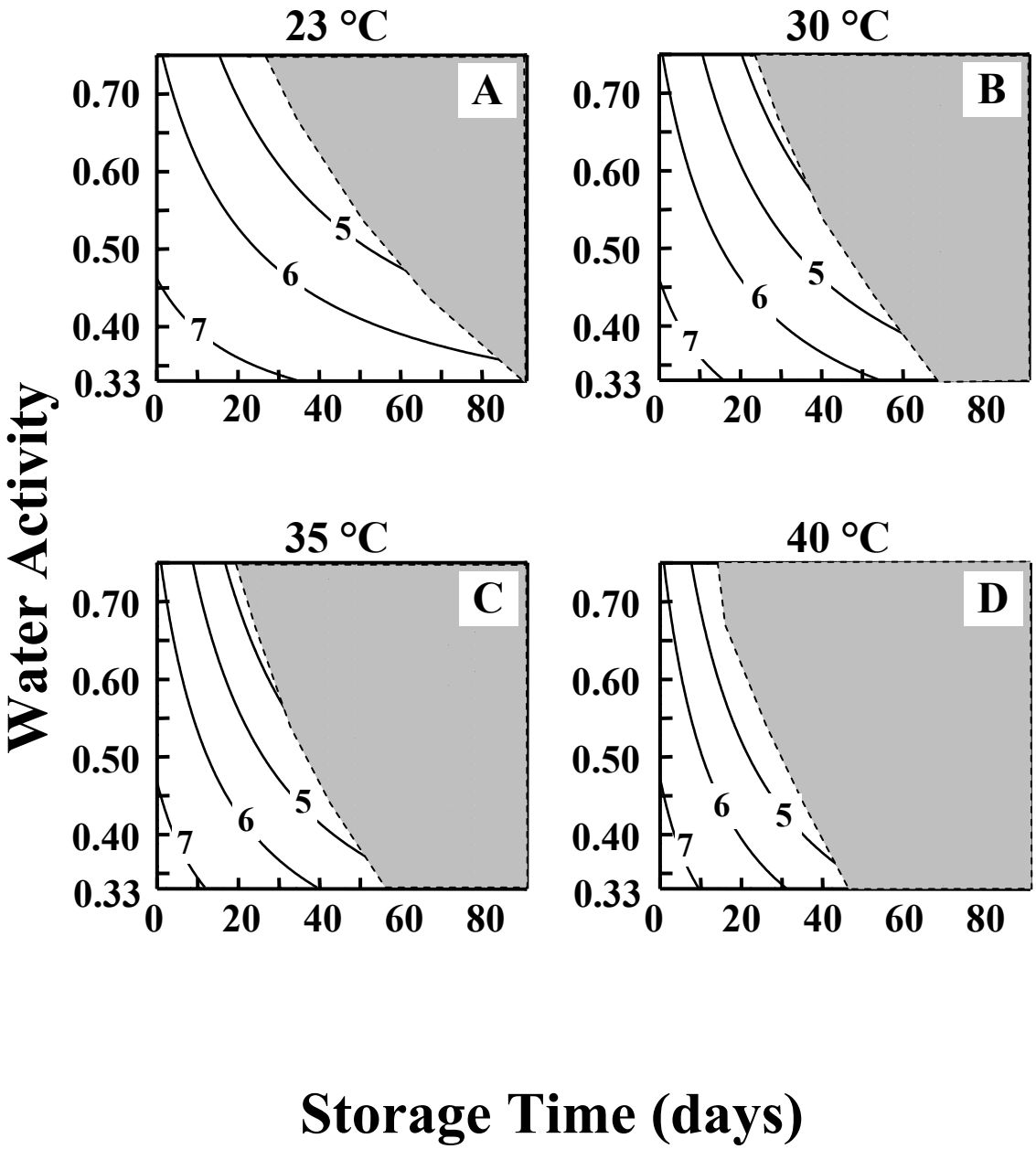

23 °C
30 °C
35 °C
40 °C
A
B
C
D
5
6
7
0.70
0.60
0.50
0.40
0.33
0
20
40
60
80
Water Activity
Storage Time (days)

Figure 4.6 ─ Contour plots illustrating the effects of storage time (days) and storage water activity on the consumer crunchiness intensity ratings of roasted peanuts stored. Shaded area (▢) represents storage conditions and time that were not included in the experimental design.

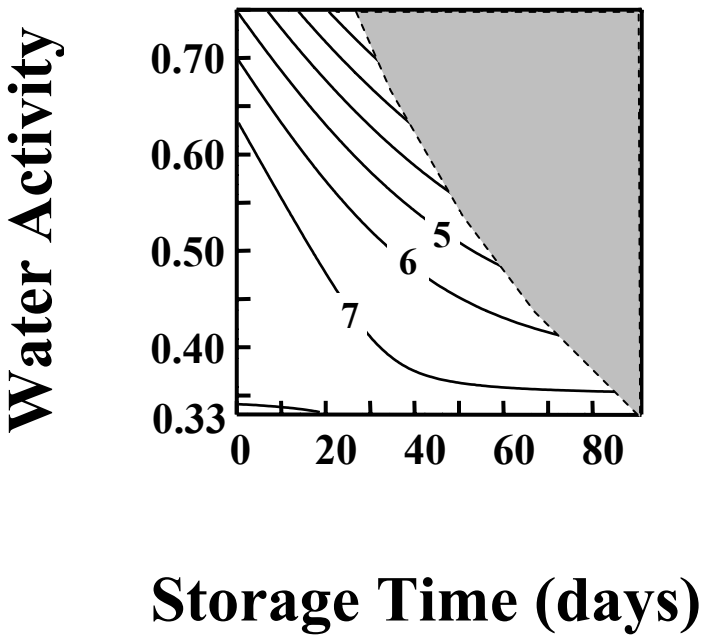

Water Activity
0.70
0.60
0.50
0.40
0.33
0
20
40
60
80
5
6
7
Storage Time (days)

Figure 4.7 ─ Contour plots illustrating the effects of storage time (days) and storage water activity on the consumer stale/oxidized/rancid intensity ratings of roasted peanuts stored at 23 (A), 30 (B), 35 (C), and 40 °C (D). Shaded areas (□) represent storage conditions and time that were not included in the experimental design.

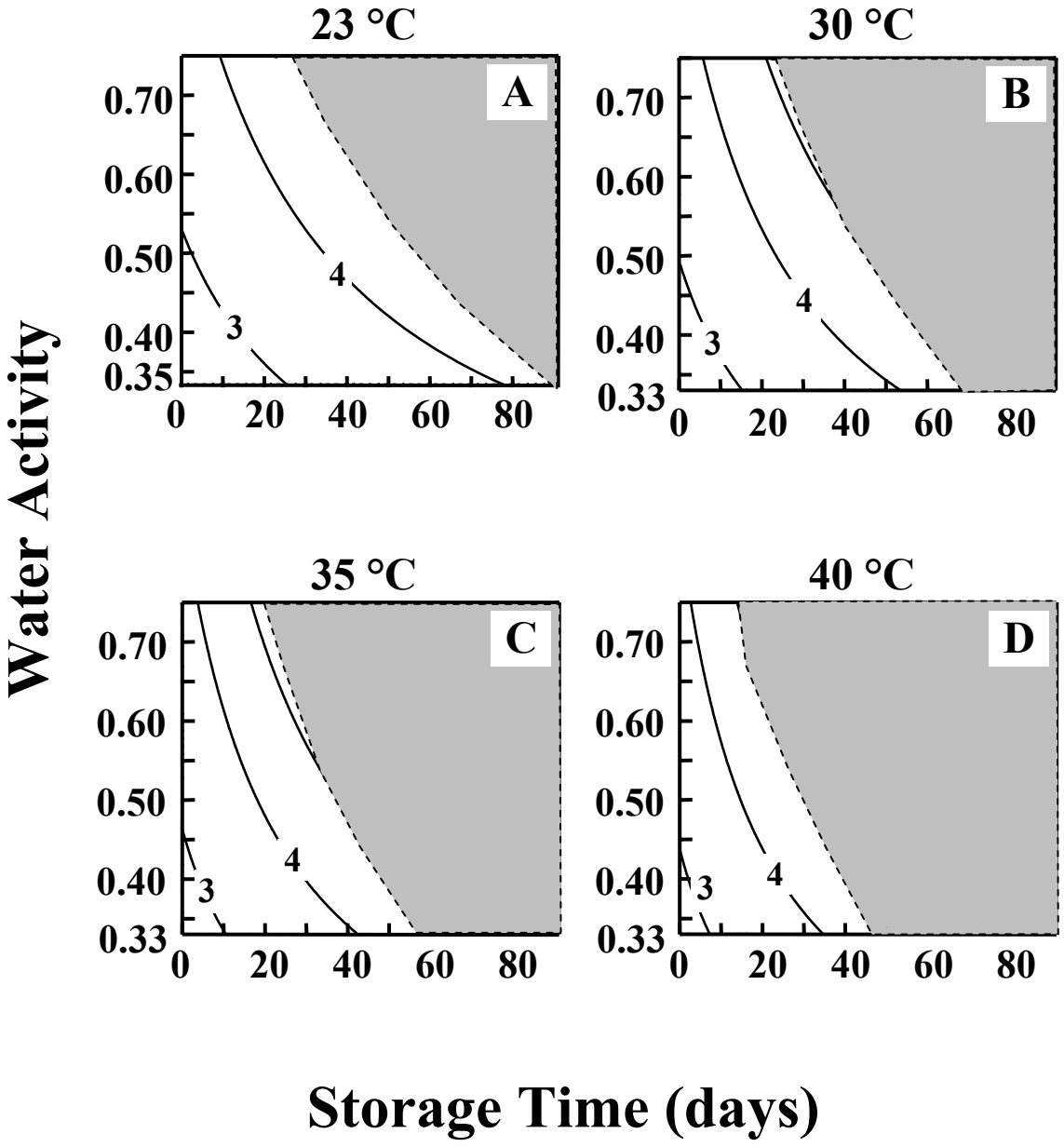

23 °C
30 °C
35 °C
40 °C
A
B
C
D
Water Activity
Storage Time (days)
0.70
0.60
0.50
0.40
0.35
0.33
0
20
40
60
80
3
4

Figure 4.8 ─ Overlaid contour plots for predicting shelf life of roasted peanuts stored at water activities between 0.33 and 0.75 and at 23°C (A) or 30 °C (B). Shaded areas (▒) represent storage conditions and time that were not included in the experimental design. Striped areas (▨) represent additive acceptable consumer acceptance (>5.0) based on color, texture, aroma, flavor, appearance and overall acceptance.

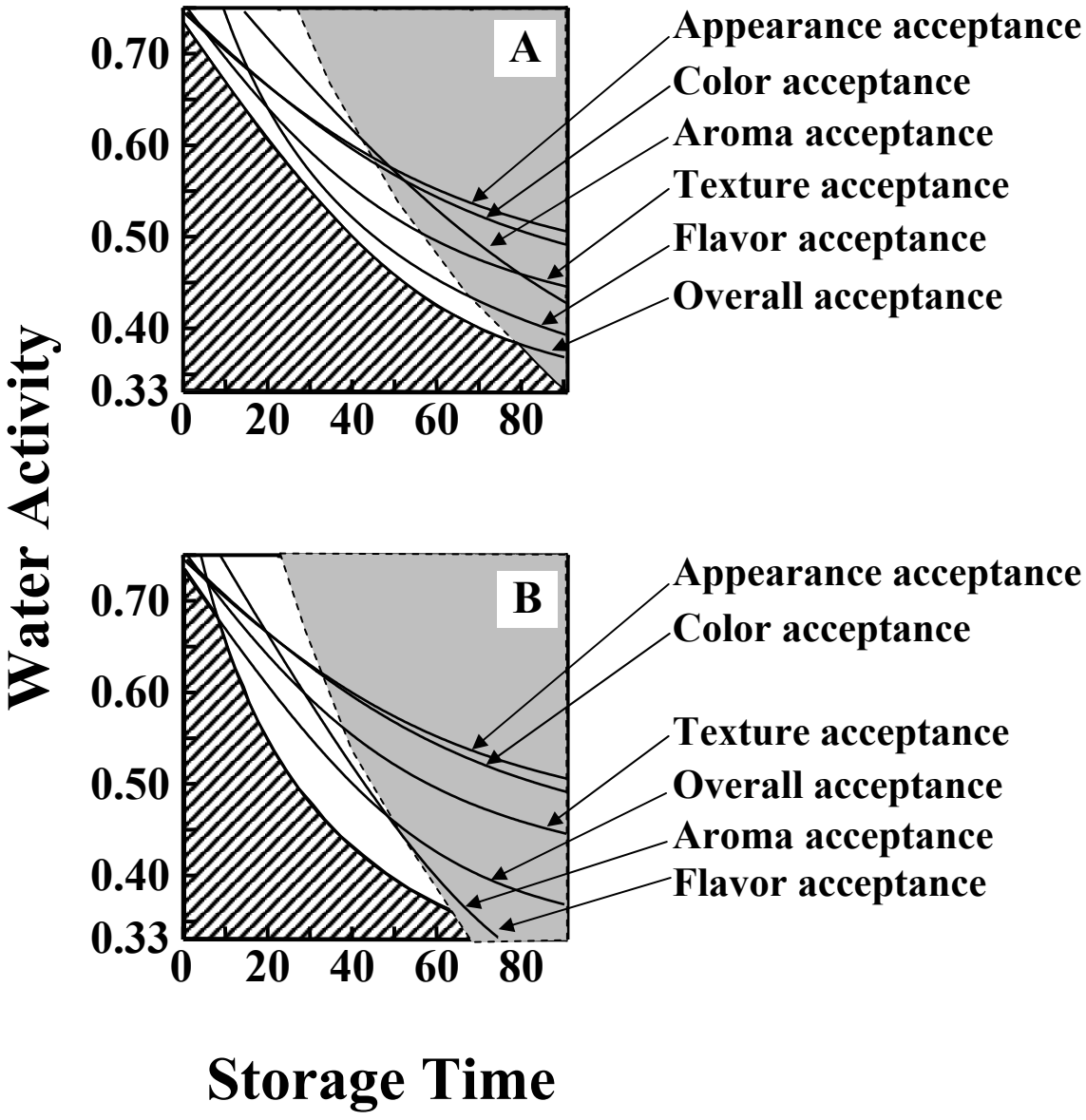
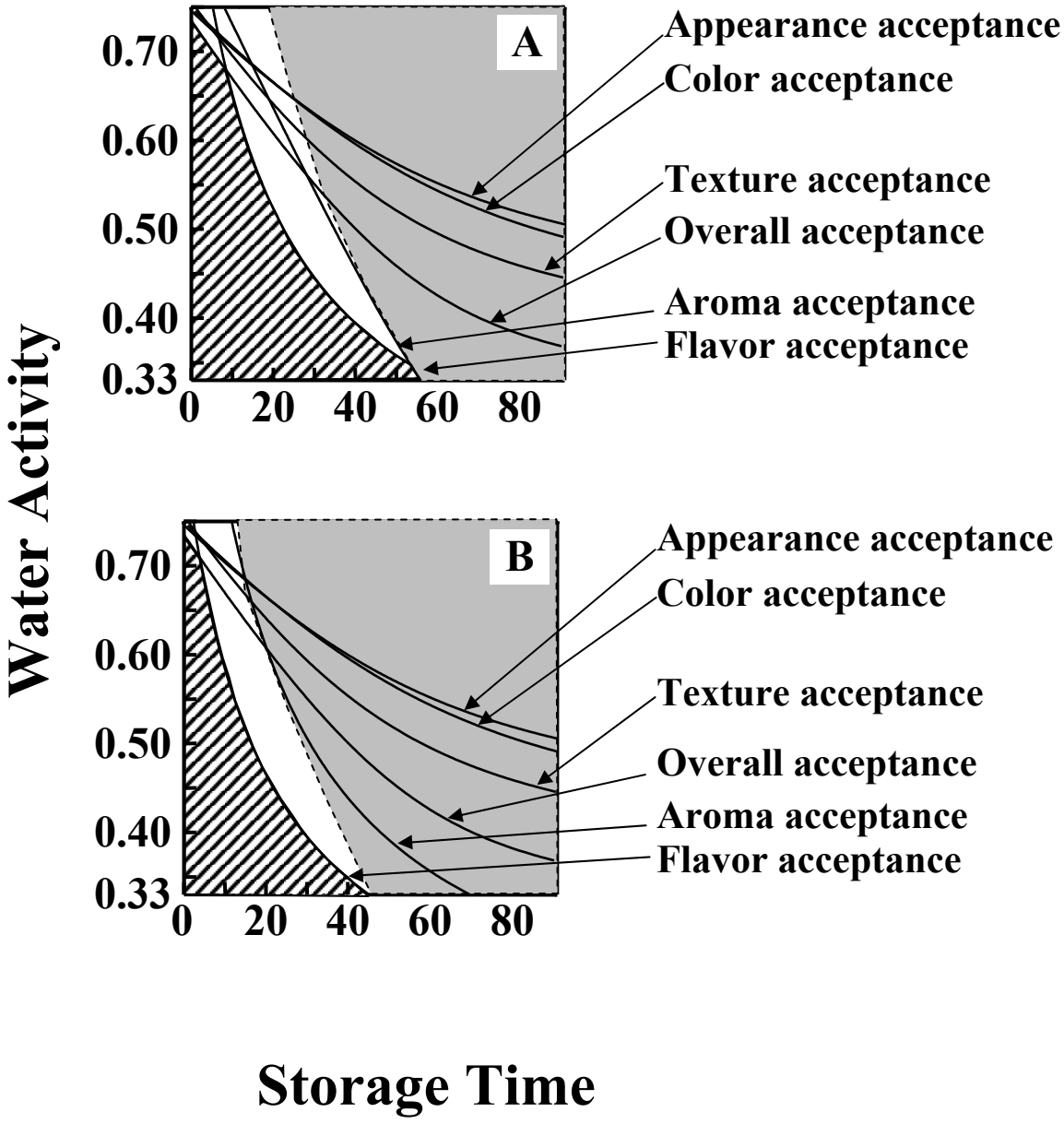

A
B
0.70
0.60
0.50
0.40
0.33
0
20
40
60
80
Water Activity
Storage Time
Appearance acceptance
Color acceptance
Aroma acceptance
Texture acceptance
Flavor acceptance
Overall acceptance
Appearance acceptance
Color acceptance
Texture acceptance
Overall acceptance
Aroma acceptance
Flavor acceptance

Figure 4.9 ─ Overlaid contour plots for predicting shelf life of roasted peanuts stored at water activities between 0.33 and 0.75 and at 35°C (A) or 40 °C (B). Shaded areas (▒) represent storage conditions and time that were not included in the experimental design. Striped areas (▨) represent additive acceptable consumer acceptance (>5.0) based on color, texture, aroma, flavor, appearance and overall acceptance.


A
B
0.70
0.60
0.50
0.40
0.33
0
20
40
60
80
Water Activity
Storage Time
Appearance acceptance
Color acceptance
Texture acceptance
Overall acceptance
Aroma acceptance
Flavor acceptance

SECTION V

PREDICTING SENSORY PROPERTIES AND CONSUMER ACCEPTANCE OF ROASTED PEANUTS STORED AT VARIOUS TEMPERATURES AND WATER ACTIVITIES USING INSTRUMENTAL MEASUREMENTS[4]

[4] Lee, C.M. and A. V. A. Resurreccion. To be submitted to *J. Texture Studies.*

ABSTRACT

Roasted peanuts were stored at twenty treatment combinations of water activity (0.33, 0.44, 0.54, 0.67, 0.75 a_w) and temperature (23, 30, 35, 40C), then evaluated after storing for 0, 20, 40, 60, 80, 100, and 110% of estimated shelf life by a descriptive panel (n=12) and by instrumental methods. Samples stored for 40 and 110% of estimated shelf life were also evaluated by a consumer panel (n=50). Regression models (R^2≥70) indicated that increasing storage water activity resulted in decreasing color lightness (L-value). Increasing storage time and water activity increased both water activity and moisture content of roasted peanuts. Moisture was the best predictor (R^2≥0.78) of descriptive texture attributes, while consumer ratings were best predicted (R^2≥0.75) by color and moisture measurement. Instrumental texture analysis, using a modified Kramer shear-compression cell or a cutting test, did not predict (R^2≤0.70) descriptive ratings or consumer ratings. Prediction models (R^2≥0.70) for descriptive and consumer ratings based on color or moisture measurements were established. Overall, instrumental measurements such as color, water activity and moisture successfully predicted both consumer acceptance and descriptive ratings.

INTRODUCTION

Roasted peanut is one of the most widely consumed foods in the world. Maintaining quality products has a significant impact on the world food supply; consequently, understanding the changes in sensory properties of food with storage time is of keen interest. Roasted peanuts, when exposed to higher storage water activities (a_w) or higher temperatures become unacceptable in flavor or texture in shorter time (Braddock *et al.* 1995; Warner *et al.* 1996; Mugendi *et al.* 1998; Brannan *et al.* 1999; Baker *et al.* 2002). The critical storage conditions for roasted peanuts include <6% moisture (Woodroof 1983) or between 0.33 and 0.44 a_w (Baker *et al.* 2002). Understanding the additive effect of temperature and water activity on the quality of stored roasted peanuts is necessary.

The texture of roasted peanuts is critical to consumer perception and contributes to the overall sensory perception of foods containing such nutmeats. Crispness and crunchiness are two important textural attributes of roasted peanuts (Hung and Chinnan 1989). Crispness is the force required to break a whole peanut with the front teeth, while crunchiness is the energy required to break the sample using the molar teeth (Hung and Chinnan 1989). Both attributes of peanuts have been shown to decrease with increasing water activity (a_w), and the range between 0.5 and 0.8 a_w was identified as the most critical in influencing this decrease (Hung and Chinnan 1989).

The use of objective measurements allows a more flexible analysis of quality attributes in terms of time and cost. Hung and Chinnan (1989) investigated the changes in textural quality of peanuts stored at varying water activity levels (0.12 to 0.76 a_w) using different instrumental methods. Their study demonstrated that a modified Kramer-shear test provided the best objective measurement and that these results correlated well with the sensory measurements

(Hung and Chinnan 1989). However, these researchers concluded that the further investigation was deemed necessary between 0.5 and 0.8 a_w (Hung and Chinnan 1989).

The objective of this study was to evaluate the changes in physicochemical properties of roasted peanuts when exposed to a surrounding water activity of 0.3-0.8. The specific objectives were to study the effect of storage temperature, water activity, and time on the instrumental properties of roasted peanuts; to correlate the instrumental measurements and sensory attributes of roasted peanuts; and to develop regression equations for the prediction of sensory attribute ratings.

MATERIALS AND METHODS

Sampling scheme

A sampling scheme was established and used in planning the storage of roasted peanuts for each temperature and water activity treatment. Samples were removed at intervals of 20% of estimated shelf life (ESL) up to 100% and including 110% ESL. Knowing that the shelf life of roasted peanuts is approximately 90 d (Anon. 1971; Anon. 1978), the shelf life of roasted peanuts stored at accelerated temperatures (T_2) of 30, 35, and 40C were estimated using:

$$\theta_{T_2} = \theta_{T_1} \times Q_{10}^{\Delta/10}$$

where θ = shelf life, T= temperature where $T_1<T_2$, and $\Delta = T_1 - T_2$. Using an assumed Q_{10} of 1.5, a 90 d shelf life of peanuts at 23C was estimated as 68, 55 and 45 d at 30, 35 and 40C, respectively. To further estimate the shelf life of roasted peanuts as affected by storage water activity, the equation was adapted to reflect a change in a_w instead of temperature:

$$\theta_{a_w''} = \theta_{a_w'} \times Q_a^{-|\Delta|/0.1}$$

where θ = shelf life, a_w' = water activity 1, a_w'' = water activity 2, $\Delta = a_w'-a_w''$, and Q_a=accelerating factor due to a 0.1 change in a_w. Using the revised equation and an assumed Q_a of 1.3, the storage time of each treatment was estimated for 20, 40, 60, 80, 100 and 110% ESL (Table 5.1).

Experimental Design

The experiment consisted of a 4x5 factorial design, including four storage temperatures (23, 30, 35, and 40C) and five storage water activity levels (0.33, 0.44, 0.54, 0.67, and 0.75). Depending on the treatment, samples were stored and evaluated between 2 to 91 d of storage. Two replications were conducted, and a total of forty samples were collected during each of the six sampling times of 20, 40, 60, 80, 100, and 110% ESL (Anon. 1993). Control samples, prepared from the same lot of roasted peanuts used in the study, were immediately packaged in 0.075 mm (3-mil.) polyethylene bags (Koch Supplies, Kansas City, MO, U.SA.) after roasting and cooling, then flushed with 99% nitrogen and refrigerated at 4C. In addition, any samples removed from storage were similarly packaged and refrigerated until tested to minimize any changes. The properties of the forty stored roasted peanut samples were evaluated by a descriptive panel (n=12) over two sessions for each of the six sampling times. Instrumental properties for these samples were also measured, specifically, color, water activity, moisture, and instrumental texture. Consumers (n = 50) evaluated samples stored for 40 and 110% ESL without replication.

Storage Chambers

To maintain the water activity of the storage chambers (Figure 5.1) at 0.33, 0.44, 0.54, 0.67 and 0.75 a_w, the following chemicals were used respectively: magnesium chloride (Fisher Scientific, Yonkers, NY, U.S.A.), potassium carbonate (Mallinckrodt Baker, Inc., Phillipsburg, NJ, U.S.A.), magnesium nitrate (Mallinckrodt Baker, Inc., Phillipsburg, NJ, U.S.A.), sodium bromide (Mallinckrodt Baker, Inc., Phillipsburg, NJ, U.S.A.), sodium nitrite (Mallinckrodt Baker, Inc., Phillipsburg, NJ, U.S.A.), potassium iodide (Mallinckrodt Baker, Inc., Phillipsburg, NJ, U.S.A.) and sodium chloride (Morton International, Inc., Chicago, IL, U.S.A.). Due to the variability in water activity of such chemical salts at different temperatures, different chemicals were used if the variability was expected to be larger than 0.05 a_w when estimated using established equations (Labuza *et al*., 1985). Magnesium nitrate was used for 0.54 a_w storage chambers stored at 23 and 30C, while sodium bromide was used for chambers maintained at 35 and 40C (Table 5.2). Similarly, 0.67 a_w storage chambers consisted of sodium nitrite when the jars were stored at 23C, and potassium iodide when stored at 30, 35 and 40C.

The storage chambers were constructed using half-gallon wide-mouth Mason jars (Ball Corp., Broomfield, CO, U.S.A.). Saturated salt slurries were added to the bottom of the jars. Samples were held in plastic nets with 0.5 cm holes suspended in a plastic coil (Magic Spring, Dolgencorp, Inc., Goodlettsville, TN, U.S.A.). Each of the plastic nets was held in a cylindrical shape by threading the plastic coil through the net. Depending on the intended storage temperatures, the storage chambers were prepared at ambient temperature (23C) or inside a water bath (Model 220A, Napco Inc., Portland, OR, U.S.A) maintained at 30, 35, or 40C (Labuza 2001). Saturated salt slurries were prepared inside the Mason jars (AOAC 1995) such that there was approximately 2 mm of liquid above the salts (Labuza 2001).

Storage chambers were stored inside incubators maintained at 30C (Model 3107, The Electric Hotpack Company, Inc., Philadelphia, PA, U.S.A.), 35C (American Instrument Co., Silver Spring, MD, U.S.A.), and 40C (Model 645 Treas, Precision Scientific, Winchester, VA, U.S.A.). In addition, storage chambers stored at 23C were kept inside corrugated paperboard boxes to exclude light. The relative humidity of the storage chambers were measured using the Safe Storage Monitor (Decagon Devices, Inc., Pullman, WA, U.S.A.), without samples, for two weeks. For each treatment, the actual water activity was found to be approximately the same as the estimated water activity based on the equation of Labuza *et al*. (1985) (Table 5.2). Throughout storage, the chambers were inspected every week and distilled water or salt was added to maintain the slurry. Storage chambers were equilibrated to ambient temperature (23C) prior to opening for filling or sampling of peanuts.

Sample Preparation

Shelled, raw medium Georgia Green peanuts (2001 crop, McCleskey Mills, Smithville, GA, U.S.A.) were obtained and stored at 4C (Nor-Lake, Inc., Hudson, Wis., GA, U.S.A.) for approximately two weeks prior to processing. During this two week period, peanut kernels were sorted for defects or foreign material, and returned to storage at 4C. Prior to roasting, peanuts were equilibrated to ambient temperature for at least 12 h. Peanuts were heated in 4 kg batches to 190C for approximately 6 min in a rotary gas roaster (Model L5, Probat Inc., Memphis, TN, U.S.A.) in order to attain a medium roast, or Hunter color *L*-value of 50 ± 1.0 (Johnsen *et al.* 1988) by measuring with a Garner XL-800 colorimeter (Pacific Scientific, Bethesda, MD, U.S.A.). After roasting, peanuts were cooled, blanched, sorted, and further cooled and mixed inside a rotating coating pan (Stokes Equipment Inc., OH, U.S.A.). The latter step was to allow

mixing of the thirty batches of roasting. Roasted peanuts (350 *g*) were cooled to ambient temperature (23C) before filling into each of the storage chambers. The storage chambers were stored at their respective storage temperatures. Control samples were packaged as previously described and stored at 4C.

Sampling Procedure

After storing for the designated period (Table 5.1), storage chambers were removed from their original storage conditions and equilibrated to ambient temperature (23C) for at least 30 min before opening the jars. This was to prevent sudden condensation of moisture onto samples inside the jars (Labuza 2001) and the removed samples were then immediately packaged in the same fashion as the control. After all of the twenty treatments from each ESL were collected, they were analyzed by sensory and instrumental methods.

Descriptive Analysis

A hybrid descriptive panel (Einstein 1991) trained on Spectrum, Quantitative Descriptive Analysis, and Texture Profile Analysis, was used. The process of recruitment, screening, training and evaluation was conducted as follows.

Panel. The panel consisted of twelve panelists who were recruited, trained and calibrated for the descriptive analysis of roasted peanuts. The recruitment criteria included 1) between the age of 18 and 64, 2) non-smokers, 3) not allergic to peanuts, 4) consume peanuts, 5) able to attend all training and testing sessions, 6) interested in participation, and 7) ability to communicate verbally about the product (Plemmons and Resurreccion 1998). Potential panelists that met the above criteria were screened for their ability to identify and discriminate between

different tastes and aromatic compounds (Plemmons and Resurreccion 1998). Recruited panelists (*n*=12) had 3 mo to 20 y of experience with descriptive analysis, with a combined experience of 34 years. Panelists always signed a consent form approved by the University of Georgia Institutional Review Board prior to either screening or training session, and were paid for their participation.

Training. Panelists were trained for descriptive analysis following procedures adapted from Meilgaard *et al.* (1991). A total of three two-hour training sessions were conducted over three days. Presented with samples of roasted peanuts previously stored under different humidity conditions, panelists came up with possible terms for describing the descriptive properties. With the assistance of a lexicon of descriptive terms (Szczesniak *et al.* 1963; Johnsen *et al.* 1980; Meilgaard *et al.* 1991; Muego-Gnanasekharan and Resurreccion 1992; Ward 1995; Plemmons and Resurreccion 1998; Gills and Resurreccion 2000), panelists accepted or modified the terms, definitions, evaluating instructions, external references, and control (Table 5.3 & 5.4). For rating, the panel used 150-mm unstructured line scales, with anchors at 12.5 and 137.5 mm, corresponding to weak and strong, respectively. Control and external references were provided and their respective intensities were provided on the paper and computer ballots (Table 5.3 & 5.4).

Ballot. The panel developed and agreed on 23 attributes relating to the appearance, texture, flavor, taste and aftertaste of stored roasted peanuts. A paper ballot was used during calibration and was the same as the computer ballot (Compusense *five*, Version 4.2, Compusense, Inc., Guelph, Ontario, Canada) used during testing. Both ballots consisted of instructions, definitions, references, control, and intensities for both the control and references. During testing, the computer ballot was designed such that only monadic presentation of samples

was allowed but panelists were permitted to move back and forth between attributes with the same sample.

Calibration. During the first hour of testing sessions, a one hour calibration session was conducted and panelists calibrated themselves, as a group, by evaluating the four basic taste solutions, references and control samples. In addition, panelists evaluated a warm-up sample using a paper ballot and their reliability was checked after each session by comparing the ratings of the warm-up sample with a blind duplicate sample inserted among the samples. While evaluating the warm-up sample, panelists whose rating was not within 10% of the mean panel rating were asked to justify their deviation, and if necessary, allowed the panelists to adjust their ratings when a consensus was reached.

Test Conditions. All sessions were conducted at the Department of Food Science & Technology at the University of Georgia in Griffin, GA. Panelists evaluated samples in individually partitioned booths, illuminated with two 50 W white incandescent bulbs providing 738 lx of light, and used computers for entry of ratings.

Test Procedure. At least one hour before testing, samples (10g) were removed from their original package, placed into 28.57 *g* plastic cups and covered with lids (Solo Cup Co., Highland, IL, U.S.A.). Panelists evaluated a control and twenty treatment samples during each session, with mandatory breaks of 5 min after the 5^{th}, 10^{th}, and 15^{th} samples. Samples, coded with three-digit random numbers, were served at ambient temperature (23C) on a stainless steel tray lined with white paper. Unsalted crackers and deionized water were provided for rinsing between samples and panelists were instructed to expectorate all samples. A randomized block design was used and the sequence of evaluation was controlled by Compusense *five* (Version 4.2, Compusense Inc., Guelph, Ontario, Canada).

Consumer Test

Fifty untrained consumers, consisting of employees, students and faculty members, were recruited from the University of Georgia Griffin Campus for the test. They were screened for the following criteria for eligibility (a) they were not allergic to peanuts, (b) their ages were between 19 and 65 years, and (c) they ate peanut or peanut products at least once a month. Four consumer tests, each with fifty panelists, were conducted on control samples and samples of 40 and 110% ESL. Consumers who participated in one of the consumer tests did not necessarily participate in another test. Refreshments were provided to consumers after evaluating the samples.

Eleven samples (10 *g*), including the control sample, were evaluated in a monadic sequential order during each test day. The test was conducted in partitioned booths as previously described. To reduce panelist fatigue, a mandatory break of 5 min between the 5^{th} and 6^{th} samples was inserted. A total of 2 d of testing was conducted to completely test all 20 treatment samples for each of the 40 or 110% ESL. During the break, panelists filled out a computerized demographics questionnaire regarding their age, gender, marital status, occupation, educational background, income and eating habits. The evaluation sequence was based on a randomized complete block design, controlled by Compusense *five*.

Ballot. Consumers recorded their answers on computer ballots consisting of acceptance and intensity questions. Panelists rated stored roasted peanuts in terms of overall acceptance, acceptance of appearance, color, aroma, flavor, and texture using a 9-point hedonic scale, with 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely (Peryam 1964). For overall, flavor and texture acceptance, panelists were instructed to eat two pieces of roasted peanut to evaluate the attributes. In addition, panelists rated the intensities of crunchiness, roasted peanutty flavor and stale/oxidized/rancid flavor using a 9-point intensity scale anchored

at the two ends of the scale. For crunchiness intensity, the anchor words were "not crunchy at all" and "very crunchy", representing the 1- and 9-point on the scale. The anchor words for roasted peanutty and stale/oxidized/rancid flavor intensities were "none" and "high" for the 1- and 9-point ratings, respectively. Panelists were instructed to eat three pieces of the samples to evaluate all three intensity attributes. For each panelist, unsalted saltine crackers and distilled water were provided for rinsing and cups with lids were provided for expectoration.

Physicochemical Measurements

Mechanical tests

Modified Kramer shear cell. A modified Kramer shear test was conducted using the Instron Universal Testing Machine (Model 1122, Instron, Inc., Canton, MA, U.S.A.) equipped with a load cell of 500 kg capacity (Hung and Chinnan 1989). A standard Kramer cell (Model CS-1, Food Technology Corporation, Reston, VA, U.S.A.), modified according to Hung *et al.* (1988), was used to pass through samples at a crosshead speed of 100 mm/min. For each treatment, three replicates of roasted peanut samples (50 *g*) were tested (Hung and Chinnan 1989). Parameters interpreted from the force-deformation curves include maximum force (N) and energy (J), which are associated with shearing and compression forces, respectively (Hung and Chinnan 1989). The energy required for both shearing and compression was computed as the area under the force-deformation curve up to the peak force (Hung and Chinnan 1989).

Inverted V-blade cutting test. An Instron Universal Testing Machine was fitted with a 500 kg load cell and an inverted V-blade. Halved peanut samples were cut with the flat side down. Preliminary study indicated that at a crosshead speed of 250 mm/min, the cutting test successfully distinguished (α=0.05) between crunchy and chewy peanuts (data not shown). A

total of 26 tests were conducted for each sample and the maximum force (N) and energy (J) were recorded.

Color measurements

Color of roasted peanuts was measured using a Gardner XL-800 colorimeter with an XL-845 circumferential sensor (Gardner XL-800, Pacific Scientific, Bethesda, MD, U.S.A.) that was set against a yellow reference tile (*L*=79.56, *a*=-2.17, *b*=22.98). Peanuts (100 *g*) were evenly filled onto the sample cup to a depth of approximately 10 mm so that the sample cup was fully covered with peanuts and no light could pass through the cup. The cup was covered and three readings were obtained by rotating the sample 90° after each reading.

Water activity (a_w) measurements

The water activity (a_w) values of peanuts were measured at 25C using an Aqua Lab CX-2TE (Decagon Devices, Inc., Pullman, WA, U.S.A.) water activity meter. Triplicate readings of five halved peanuts of each sample were obtained.

Moisture measurements

Moisture contents (dry basis, *g* water/*g* solids) of peanuts were determined by difference in weight. A vacuum oven (80C at 25 mmHg) was used. Samples, of approximately 2 *g*, were placed onto aluminum liners in each of the metal dish and dried for 12 h until a constant weight was obtained (AACC 1983). Duplicate tests were conducted for each sample.

Statistical Analyses

All statistical analyses were performed using SAS (Version 8e, SAS Institute Inc. 1987). Results of descriptive analysis were first analyzed using cluster analysis with PROC VARCLUS procedure to identify any outlier panelists for each sampling time (Malundo and Resurreccion 1992). In addition, raw data were plotted for each sample to identify panelists who did not perform consistently with the panel. Two panelists were identified as outlier and their data were removed from the data set. Results from the remaining ten panelists who were not outliers were used for the remaining statistical analyses.

Regression analysis (PROC REG) was used to construct the relationships of each physicochemical measurement with respect to storage water activity, temperature and time. Significant prediction models ($p<0.05$) were determined for each attribute. Reduced models with adjusted $R^2 \geq 0.70$, having the highest adjusted coefficient of determination (R^2), the lowest mean square error (MSE) and Mallow's C_p value, and that were not significantly different ($p>0.05$) from it's corresponding full model were selected for the prediction model. The partial F-statistic employed in the determination of significance difference between the reduced model and the full model was given by:

$$F = \frac{(SSE_{reduced} - SSE_{full})}{(df_{reduced} - df_{full})}$$

where *SSE* is the sum of squares of error, *MSE* is the mean square error and *df* is the degrees of freedom. The selected full model selected was a second order polynomial regression model with three linear terms, including storage time (x_1), storage water activity (x_2), and storage temperature (x_3); their squared terms; and all possible cross products:

$$Y=\beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3+\beta_{11}x_1^2+\beta_{22}x_2^2+\beta_{33}x_3^2+\beta_{12}x_1x_2+\beta_{13}x_1x_3+\beta_{23}x_2x_3+\beta_{123}x_1x_2x_3+\varepsilon$$

where Y is the rating of the descriptive attribute; β_0 is the intercept when x_1, x_2 and x_3 equal 0; β_1, β_2 and β_3 are parameter estimates of x_1, x_2 and x_3, representing storage time, temperature and water activity respectively; β_{11}, β_{22} and β_{33} are the parameter estimates of their square terms x_1^2, x_2^2 and x_3^2; and β_{12}, β_{13}, β_{23}, and β_{123} are the parameter estimates of their cross product terms, x_1x_2, x_1x_3, x_2x_3, and $x_1x_2x_3$. Contour plots for each significant model of the physicochemical measurement were constructed using Statistica Version 6.0 (Statsoft, Inc., Tulsa, OK, U.S.A.).

In addition, prediction models for each descriptive attribute and the consumer ratings were established and based on independent instrumental parameters. Models with adjusted-R^2 greater or equal to 0.65, showing no significant difference between itself and its full model, were selected. The following model was used:

$$Y=b_0+b_1x_1+b_2x_1^2$$

where Y is the dependent sensory variable; b_0 is the intercept when x_1 equals 0; b_1 is the parameter estimate of the instrumental measurement, x_1; and b_2 is the parameter estimate of x_1^2. For color measurements, the following model was used:

$$Y=b_0+b_1x1+b_2x_2+b_3x_3+b_4x_1^2+b_5x_2^2+b_6x_3^2$$

where Y is the dependent sensory attribute; b_0 is the intercept when x_1, x_2 and x_3 equals 0; b_1, b_2, and b_3 are the parameter estimates of x_1, x_2, and x_3, which are color *L*, *a*, and *b* values, respectively; and b_4, b_5 and b_6 are the parameter estimates for x_1^2, x_2^2, and x_3^2, respectively.

RESULTS AND DISCUSSION

Regression models for color lightness (*L*-value), measured water activity, and percent moisture, that had R^2>0.70, and that were no different (α=0.05) from the full model, were obtained. Contour plots based on such models, depicting changes in instrumental measurement

as affected by storage time and water activity, are shown in Figure 5.2. As the storage time for each treatment was different, the contour plots were shaded to indicate water activity and storage times that were not studied, and no further implications were made.

L-values of stored roasted peanuts decreased with increasing storage water activity (Fig. 5.2A), and was independent of storage time, as shown by the horizontal lines across the chart (Fig. 5.2A). The rate of change in *L*-value increased with increasing storage water activity, and the *L*-value decreased from 51 at lower a_w to less than 48 at higher a_w (Fig. 5.2A). This indicates that roasted peanuts absorbed moisture and turned darker upon exposure to increasing humidity.

The measured water activity of roasted peanuts increased from 0.39 in its fresh form, but did not necessarily reach the a_w of the surroundings. The maximum a_w reached was 0.60 for samples stored at 0.75 a_w (Fig. 5.2B). At higher storage water activity, samples had higher measured water activity. Overall, increasing storage time promoted the increase in water activity of roasted peanuts. The water activity of samples stored at 0.33, 0.44 and 0.54 a_w increased slightly and remained around 0.50 a_w throughout the storage period. Texture acceptability of roasted peanuts stored between 0.33 and 0.55 a_w was rated above 5 on a 9-point scale, indicating that the critical water activity was around 0.52. This value is similar to the critical water activities for acceptable texture of potato chips, popcorn, puffed corn curls and saltines, which are between 0.35 and 0.50 a_w (Katz and Labuza 1981).

The moisture content of freshly roasted peanuts is about 1.57% (*g*/*g*) and exposure to storage a_w between 0.33 and 0.75 resulted in peanuts that were between 2 to 3% moisture (Fig. 5.2C). Increasing storage water activity resulted in increasing sample moisture of more than 3%. Samples stored at $a_w<0.55$ contained less than 3.0% moisture throughout the study (Fig. 5.2C). In contrast, peanuts stored $a_w\geq0.60$ had moisture content of 3% or more by the end of storage

(Fig. 5.2C). In a similar study, Cecil and McWatters (1970) found that dry-roasted peanuts stored at 37.8C for three months had 3.1 to 3.9% moisture, and were rated unacceptable in flavor and texture.

Regression analysis suggested that descriptive texture attributes, including crispness, fracturability, crunchiness, hardness, chewiness, or toothpack can be explained (R^2>0.70) by at least one instrumental measurement, including color lightness, composite color, water activity, and moisture (Table 5.5). Models based on water activity and moisture were significant (α=0.05, R^2>0.70) for all texture attributes except hardness. Roasted peanutty flavor was the only flavor attribute that could be predicted by percent moisture. In addition, percent moisture was the best predictor (R^2>0.77) for all significant attributes except hardness (Table 5.5). For hardness, color lightness or color was the best predictor (R^2=0.70). None of the instrumental texture measurements were significant in predicting descriptive attributes. Our findings disagree with Hung and Chinnan (1989), who found the modified Kramer shear-compression test was predictive of sensory crunchiness. One of the main differences between the two studies lies on the number of observations used to establish the regression model, which were sixty in our study compared with seven in the earlier study (Hung and Chinnan 1989).

Significant regression models (α=0.05) for descriptive attributes predicted by moisture or color were established based on a total of 120 observations (Table 5.6). Crispness, crunchiness and chewiness were best predicted (R^2>0.70) by percent moisture, followed by fracturability, tooth packing, and roasted peanutty (Table 5.6). Hardness was best predicted by color (R^2=0.71). While the best prediction models were based on moisture measurements, prediction models based on color would be a good alternative considering the quick turnaround of the color measurement.

The relations between consumer ratings and physicochemical measurements revealed more than that of descriptive analysis. Table 5.7 illustrates significant prediction models ($R^2 \geq 0.70$) relating consumer attribute ratings and physicochemical measurements. Color lightness, composite color, peak force measured using the modified Kramer shear test, water activity, and moisture predicted at least one of the consumer attributes (Table 5.7). Models based on other physicochemical measurements, such as peak energy by modified Kramer method, as well as peak force or peak energy by the inverted V-blade cutting method, had adjusted R^2 less than 0.65 and were not shown (Table 5.7).

Except for appearance acceptance, color was the best predictor ($R^2 \geq 0.75$) of all consumer ratings, accounting for 80% or more of the variation in consumer ratings (Table 5.7). In particular, color measurement predicted 90% or more of the variation in color and texture acceptance ratings, as well as intensity ratings of roasted peanutty and crunchiness (Table 5.8). Overall acceptance was best predicted ($R^2=0.85$) by color or moisture (Table 5.7). As shown in Table 5.7, consumer ratings of stored roasted peanut, except for staled/oxidized/rancid flavor intensity, can also be predicted by measuring water activity ($R^2>0.73$) or by moisture ($R^2>0.74$). Color lightness predicted selected consumer ratings, including overall, appearance, color, and texture acceptance, along with crunchiness intensity (Table 5.7). Peak force measured by a modified Kramer shear cell predicted ($R^2=0.70$) color acceptance and roasted peanutty intensity (Table 5.7). Prediction models for consumer ratings, based on color or moisture measurement, were constructed and shown in Table 5.8. Color measurement of stored roasted peanuts provides an affordable and rapid method of predicting consumer acceptance.

CONCLUSIONS

Roasted peanuts stored at various water activities and temperatures were measured for their color, water activity, moisture, and by using instrumental Kramer shear-compression cell and instrumental cutting test. Moisture was the best physicochemical method for predicting descriptive texture attributes ratings, whereas color was the best predictor for consumer acceptance and intensity ratings. In addition, water activity of peanuts was also a good predictor of descriptive texture attributes and consumer ratings. Instrumental measurements were better predictors of consumer acceptance than descriptive attribute ratings. Prediction models based on color or moisture measurement were established and can be used in predicting consumer acceptance and intensity ratings of stored roasted peanuts.

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REFERENCES

AACC. 1983. Moisture - modified vacuum-oven method. Method 44-40, pp 1-2.

ANONYMOUS. 1971. Food stability survey, Vol II. Rutgers University, Dept. of Food Science. State of New Jersey, Dept. of Health: U.S. Dept. of Agriculture/Economic Research Service. pp. 57. U.S. Government Printing Office, Washington D.C.

ANONYMOUS. 1993. Shelf life of foods - guidelines for its determination and prediction. pp 55. Institute of Food Science & Technology, London, U.K.

AOAC, INTERNATIONAL. 1995. Water activity of canned vegetables. Method No. 978.18. Official Methods of Analysis, 16th ed. Ch. 42. pp 1-2. Association of Official Analytical Chemists, Gainthersburg, MD.

BAKER, G.L., SIMS, C.A., GORBET, D.A., SANDERS, T.H., and O'KEEFE, S.E. 2002. Storage water activity effect on oxidation and sensory properties of high-oleic peanuts. J. Food Sci. *67*(5), 1600-1603.

BRADDOCK, J.C., SIMS, C.A., and O'KEEFE, S.F. 1995. Flavor and oxidative stability of roasted high oleic acid peanuts. J. Food Sci. *60*(3), 489-493.

BRANNAN, G.L., KOEHLER, P.E., and WARE, G.O. 1999. Physico-chemical and sensory characteristics of defatted roasted peanuts during storage. Peanut Sci. *26*(1), 44-53.

CECIL, S.R. and McWATTERS, K. 1970. Staling of dry-roasted peanuts in storage. Proc. 67th Ann. Assoc. Southern Agr. Workers. pp. 65. Assoc. of Southern Agric. Workers.

CIVILLE, G.V. and LYON, B.G. 1996. Aroma and flavor lexicon for sensory evaluation: terms, definitions, references, and examples. ASTM Data Series Publication DS 66. pp 74.

DIVINO, G.L., KOEHLER, P.E., and AKOH C.C. 1996. Enzymatic and autoxiadation of defatted peanuts. J. Food Sci. *61*(1), 112-115, 120.

EINSTEIN, M.A. 1991. Descriptive techniques and their hybridization. Sensory Science Theory and Applications in Food (LAWLESS, H.T. and KLEIN, B.T., eds.). pp. 317-338. Marcel Dekker, Inc., New York.

GILLS, L.A. and RESURRECCION, A.V.A. 2000. Sensory and physical properties of peanut butter treated with palm oil and hydrogenated vegetable oil to prevent oil separation. J. Food Sci. *65*(1), 173-180.

GROSSO, N.R. and Resurreccion, A.V.A. 2002. Predicting consumer acceptance ratings of cracker coated and roasted peanuts from descriptive analysis and hexanal measurements. J. Food Sci. *67*(4), 1530-1537

HUNG, Y.C. and CHINNAN, M.S. 1989. Mechanical texture measurement of whole and chopped peanuts. Peanut Sci. *16*(1), 32-37.

JOHNSEN, P.B., CIVILLE, G.V., VERCELLOTTI, J.R., SANDERS, T.H. and DUS, C.A. 1988. Development of a lexicon for the description of peanut flavor. J. Sensory Stud. *3*, 9-17.

KATZ, E.E. and LABUZA, T.P. 1981. Effect of water activity on the sensory crispness and mechanical deformation of snack food products. J. Food Sci. *46*(2), 403-409.

LABUZA, T.P. 2001. Standard Desiccator Method for Isotherms. Available from: http://fscn1.fsci.umn.edu/ted_Labuza/awimages/Salt%20solutions%20FOR%20Isotherm.pdf. Accessed Jan 16.

LABUZA, T.P. and SCHMIDL, M.K. 1985. Accelerated shelf-life testing of foods. Food Technol. *39*(9), 57-64, 134.

LABUZA, T.P., KAANANE A., and CHEN J.Y. 1985. Effect of temperature on the moisture sorption isotherms and water activity shift of two dehydrated foods. J. Food Sci. *50*, 385-391.

MALUNDO, T.M. and RESURRECCION, A.V.A. 1992. A comparison of performance of panels selected using analysis of variance and cluster analysis. J. Sensory Stud. *7,* 63-75.

MEILGAARD, M., CIVILLE, G.V. and CARR, B.T. 1991. Sensory Evaluation Techniques, 2nd ed. CRC Press, Boca Raton, FL.

MUEGO-GNANASEKHARAN, K.F. and RESURRECCION, A.V.A. 1992. Physicochemical and sensory characteristics of peanut paste stored at different temperatures. J. Food Sci. *57*(6), 1385-1389.

MUGENDI, J.B., SIMS, C.A., GORBET, D.W., and O'KEEFE, S.F. 1998. Flavor stability of high-oleic peanuts stored at low humidity. J. Am. Oil Chem. Soc. *75*(1), 21-25.

PERYAM, D.M. 1964. Consumer preference evaluation of the storage stability of foods. Food Technol. *18*, 1460-1463.

PLEMMONS, L.E. and RESURRECCION, A.V.A. 1998. A warm-up sample improves reliability of responses in descriptive analysis. J. Sensory Stud. *13*, 359-376.

SAS INSTITUTE, INC. 2002. SAS/STAT Guide for Personal Computers. 8th ed. SAS Institute, Cary, N.C.

SZCZESNIAK, A.S., BRANDT, M.A. and FRIEDMAN, H.H. 1963. Development of standard rating scales for mechanical parameters of texture and correlation between the objective and the sensory methods of texture evaluation. J. Food Sci. *28*, 397-403.

WARD, C.D.W. 1995. Effects of physicochemical and sensory properties on functionality and consumer acceptance of snack chips formulated with cowpea, corn, and wheat flour mixtures. Ph.D. Dissertation. University of Georgia, Athens. pp. 69-70.

WARNER, K.J.H., DIMICK, P.S., ZIEGLER, G.R., MUMMA, R.O. and HOLLENDER, R. 1996. 'Flavor-fade' and off-flavors in ground roasted peanuts as related to selected pyrazines and aldehydes. J. Food Sci. *61*(2), 469-472.

WOODROOF, J.G. 1983. Peanut confections. Peanuts: Production, processing, products. 3rd ed. (WOODROOF, J.G., ed.) pp.265-292. AVI Publishing Company Inc., Westport, CT.

TABLE 5.1.
STORAGE PERIOD (DAYS) OF ROASTED PEANUTS EACH TEMPERATURE AND WATER ACTIVITY TREATMENTS

Treatment Combination		Storage period (days)[a]
Temperature	**Water Activity**	
23C	0.33	17, 33, 50, 66, 83, 91
	0.44	12, 25, 37, 50, 62, 68
	0.54	10, 19, 29, 38, 48, 53
	0.67	7, 14, 20, 27, 34, 37
	0.75	6, 11, 17, 22, 28, 31
30C	0.33	13, 25, 38, 50, 63, 69
	0.44	9, 19, 28, 38, 47, 52
	0.54	7, 14, 22, 29, 36, 40
	0.67	5, 10, 16, 21, 26, 29
	0.75	4, 8, 13, 17, 21, 23
35C	0.33	10, 20, 30, 40, 51, 56
	0.44	8, 15, 23, 30, 38, 42
	0.54	6, 12, 17, 23, 29, 32
	0.67	4, 8, 13, 17, 21, 23
	0.75	3, 7, 10, 14, 17, 19
40C	0.33	8, 17, 25, 33, 41, 46
	0.44	6, 12, 19, 25, 31, 34
	0.54	5, 10, 14, 19, 24, 26
	0.67	3, 6, 8, 11, 14, 15
	0.75	2, 5, 7, 10, 12, 13

[a]Storage period representing 20, 40, 60, 80, 100 and 110% of estimated shelf life (ESL) for each treatment combination.

TABLE 5.2.
ESTIMATED AND ACTUAL WATER ACTIVITY OF SATURATED SALTS INSIDE CONTROLLED HUMIDITY STORAGE CHAMBERS AT VARIOUS TEMPERATURES

Water activity	Temperature	Saturated salt	Estimated water activity[a]	Actual water activity[b]
0.33	23C	Magnesium chloride	0.33	0.32
	30C	Magnesium chloride	0.33	0.31
	35C	Magnesium chloride	0.32	0.30
	40C	Magnesium chloride	0.32	0.30
0.44	23C	Potassium carbonate	0.43	0.42
	30C	Potassium carbonate	0.43	0.45
	35C	Potassium carbonate	0.43	0.44
	40C	Potassium carbonate	0.43	0.41
0.54	23C	Magnesium nitrate	0.54	0.53
	30C	Magnesium nitrate	0.53	0.52
	35C	Sodium bromide	0.55	0.55
	40C	Sodium bromide	0.53	0.51
0.67	23C	Sodium nitrite	0.67	0.63
	30C	Potassium iodide	0.68	0.69
	35C	Potassium iodide	0.67	0.66
	40C	Potassium iodide	0.66	0.66
0.75	23C	Sodium chloride	0.77	0.77
	30C	Sodium chloride	0.75	0.76
	35C	Sodium chloride	0.74	0.72
	40C	Sodium chloride	0.73	0.79

[a]Based on established equations (Labuza *et al.*, 1985)
[b]Water activity was measured using a Decagon Safe Storage Monitor (Decagon Devices, Inc., Pullman, WA, U.S.A.)

TABLE 5.3.
DESCRIPTIVE TERMS AND DEFINITIONS USED IN THE SENSORY ANALYSIS OF STORED ROASTED PEANUTS

Attributes[a]	Definition	References	Intensity[b]
APPEARANCE			
Brown color[c,d]	The intensity of strength of brown color from light to dark brown[d]	white paper[b] (*L*=91.42, *a*=-0.22,*b*=0.04) dry cardboard[k] (*L*=49.71, *a*=5.77, *b*=16.01)	0 30
Moist	Amount of wetness on surface	wet cardboard	100
TEXTURE			
Crispness[h]	Amount of force needed and intensity of sound (high pitch) generated from chewing a sample with incisors[h]	corn chips[h] (Frito Lay, Plano, TX)	70
Fracturability[h]	The force with which the sample breaks[h]	corn chips (Frito Lay, Plano, TX)	53
Crunchiness[c,h]	The force needed and intensity of sound (low pitch) generated from chewing a sample with molar teeth[c,h]	corn chips[h,k] (Frito Lay, Plano, TX)	75
Hardness[d,h]	Amount of force needed to compress a food between molar teeth[d]	corn chips (Frito Lay, Plano, TX)	80
Chewy[h,i]	The length of time in seconds required to masticate a sample at the rate of one chew per second in order to reduce it to a consistency satisfactory for swallowing[i]	raw peanuts	33
Tooth packing[c,h]	The degree to which product sticks on the surface of molars[c]	raw peanuts	80
FLAVOR			
Roasted peanutty[c,d,e]	The aromatic associated with medium-roast peanuts[c,d,e,h]	dark roasted peanuts (*L*=45.0±1.0)	84
Raw beany[c,e,f]	The aromatic associated with raw peanuts[c,d,f]	raw peanuts[b,k]	41
Oxidized[c,d,f]	The flavor associated with rancid fats and oils[c]	old vegetable oil[b,l] (Hunt-Wesson, Inc., Fullerton, CA)	37

(Continued on next page)

TABLE 5.3 (cont.)
DESCRIPTIVE ATTRIBUTES AND THEIR DEFINITIONS USED IN THE DESCRIPTIVE ANALYSIS OF ROASTED PEANUTS

Attributes[a]	Definition	References	Intensity[b]
Sweet aromatic[e]	The aromatics associated with sweet material such as caramel, vanilla, molasses, fruit[e]	caramel candy (Hershey Food Corporation, Hershey, PA)	60
Woody/hulls/skins[e]	The aromatics associated with base peanut character (absence of fragrant top notes) and related to dry wood, peanut hull, and skins[e]	peanut skins[k]	35
Cardboard[e,f]	The aromatic associated with somewhat oxidized fats and oils and reminiscent of wet cardboard[e,j]	wet cardboard[k]	24
Painty[e]	The aromatic associated with linseed oil, oil based paint[e]	boiled linseed oil[k] (Klean Strip, W. M. Barr & Co., Inc., Memphis, TN)	115
Burnt[e]	The aromatic associated with very dark roast, burnt starches, and carbohydrates (burnt toast or espresso coffee)[e]	burnt peanuts[b,k] (lightness value L=40±1.0)	35
Earthy[e]	The aromatic associated with wet dirt and mulch[e]	wet soil[k] (Schultz Co., St. Louis, MO)	50
Fishy[e]	The aromatic associated with trimethylamine, cod liver oil, or old fish[e]	cod liver oil (E.R. Squibb & Sons, Inc., Princeton, NJ)	79
TASTES			
Salty[c,d,e]	The taste on the tongue associated with sodium chloride[c,d,e]	0.2% sodium chloride solution 0.35% sodium chloride solution 0.5% sodium chloride solution	25 50 85
Sour[e,g]	The taste on the tongue associated with citric acids[e,g]	0.05% citric acid solution 0.08% citric acid solution 0.15 % citric acid solution	20 50 100
Bitter[b,c,d,f,g]	The taste on the tongue associated with caffeine[b,c,d,f,g]	0.05% caffeine solution 0.08% caffeine solution 0.15% caffeine solution	20 50 100

(Continued on next page)

TABLE 5.3 (cont.)
DESCRIPTIVE ATTRIBUTES AND THEIR DEFINITIONS USED IN THE DESCRIPTIVE ANALYSIS OF ROASTED PEANUTS

Attributes[a]	Definition	References	Intensity[b]
Sweet[c,d,e,f]	The taste on the tongue associated with sugars[c,d,e,f]	2.0% sucrose solution	20
		5.0% sucrose solution	50
		10.0% sucrose solution	100
		15.0% sucrose solution	150
CHEMICAL FEELING FACTOR			
Astringency	The puckering or drying sensation of the mouth or tongue surface	grape juice (Welch's, Concord, MA)[f]	65

[a]Attributes as listed in the order perceived by the panelists
[b]Intensity ratings based on 150 mm, unstructured line scales
[c]Plemmons and Resurreccion (1998)
[d]Gills and Resurreccion (2000)
[e]Johnsen *et al.*(1980)
[f]Muego-Gnanasekharan and Resurreccion (1992)
[g]Meilgaard *et al.*(1991)
[h]Ward (1995)
[i]Szenesniak *et al.*(1963)
[j]Civille and Lyon (1996)
[k]Grosso and Resurreccion (2002)
[l]Divino *et al.* (1996)

TABLE 5.4.
INTENSITY RATINGS OF DESCRIPTIVE ATTRIBUTES FOR CONTROL SAMPLES[a] USED IN ANALYSIS OF STORED ROASTED PEANUTS

Attributes	Intensity[b]
APPEARANCE	
Brown color	23
Moist	0
TEXTURE	
Crispness	29
Fracturability	50
Crunchiness	60
Hardness	85
Chewy	15
Tooth packing	67
FLAVOR	
Roasted peanutty	74
Raw beany	0
Oxidized	0
Sweet aromatic	14
Woody/hulls/skins	12.5
Cardboard	0
Painty	0
Burnt	0
Earthy	5
Fishy	0
TASTES	
Sweet	12
Sour	0
Salty	12
Bitter	12
FEELING FACTOR	
Astringent	15

[a]Medium roasted Georgia Green medium runner peanuts (L = 50.0 ± 1.0)
[b]Intensity ratings are based on 150 mm, unstructured line scales

TABLE 5.5
ADJUSTED R-SQUARE VALUES OF SIGNIFICANT PREDICTION MODELS (α=0.05) RELATING INSTRUMENTAL PARAMETERS AND DESCRIPTIVE ATTRIBUTE RATINGS

Descriptive Attribute	Instrumental Measurements							
	Kramer Force[a]	Kramer Energy[b]	Cutting Force[c]	Cutting Energy[d]	Color Lightness[e]	Color[f]	Water Activity[g]	Moisture[h]
Crispness	—	—	—	—	0.76	0.77	0.75	0.87
Fracturability	—	—	—	—	0.72	0.73	0.74	0.82
Crunchiness	—	—	—	—	0.76	0.77	0.78	0.88
Hardness	—	—	—	—	0.70	0.70	—	—
Chewiness	—	—	—	—	0.77	0.78	0.78	0.85
Toothpack	—	—	—	—	0.71	0.71	0.73	0.82
Roasted Peanutty	—	—	—	—	—	—	—	0.78

[a]Peak force (N) measured using Modified Kramer shear-compression cell mounted on an Instron Universal Testing Machine
[b]Peak energy (J) measured using Modified Kramer shear-compression cell mounted on an Instron Universal Testing Machine
[c]Peak force (N) measured using an inverted V-blade mounted on an Instron Universal Testing Machine
[d]Peak energy (J) measured using an inverted V-blade mounted on an Instron Universal Testing Machine
[e]Color lightness, *L*-value, measured using a Gardner XL-800 colorimeter
[f]Color, expressed by *L*, *a*, *b*, measured using a Gardner XL-800 colorimeter
[g]Water activity measured at 25C using an AquaLab CX-2TE water activity meter
[h]Moisture measured on a dry-weight basis (*g* water/*g* solid).

TABLE 5.6
SIGNIFICANT REGRESSION MODELS[1] (R^2>0.70), WITH INSTRUMENTAL MEASUREMENT AS THE INDEPENDENT VARIABLE (X)[2], FOR THE PREDICTION OF DESCRIPTIVE ATTRIBUTE RATINGS

Descriptive Attribute	Regression Equation
Crispness	$21.5214 + 1254.0435x_1 - 44724x_1^2$
Fracturability	$59.4103 - 1136.0690x_1 + 37494x_1^2$
Crunchiness	$13.3831 + 5802.0184x_1 - 176622x_1^2$
Hardness	$-1117.0680 + 44.6458x_2 + 1.5692x_3 + 0.2124x_4 - 0.4181x_2^2 - 0.0665x_3^2 - 0.0020x_4^2$ 0.71
Chewiness	$32.5671 - 2078.6504x_1 + 63100x_1^2$
Tooth packing	$70.2512 - 544.3167x_1 + 22068x_1^2$
Roasted Peanutty	$119.1418 - 3291.1115x_1$

[1]Regression models based on 120 points, all models presented are significant at α=0.05
[2]Independent variables are moisture (x_1), color measurements *L* (x_2), *a* (x_3), and *b* (x_4)

TABLE 5.7
ADJUSTED R-SQUARE VALUES OF SIGNIFICANT PREDICTION MODELS (α=0.05) RELATING INSTRUMENTAL PARAMETERS AND CONSUMER ATTRIBUTE RATINGS

Descriptive Attribute	Instrumental Measurements							
	Kramer Force[a]	Kramer Energy[b]	Cutting Force[c]	Cutting Energy[d]	Color Lightness[e]	Color[f]	Water Activity[g]	Moisture[h]
Acceptance Ratings								
Overall	—	—	—	—	0.72	0.85	0.83	0.85
Aroma	—	—	—	—	—	0.82	0.81	0.74
Flavor	—	—	—	—	—	0.83	0.81	0.81
Appearance	—	—	—	—	0.76	0.79	0.73	0.85
Color	0.70	—	—	—	—	0.90	0.82	0.83
Texture	—	—	—	—	0.82	0.90	0.83	0.89
Intensity Ratings								
Roasted Peanutty	0.70	—	—	—	—	0.90	0.82	0.83
Crunchiness	—	—	—	—	0.80	0.90	0.70	0.89
Staled/oxidized/rancid	—	—	—	—	—	0.75	—	—

[a]Peak force (N) measured using Modified Kramer shear-compression cell mounted on an Instron Universal Testing Machine
[b]Peak energy (J) measured using Modified Kramer shear-compression cell mounted on an Instron Universal Testing Machine
[c]Peak force (N) measured using an inverted V-blade mounted on an Instron Universal Testing Machine
[d]Peak energy (J) measured using an inverted V-blade mounted on an Instron Universal Testing Machine
[e]Color lightness, *L*-value, measured using a Gardner XL-800 colorimeter
[f]Color, expressed by *L*, *a*, and *b*, measured using a Gardner XL-800 colorimeter
[g]Water activity measured at 25C using an AquaLab CX-2TE water activity meter
[h]Moisture measured on a dry-weight basis (*g* water/*g* solid).

TABLE 5.8
SIGNIFICANT REGRESSION MODELS (R^2>0.70), WITH INSTRUMENTAL MEASUREMENTS AS INDEPENDENT VARIABLES (X)[a], FOR THE PREDICTION OF CONSUMER ATTRIBUTE RATINGS[1]

Consumer Attribute	Regression Equation[b]
Acceptance Ratings	
Overall	$21.3283 + 10.6364x_1 - 6.9782x_2 - 27.2446x_3 - 0.1008x_1^2 + 0.6001x_2^2 + 0.6724x_3^2$ 0.85
Aroma	$-17.8932 + 6.8089x_1 - 14.7110x_3 - 0.0664x_1^2 + 0.3583x_3^2$
Flavor	$88.3198 + 6.6178x_1 - 25.3019x_3 - 0.0624x_1^2 + 0.6195x_3^2$
Appearance	$2.2540 + 359.8315X_4 - 9778.3847X_4^2$
Color	$-70.1623 + 2.8273x_1 - 0.0263x_1^2$
Texture	$115.3803 + 5.6229x_1 + 1.1219x_2 - 27.6796x_3 - 0.0468x_1^2 + 0.6817x_3^2$
Intensity Ratings	
Roasted Peanutty	$151.9533 + 5.9827x_1 - 0.5855x_2 - 30.0576x_3 - 0.0551x_1^2 + 0.0745x_2^2 + 0.7340x_3^2$ 0.90
Crunchiness	$206.2210 + 1.2992x_1 - 37.3843x_3 - 0.0465x_1^2 + 0.9239x_3^2$ 0.90
Oxidized	$-45.2179 - 6.5872x_1 + 21.4258x_3 + 0.0642x_1^2 - 0.5258x_3^2$

[a]Regression models based on 60 points, all models presented are significant at α=0.05
[b]Independent variables are color measurements *L* (x_1), *a* (x_2), and *b* (x_3), and moisture (x_4).

FIG. 5.1 – STORAGE CHAMBER USED IN THE STUDY OF ROASTED PEANUTS STORED AT DIFFERENT WATER ACTIVITY CONDITIONS.

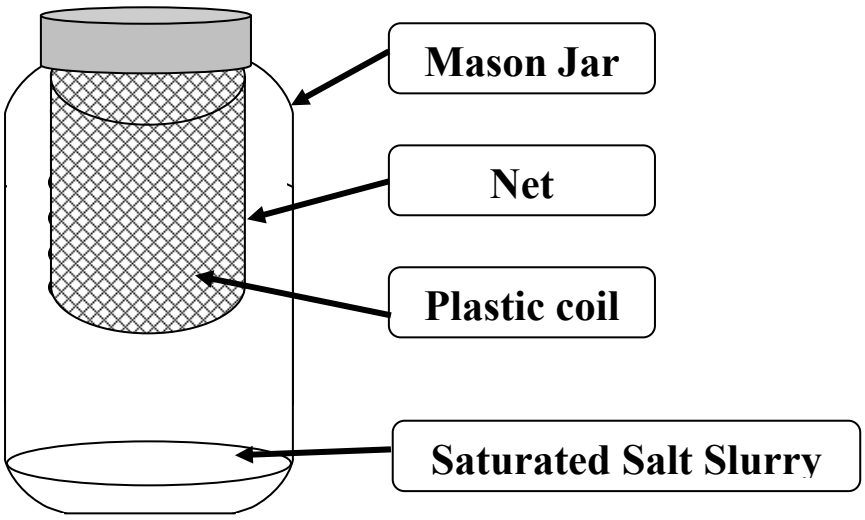
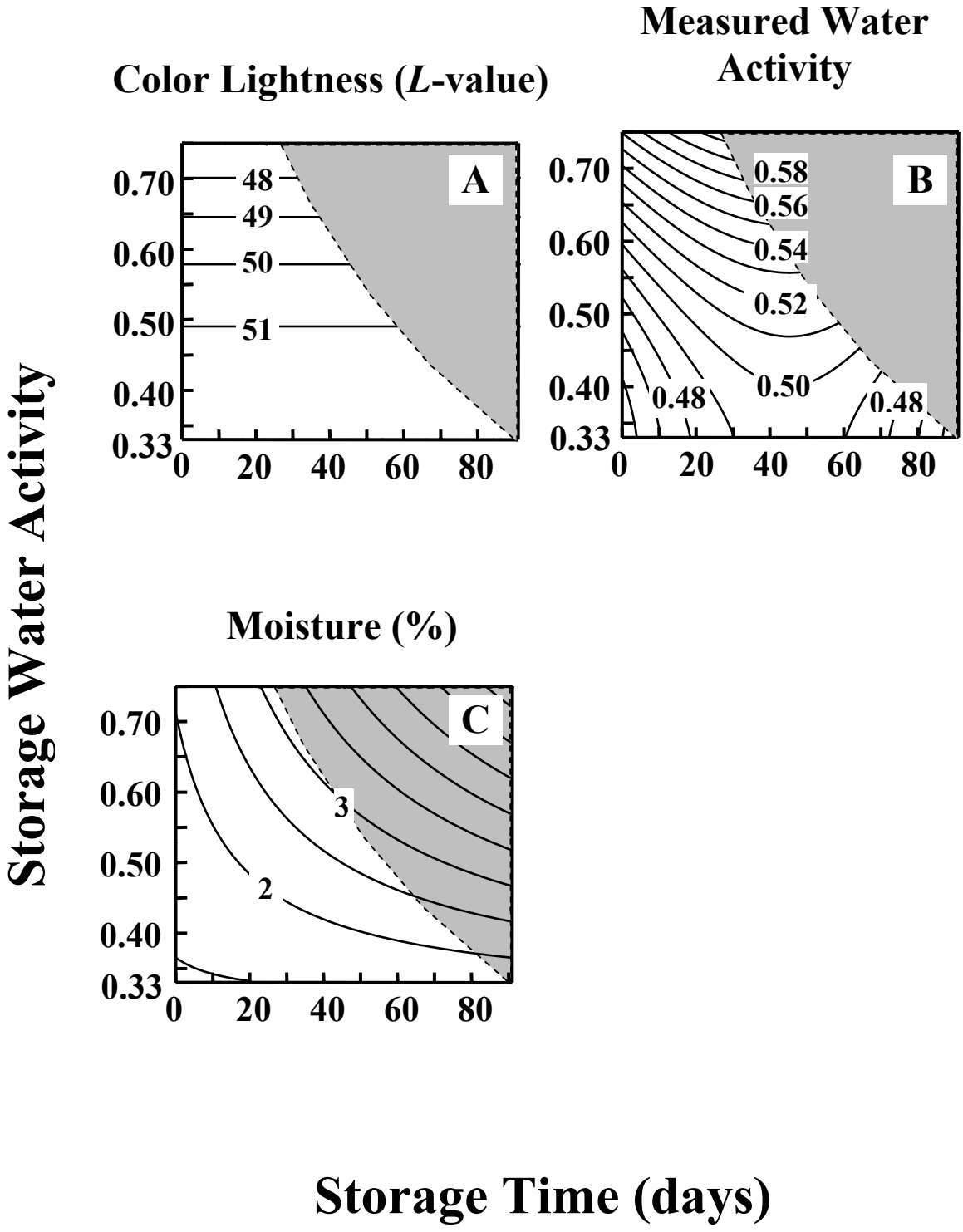

Mason Jar
Net
Plastic coil
Saturated Salt Slurry

FIG. 5.2 – CONTOUR PLOTS ILLUSTRATING THE EFFECTS OF STORAGE TIME (DAYS) AND STORAGE WATER ACTIVITY ON THE (A) COLOR LIGHTNESS (*L*-VALUE), (B) WATER ACTIVITY, AND (C) PERCENT MOISTURE OF STORED ROASTED PEANUTS. (Shaded areas are not included in the study and no implications were made within the region)


Color Lightness (L-value)
Measured Water Activity
Moisture (%)
Storage Water Activity
Storage Time (days)
A
B
C
48
49
50
51
0.58
0.56
0.54
0.52
0.50
0.48
0.48
3
2
0.70
0.60
0.50
0.40
0.33
0
20
40
60
80

SECTION VI

RELATING CONSUMER ACCEPTANCE AND DESCRIPTIVE PROFILES OF STORED ROASTED PEANUTS USING PARTIAL LEAST SQUARES REGRESSION[1]

[1] Lee, C.M. and A. V. A. Resurreccion. Submitted to *J. Food Quality & Preference,* 2/21/2004.

ABSTRACT

Roasted peanuts were stored at 20 treatment combinations of water activities (0.33, 0.44, 0.54, 0.67, 0.75 a_w) and temperatures (23, 30, 35, 40 °C), and evaluated after storing for 0, 40, and 110% of their respective estimated shelf life. A descriptive panel (*n*=12) and a consumer acceptance panel (*n*=50) evaluated the sensory characteristics of stored roasted peanut. At low storage (0.33 to 0.54 a_w), samples stored up to 35 days were rated similar to control. Samples stored at high a_w (0.67 to 0.75 a_w) were oxidized and had a chewy texture. After prolonged storage of 5 to 13 days, high a_w treatments were chewy and had raw beany flavor, where as samples stored at low a_w for 25 to 91 days were oxidized and hard. Positive consumer acceptance was characterized by descriptive attributes grouped as “peanut flavor” and “desirable textures”, and inversely related to “texture defects” and “oxidized flavors”.

INTRODUCTION

Americans consume about 4 kg of peanuts and peanut products per year, of which about 20% are used as ingredients in candy products (Schaub, 1990). The presence of peanut or peanut butter in candy products results in the problem of water activity migration from other ingredients and affects the quality of the peanut-based product. Sensory profiles of stored roasted peanut have been studied by many researchers using descriptive analysis (Johnsen, Civille, Vercellotti, Sanders & Dus, 1988; Baker, Sims, Gorbet, Sanders, & O'Keefe, 2002, Braddock, Lee, Trezza, Guinard & Krochta, 2002) but no consumer acceptance measurements were made. There is a need to relate the sensory profiles and consumer acceptance ratings of stored roasted peanuts.

Consumer tests are commonly conducted to measure the acceptance of products. However, the high cost of conducting consumer test in terms of employee time or honorarium to non-employee, and preparation makes frequent testing expensive. Munoz (1997) discussed the need and methods to relate between descriptive analysis and consumer test. The initial statistical procedure recommended for relating two sets of data are regression and correlation analyses (Gacula, 1997). Ordinary least squares regression assumes that explanatory variables (x) are independent of each other and the number of explanatory variables is equal or less than the number of samples or treatments (Kolsky, 2000). However, descriptive attributes may be highly correlated due to context, synergistic or antagonistic effects of the various ingredients in a product (Gacula, 1997), resulting in the problem of multicollinearity. Subsequently, such regression models are not always accurate in predicting the dependent variable. Instead, a multivariate statistical procedure that takes advantage of the correlated attributes can be used to understand the relationship between descriptive and consumer data (Gacula, 1997).

Partial least squares regression (PLSR) is a modeling statistical procedure that has gained popularity in food research in recent years. PLSR does not assume independence of explanatory variables (x) and it can handle as more explanatory variables than number of objects (Tobias 2002; Kolsky, 2000). There are 2 types of PLSR, namely univariate PLSR and multivariate PLSR. Univariate PLSR refers to a statistical method of modeling the relationships between one dependent variable and a number of explanatory variables (Garthwaite, 1994). In multivariate PLSR, the number of dependent variable is greater than 1. In both cases, the linear components of the explanatory variables are related to the dependent variables by ordinary least squares regression and equations are determined (Garthwaite, 1994). In most situations, the univariate method is likely to construct better prediction equation than multivariate PLSR (Garthwaite, 1994). In a simulation study, univariate PLSR was found to be superior to other methods of forming prediction equations, including ordinary least squares, forward variable selection and principal components regression (Garthwaite, 1994).

The objective of this study was to apply multivariate analysis to describe the relationship between descriptive and consumer data of roasted peanuts stored at different temperatures and water activities. The specific objectives were to: 1) conduct principal component analyses (PCA) on both descriptive and consumer ratings, 2) identify relations, if any, between descriptive and consumer rating of stored roasted peanut using multivariate PLSR, and 3) describe relations between descriptive or consumer attributes and treatment variables.

MATERIALS & METHODS

Sampling

A scheme was established such that roasted peanuts were stored at different water activities and temperatures for periods of time that represent 40 and 110% of their estimated shelf life (ESL). Depending on the storage temperature and relative humidity, the shelf life of roasted peanuts stored has been found to be between 42 to 136 d (Baker *et al.*, 2002; Braddock *et al.*, 1995; Ramos, 1995; Lee & Krochta, 2002; Shewfelt & Young, 1977; Anon., 1971). A survey conducted among retailers found that the shelf life of roasted peanuts stored at ambient is 90 d (Anon., 1971). If the accelerating factor (Q_{10}) is known, the following equation (Labuza & Schmidl, 1985) can be used to estimate the shelf life at an accelerated temperature of T_2:

$$\theta_{T_2} = \theta_{T_1} \times Q_{10}^{\Delta/10}$$

where θ = shelf life, $T_1<T_2$,$\Delta = T_1 - T_2$. By applying an assumed Q_{10} of 1.5, the shelf life of peanuts at 23 °C of 90 d was projected at 68, 55 and 45 d at 30, 35 and 40 °C, respectively. The same equation was modified to reflect a change in water activity such that shelf life can be projected:

$$\theta_{a_w''} = \theta_{a_w'} \times Q_a^{-|\Delta|/0.1}$$

where θ = shelf life, a_w' = water activity 1, a_w'' = water activity 2, $\Delta = a_w' - a_w''$, and Q_a=accelerating factor due to a 0.1 change in a_w. Using an assumed Q_a of 1.3, the modified equation was applied in calculating the ESL of each treatment. The sampling scheme (Table 6.1) was used and samples were removed from storage after 40 and 110% of ESL.

Experimental Design

The experimental design consisted of a 4x5 factorial design with 4 storage temperatures of 23, 30, 35, 40 °C and 5 water activities of 0.33, 0.44, 0.54, 0.67 and 0.75. Depending on the treatment, samples were evaluated over a storage period of 2 to 91 d. The experiment was replicated twice with a total of 40 samples per sampling time at 40 and 110% of ESL. Control samples, consisting of roasted peanuts from the same batch of roasted peanuts used throughout the study, were packaged immediately in 0.075 mm (3-mil.) polyethylene bags (Koch Supplies, Kansas City, MO) and flushed with 99% nitrogen, then stored at 4 °C. Stored samples were similarly packaged and held at 4 °C to minimize changes until all samples belonging to the same ESL were collected. A total of 40 stored roasted peanut samples were evaluated by a descriptive panel (n=12) over 2 sessions during each of the 2 sampling times. Likewise, consumers (n=50) evaluated the 20 treatment samples collected during the 2 sampling times over 4 sessions.

Controlled Humidity Jar Set-up

To achieve controlled humidity levels of 0.33, 0.44, 0.54, 0.67 and 0.75, the following salts were used: magnesium chloride (Fisher Scientific, Yongers, NY), potassium carbonate (Mallinckrodt Baker, Inc., Phillipsburg, NJ), magnesium nitrate (Mallinckrodt Baker, Inc., Phillipsburg, NJ), sodium bromide (Mallinckrodt Baker, Inc., Phillipsburg, NJ), sodium nitrite (Mallinckrodt Baker, Inc., Phillipsburg, NJ), potassium iodide (Mallinckrodt Baker, Inc., Phillipsburg, NJ) and sodium chloride (Morton International, Inc., Chicago, IL). Since water activity of each saturated salt varies with changes in temperature, the water activity of each temperature-chemical combination was estimated using published equations (Labuza 2001; Webb & Labuza, 2002) and is shown in Table 6.2. To minimize the effect of varying water

activity at different temperatures, different chemicals were used for 0.54 and 0.67 a_w. For 0.54 a_w, magnesium nitrate was used for jars stored at 23 and 30 °C, and sodium bromide was used for those stored at 35 and 40 °C (Table 6.2). Similarly for 0.67 a_w, sodium nitrite was used for jars stored at 23 °C and potassium iodide was used for those intended for 30, 35 and 40 °C (Table 6.2).

A set-up was established such that there was a maximum exposure of the samples to the surrounding humidity while preventing it from contact with the saturated salt slurries (Fig. 6.1). The set-up consisted of a half-gallon wide mouth Mason jar (Ball Corp., Broomfield, CO), saturated salt slurries and a plastic net with 0.5 cm holes. By threading a plastic coil (Magic Spring, Dolgencorp, Inc., Goodlettsville, TN) around the net, the net was formed into a cylindrical shape (Fig. 6.1). Since materials such as wood and cotton interfere with the equilibrium a_w, only materials made of plastic were used inside the jar. Salts were added to Mason jars at ambient temperature of 23 °C or inside a water bath (Model 220A, Napco Inc., Portland, OR) maintained at 30, 35 or 40 °C to attain water activities of 0.33 to 0.75 (AOAC, 1995). The plastic net cylinder was suspended at least 5 cm above the saturated slurry by securing it with 2 rubber bands outside the jar.

Jars were cleaned, dried and filled with saturated salts. Treatments of lower water activity ($a_w<0.40$) and higher water activity ($a_w\geq0.40$) were prepared by filling the jars with the respective salts up to 4 cm and 1.5 cm in depth, respectively (AOAC, 1995). For each jar, 2 mL of double-deioinized water added and stirred without splashing onto the inside wall. This was repeated until the salt was saturated and no more salts could be dissolved (AOAC, 1995). Eventually, enough water was added so that there were approximately 2 mm of liquid above the salt (Labuza, 2001).

To equilibrate the water activity, jars prepared with saturated salt slurries were stored at their storage temperatures for at least one week (Labuza, 2001). The water activity of each jar was measured using the Safe Storage Monitor (Decagon Devices, Inc., Pullman, WA) by monitoring the equilibrium relative humidity without sample for 2 weeks. The data collected was then transferred to a personal computer via the SafeLink software (Decagon Devices, Inc., Pullman, WA) provided with the Safe Storage Monitor. The water activities measured had very little difference from the calculated water activities (Table 6.2). Every week during storage, the jars were inspected and distilled water or salt was added to maintain the slurry with 2 mm liquid above the salt.

Sample Preparation

Shelled, raw, medium size Georgia Green peanut kernels (2001 crop, McClesky Mills, Smithville, GA) were sorted for defective kernels and foreign materials. Sorted peanuts were stored at 4 °C (Nor-Lake, Inc., Hudson, WI) for up to 2 weeks prior to roasting, and were equilibrated to 23 °C at least 12 h before processing. Peanuts were heated in 4 kg batches at 190 °C for approximately 6 min in a rotary gas roaster (Model L5, Probat Inc., Memphis, TN) to attain a medium roast such that the color Lightness (L) value was 50 ± 1.0 (Johnsen *et al.*1988). Color was measured using a Gardner XL-800 colorimeter (Pacific Scientific, Bethesda, MD) that was standardized using a yellow reference tile (L=79.56, a=-6.17, b=22.98). The color of the roasted and blanched peanut was measured by filling the colorimeter sample cup to a depth of 1 cm and 4 readings were performed for each sample.

Immediately after roasting, peanuts were cooled for 3 min in a 64 cm diameter circular perforated stainless steel tray with a suction fan underneath and a rotating brush that spread the

roasted peanut in a circle (Model L5, Probat Inc., Memphis, TN). Cooled, roasted peanuts were then blanched using a dry peanut blancher (Model EX, Ashton Food Machinery Co., Inc., Newark, NJ). Roasted and blanched peanuts were sorted manually, and peanuts that were discolored, damaged, or had any remaining testa were rejected. Workers wore plastic gloves to prevent transfer of moisture, lipoxygenase and foodborned microorganisms to the roasted peanuts. A non-heated rotating coating pan (Stokes Equipment Inc., OH) was used to mix and cool the different roasting batches. Three hundred and fifty grams of roasted peanuts were added to the plastic net cylinders and the jars were capped, sealed tightly and stored at the designated temperature for the pre-determined ESL (Table 6.1). The incubators were maintained at 30 °C (Model 3107, The Electric Hotpack Company, Inc., Philadelphia, PA), at 35 °C (American Instrument Co., Silver Spring, MD) or at 40 °C (Model 645 Treas, Precision Scientific, Winchester, VA). Jars maintained at 23 °C were stored in corrugated paperboard boxes to exclude light so that the condition was similar to that of those stored in incubators at higher temperatures. Control samples were packaged and stored at 4 °C.

Sampling Procedure

After storing for the designated period, sample jars were equilibrated to room temperature (23 °C) for at least 4 h prior to opening. This was to prevent sudden condensation of moisture onto the samples (Labuza 2001). Stored samples were removed from the jar and packaged in 0.075 mm (3-mil.) polyethylene bags (Koch Supplies, Kansas City, MO), vacuum and flushed with 99% nitrogen, and stored at 4 °C until all 20 treatment samples representing the 40% or 110% ESL were collected.

Sensory Evaluation

Descriptive Analysis

A descriptive panel was trained using a hybrid (Einstein, 1991) of Spectrum, Quantitative Descriptive Analysis and Texture Profile Analysis. Panelists were recruited, screened and trained as follows:

Panel. Potential panelists were screened and a total of 12 panelists were recruited, trained, and calibrated on descriptive analysis of roasted peanuts. A panelist was recruited if he or she met the criteria of 1) between the age of 19 to 65, 2) does not smoke 3) is not allergic to peanuts, 4) eats peanuts, 5) is available to attend all training and testing sessions, 6) is interested in participating, and 7) can communicate verbally about the product (Plemmons & Resurreccion, 1998). Prior to screening, potential panelists were required to sign a consent form approved by the University of Georgia Institutional Review Board and they were paid cash for their participation. During screening, potential panelists were tested on their ability to identify and differentiate different tastes and aromatic compounds (Plemmons & Resurreccion, 1998). Panelists' experience in descriptive analysis ranged from 3 mo to 20 y. Recruited panelists signed a consent form approved by the University of Georgia Institutional Review Board that is applicable for the duration of the training and testing sessions. They were also paid for their attendance.

Training. Recruited panelists were trained on descriptive analysis using the procedure adapted from Meilgaard, Civille & Carr (1991). A total of three 2-hour training sessions were conducted before the panelists were trained and calibrated. Panelists were presented with 3 samples stored at varying a_w condition during training and a lexicon of descriptive terminology was developed to characterize their different sensory properties (Sznenesniak, Brandt &

Friedman, 1963; Johnsen *et al.,* 1980; Meilgaard *et al.,* 1991; Muego-Gnanasekharan & Resurreccion, 1992; Ward, 1995; Divino, Koehler & Akoh, 1996; Civille & Lyon, 1996; Plemmons & Resurreccion, 1998; Gills & Resurreccion, 2000; Grosso & Resurreccion 2002). Panelists agreed on a final list of attributes, definitions, evaluating instructions and external references (Table 6.3). The panel used a 150-mm unstructured line scale with anchors at 12.5 and 137.5 mm, or weak and strong, respectively. Standard references and a control, and their respective attribute intensities (Table 6.3 & 6.4) were listed on both paper and computer ballots.

Ballot. The panel developed and used a ballot consisting of 23 attributes representing the appearance, texture, flavor, taste, and aftertaste of stored roasted peanuts. The paper and computer ballots (Compusense® *five*, version 4.2, Compusense, Inc., Guelph, Ontario, Canada) used during calibration and testing respectively, were identical. A monadic presentation was used in the design of the computer ballot so that panelists were not allowed to move backward or forward between samples. Rather, panelists were allowed to move back and forth among attributes within the same sample. Evaluating instructions, definitions, references, control and reference intensities were provided on both the paper and computer ballots. The attributes were evaluated in the order of perception similar to normal peanut consumption, except the texture attributes that were presented before flavor attributes due to their importance in roasted peanut characteristics.

Calibration. A one-hour calibration session was conducted during the first hour of each testing session. Panelists were calibrated with aqueous solutions of sucrose, sodium chloride, caffeine, and citric acid, representing sweet, salty, bitter and sour taste respectively. At least 3 concentrations, equivalent to 3 different intensities spanning the 150-point scale, were evaluated. Panelists also evaluated reference samples and a control prior to evaluation to improve the

reliability of the panel. In addition, panelists evaluated a warm-up sample using a paper ballot. They were required to reach a consensus rating of within 10% of the mean rating for each attribute, by means of re-evaluating the sample and adjusting their ratings until the panel arrived at a consensus. Sample evaluation was conducted in partitioned booths using computerized ballots Panelists used a computer mouse for rapid and accurate entry of ratings.

Test Conditions. Screening, training, and testing sessions were held at the Department of Food Science & Technology, University of Georgia in Griffin, GA. Panelists evaluated samples in environmentally-controlled partitioned booths illuminated with two 50 W white incandescent bulbs providing 738 lx of light.

Test Procedure. Samples (10g) were filled into each of the 28.57-g plastic cups with lids (Solo Cup Co., Highland, IL) at least 1 hr prior to evaluation. Twenty treatment samples and 1 control sample were evaluated during each session and mandatory breaks of 5 min were enforced after the fifth, tenth, and fifteenth samples to reduce panelist fatigue. Samples were labeled with 3-digit random numbers and were served at ambient temperature (23 °C) on a stainless steel tray lined with white paper. A randomized complete block design was used and the order of presentation was controlled using Compusense® *five*. Panelists were instructed to expectorate all samples and rinsed with deionized water and unsalted crackers between samples. The testing sessions were conducted between 10 am and 12 pm of each day, for a total of 5 d.

Consumer Test

For each consumer test, fifty untrained consumers were recruited for the test if they (a) are not allergic to peanuts, (b) are between 19 to 65 years, and (c) eat peanuts or peanut products at least once a month. Five consumer tests, each with 50 panelists, were conducted for samples

of 0, 40, and 110% ESL, respectively. All consumers agreed to and signed a consent form approved by the University of Georgia Institutional Review Board prior to their participation. Completion of a demographic form on age, gender, marital status, occupation, educational background, income and eating habits was required for all consumers. The first consumer test (n=50) was conducted to evaluate three 0% ESL samples and to establish a baseline for comparison with the treated samples. Subsequently, a total of 4 consumer tests (n=50) were conducted to complete the evaluation of the 40 samples from both 40 and 110 % ESL. On each test day, consumers evaluated 6 samples, followed by a break of 5 min before evaluating the next 5 samples. In addition, a control sample that represents "fresh" roasted peanut was served among the test samples for each session. The test was conducted in partitioned booths as described above.

Test Location. The consumer tests were conducted at the Department of Food Science and Technology, Griffin Campus in nine hourly sessions between 9 and 11pm, and between 2 and 7 pm on each day. The test was conducted in a laboratory setting of ten partitioned booths illuminated with two 50 W white incandescent bulbs providing 738 lx of light.

Test material. Roasted peanuts, as previously described, were evaluated by the consumer panels. In addition to the twenty treatment samples, the control sample was also evaluated. Approximately 2 h prior to testing, 5 g of each sample was removed from its package and placed into 28.57-g plastic cups with lids (Solo Cup Co., Highland, Ill., U.S.A.). Samples coded with three-digit random numbers were served at ambient temperature (23 °C) on a stainless steel tray lined with white paper.

Test procedure. Consumers evaluated ten samples and a control sample of roasted peanut in a monadic sequential order during each day. A mandatory break of 5 min after the 4th

and 8th samples was inserted to reduce panelist fatigue. During the first break, panelists were required to fill out a computerized demographic questionnaire relating to age, gender, marital status, occupation, educational background, income and eating habits. For each of the 40 or 110% ESL samples, twenty treatment samples were evaluated using a randomized block design in 2 testing days.

Ballot. The consumer ballot contained both acceptance and intensity rating questions. Acceptance questions included overall, appearance, color, aroma, flavor, and texture acceptance which were based on a 9-point hedonic scale, with 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely (Peryam 1964). Panelists also rated the intensity ratings of crunchiness, roasted peanutty flavor and stale/oxidized/rancid flavor using a 9-point intensity scale anchored at both ends of the scale. The scale for crunchiness intensity was anchored with "not crunchy at all" and "very crunchy" at the 1- and 9-point on the scale, respectively. Furthermore, the anchor words for roasted peanutty and stale/oxidized/rancid flavor were "none" and "high" for 1- and 9-point ratings, respectively. Panelists were required to rinse their mouths with unsalted saltine crackers and deionized water between samples, and to expectorate all samples into a cup provided.

Data Analyses

Data collected was analyzed using SAS (Version 8.0e, SAS Institute Inc., Cary, NC). The descriptive analysis data was first analyzed by cluster analysis using PROC VARCLUS procedure and outlier panelists for each sampling time were identified (Malundo & Resurreccion, 1992). Additionally, raw data of each panelist were plotted for each sample to identify panelists who did not perform consistently with the panel as a group. Among the 12

panelists, two panelists were identified as outliers and their data were eliminated from the data set. The remaining results of 10 panelists were used in the analyses.

Mean data from the descriptive and consumer tests were used in the multivariate analysis. Both sets of data were standardized by dividing with the standard deviation so that the variables did not bias the analysis due to difference in scale (Esbensen, Guyot & Westad, 2000). Both PCA and PLSR were performed using the Unscrambler® 7.6 (CAMO ASA, Trondheim, Norway). PCA was conducted separately to analyze the underlying data structure of the descriptive and consumer data while PLSR was used to (1) describe the effect of storage factors on the descriptive and consumer attributes, and (2) describe the relationship between descriptive attributes and consumer acceptance attributes.

RESULTS & DISCUSSION

Loadings for descriptive attributes. PCA loading plots for descriptive attributes are shown in Fig. 6.2. The first 3 principal components (PC) account for 77% of the total variation in the descriptive data. The first, second and third PCs explain 55, 14, and 8% of the variation. Attributes with high negative loadings for PC1 are crispness (-0.261), crunchiness (-0.263), hardness (-0.241), roasted peanutty (-0.264), sweet aromatic (-0.265), woody/hulls/skins (-0.253), salty (-0.261), bitter (-0.254), and sweet (-0.254). Additionally, the following attributes have high positive loadings for PC1: chewiness (0.260), tooth packing (0.253) and cardboard (0.268). Attributes such as brown color (0.403) and fracturability (0.255) have high positive loadings whereas painty (-0.354) had high negative loadings for PC2. Burnt (-0.12) had a low negative loading on PC2. All 4 attributes, namely raw beany (0.457), oxidized flavor (0.339), earthy (0.419) and astringency (0.315) have high positive loadings on PC3 (data not presented).

Samples rated high in hardness, crunchiness and crispness are more than likely to be low in brown color, fracturability, chewiness and tooth packing because of the their inverse relation on the PCA loading plot (Fig. 6.2). Similarly, samples with high loadings on roasted peanutty, sweet, woody/hulls/skins, sweet aromatic, salty, bitter and astringency are more likely to be rated low on cardboard, oxidized, painty and burnt (Fig. 6.2). PC1 is composed of the variables crunchiness, crispness, hardness, roasted peanutty, sweet aromatic, cardboard, oxidized, tooth packing and chewiness that are most important to roasted peanuts (Fig. 6.2). Whereas, PC2 is composed mainly of negative attributes in roasted peanuts, including brown color, fracturability, painty and burnt (Fig. 6.2). Following the definition of fracturability previously established by Ward (1995), the panel rated increasing fracturability for peanuts that were low on crunchiness, crispness and hardness. The definition for fracturability would be clear to future panels if it is modified as "force required on the surface of a sample that causes it to shatter". Lastly, PC3 accounts for the remaining of the negative attributes like raw beany, oxidized, earthy and astringency (data not presented).

The sensory attributes, as appeared in the PCA loading plot can be classified into 5 groups which were identified as "defective texture", "defective flavor", "high moisture defect", "low moisture defect", "roasted peanut", and "taste" (Fig. 6.2). Attributes such as chewiness, tooth packing, fracturability, and brown color belong to the group named "defective texture" (Fig. 6.2). Another group that relates to negative flavor in peanuts is called "defective flavor" and it consists of cardboard and oxidized flavors (Fig. 6.2). "Low moisture defect" and "high moisture defect" consist of the attributes painty and raw beany, respectively (Fig. 6.2). The "roasted peanut" group consists primarily of attributes such roasted peanutty, hardness, crunchiness, crispness, astringency and sweet aromatic (Fig. 6.2). The "taste" group is made up

of sweetness, bitterness, saltiness, and woody/hulls/skins (Fig. 6.2). The remaining attributes, including fishy, sour, earthy, and burnt, did not show high loading on either PCs (Fig. 6.2).

Score and loading for descriptive data. A PCA bi-plot showing the sample scores superimposed onto the loading plot is shown in Fig. 6.3. In order to visualize the treatment identities without cluttering the bi-plot, the treatments were identified by a number as listed in Table 6.5. The scores are distributed in a manner that is mainly related to storage time and water activity. The storage times, as explained previously, consist of 0, short (40%) and long (110%) ESL. All samples that were tested initially (sample 1) and those stored under 0.55 a_w or less, rated after storing for 10 to 33 d (samples 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 27, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46 and 48) were grouped together. These had high loadings for hardness, crispness, crunchiness, roasted peanutty, sweet aromatic and astringency (Fig. 6.3). When the same samples (a_w<0.55) were tested again after prolonged storage of 32 to 91 d (samples 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 25, 27, 29, 31, 33, 35, 37, 39, 41, 43, 45, 47, 49), their sensory profiles changed and these samples are higher in cardboard, painty, burnt and oxidized flavor but remained high in intensities of crunchiness, crispiness and hardness (Fig. 6.3). Samples stored in high moisture ($a_w \geq 0.67$), evaluated after storing for 5 to 14 d (samples 50, 52, 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80) were grouped together and were rated high in chewiness, tooth packing, raw beany, brown color, sour and fishy (Fig. 6.3). Lastly, when the same high moisture samples were evaluated after prolonged storage of 13 to 37 d (samples 51, 53, 55, 57, 59, 61, 63, 65, 67, 69, 71, 73, 75, 77, 79, 81)it resulted in ratings that were high in fracturability, tooth packing, chewiness, cardboard, and oxidized flavor (Fig. 6.3). These groupings demonstrated that the samples can be classified according to their storage water activity and storage times.

Loadings for consumer attributes. A loading plot was constructed using mean consumer ratings for each treatment and is shown in Figure 6.4 along with the score plot. The first two PC's accounted for 97% of the variation, and PC1 and PC2 accounted for 92 and 5%, respectively. The underlying data structure was simple wherein that all attributes had high positive loadings on PC1, except for staled/oxidized/rancid flavor intensity, which had a high negative loading on PC1.

Scores and loadings of consumer attributes. Samples were clearly differentiated by their acceptance, thus termed "liked samples" and "disliked samples" (Fig. 6.4). "Liked" samples (samples 1 to 49, 57, 65) had high positive loadings for all consumers attributes, except staled/oxidized/rancid flavor intensity (Fig. 6.4). Samples 57 and 65 appeared to be classified wrongly knowing their high storage temperature and water activity. In contrast, "disliked samples" (samples 50 to 81, except 57 and 65) had negatively high loadings on the desirable attributes (Fig. 6.4). Compared with the descriptive panel data, this bi-plot indicates that consumers did not differentiate the samples as well as the descriptive panel.

Relations of descriptive data (X-matrix) and consumer data (Y-matrix). PLSR was used to explore the relations between 22 descriptive attributes and 9 consumer attributes, including six acceptance and three intensity attributes. Two factors were required to account for the variance in the PLSR of the data set, and the variance accounted for the descriptive data was 43% and that of the consumer data was 54%. This indicates that the model only accounted for about 50% of the variation in the data sets, which was expected due to the high variability in consumer ratings.

All consumer attributes, except stale/oxidized/rancid, had positive loadings on factor 1 (Fig. 6.5). For the descriptive attributes, principal factor 1 consisted of positive loadings of

attributes such as crispness, crunchiness, hardness, roasted peanutty and astringency. In contrast, attributes such as fracturability, chewiness, cardboard and tooth packing had negative loadings on PC1 (Fig. 6.5). Oxidized flavor had negative loading on PC2, compared to positive loadings of raw beany flavor (Fig. 6.5).

Descriptive and consumer attributes can be grouped into "roasted peanut", "taste", "low moisture defect", "high moisture defect", "defective texture" and "defective flavor." The "roasted peanut" group composed of descriptive attributes such as crunchiness, crispness, hardness, roasted peanutty and all consumer attributes excluding stale/oxidized/rancid flavor intensity (Fig. 6.5). The "taste" group consisted of sweet, bitter, salty, woody/hulls/skins, astringency, and sweet aromatic. The "defective texture" group consisted of descriptive attributes that relates to defects in roasted peanuts, including tooth packing, chewiness, fracturability and brown color (Fig. 6.5). Consumer stale/oxidized/rancid flavor intensity, and descriptive attributes such as cardboard and oxidized are grouped under "defective flavor" (Fig. 6.5). The remaining groups are "high moisture defect" and "low moisture defect" that are represented by raw beany and painty, respectively (Fig. 6.5). Attributes not classified into groups are sour, fishy, and burnt (Fig. 6.5).

PLSR grouped descriptive attributes with corresponding consumer attributes successfully. Findings of this study indicate that descriptive attributes such as roasted peanutty, crunchiness, crispness, hardness, fracturability, tooth packing, chewiness and brown color may be used to predict acceptability of roasted peanuts stored at different temperatures and water activities. Samples that were rated high in consumer acceptance were stored at 23 to 40 °C, between 0 to 91 d, and at 0.33 to 0.54 a_w. In contrast, samples stored at 23 to 40 °C, between 5 to 37 d, and at 0.67 and 0.75 a_w had high oxidized and cardboard ratings and were rated low by

consumers. Peanut products formulated with low water activity ingredients between 0.33 and 0.54 are expected to be rated high in consumer acceptance for up to 91 d, but exposing roasted peanuts to ingredients or storage environment of 0.67 or 0.75 a_w will result in products that are unacceptable in 5 to 37 d.

REFERENCES

Anonymous. (1971) Food stability survey, Vol II. Rutgers University Dept. of Food Science, for the State of new jersey Dept. of Health and the U.S. Dept. of Agriculture/Economic Research Service. pp. 57. Washington D.C.: U.S. Government Printing Office.

AOAC, International. (1995) Water activity of canned vegetables. Method No. 978.18. *Official methods of analysis*, 16th ed. (Chapter 42, pp 1-2). Arlington, VA: Association of Official Analytical Chemists.

Baker, G.L., Sims, C.A., Gorbet, D.A., Sanders, T.H. and O'Keefe, S.E. (2002) Storage water activity effect on oxidation and sensory properties of high-oleic peanuts. *J Food Sci. 67*, 1600-1603.

Braddock, J.C., Sims, C.A. and O'Keefe, S.F. (1995) Flavor and oxidative stability of roasted high oleic acid peanuts. *J Food Sci. 60*, 489-493.

Civille, G.V. and Lyon, G.V. (1996) Aroma and flavor lexicon for sensory evaluation: terms, definitions, references, and examples. pp. 74. ASTM Data Series Publication DS 66.

Divino, G.L., Koehler, P.E. and Akoh, C.C. (1996) Enzymatic and autoxidation of defatted peanuts. *J Food Sci. 61*, 112-115, 120.

Einstein, M.A. (1991) Descriptive techniques and their hybridization. In: Lawless HT, Klein BT, ed. *Sensory science theory and applications in food*. (pp. 317-338). New York: Marcel Dekker, Inc.

Esbensen, K.H., Guyot, D. and Westad, F. (2000) *Multivariate data analysis – in practice*. 4th Ed. (pp. 115-153). Woodbridge, NJ: CAMO Inc.

Gacula M.C., Jr. (1975) The design of experiments for shelf life study. *J Food Sci. 40*, 399-403.

Gacula M.C., Jr. (1997) Descriptive sensory analysis methods. In M.C. Gacula, Jr., *Descriptive sensory analysis in practice* (pp. 5-13). Trumbull, CT: Food & Nutrition Press.

Garthwaite, P.H. (1994) An interpretation of Partial Least Squares. *J American Statistical Assoc. 89*, 122-127.

Gills, L.A. and Resurreccion, A.V.A. (2000) Sensory and physical properties of peanut butter treated with palm oil and hydrogenated vegetable oil to prevent oil separation. *J Food Sci. 65*, 173-180.

Grosso, N.R., and Resurreccion, A.V.A. (2002) Predicting consumer acceptance ratings of cracker-coated and roasted peanuts from descriptive analysis and hexanal measurements. *J Food Sci. 67*, 1530-1537.

Johnsen P.B., Civille G.V., Vercellotti J.R., Sanders T.H., Dus C.A. (1988) Development of a lexicon for the description of peanut flavor. *J Sensory Stud. 3*, 9-17.

Kolsky, J.D. (2000) Using partial least squares regression in consumer research. Camo White Paper. Available at http://www.camo.com/PLSwhitepaper.PDF. Accessed August 2002.

Labuza T.P. (2001) Standard Desiccator Method for Isotherms. Available from: http://fscn1.fsci.umn.edu/ted_Labuza/awimages/Salt%20solutions%20FOR%20Isotherm.pdf. Accessed Jan 16.

Labuza, T.P. and Schmidl, M.K. (1985) Accelerated shelf-life testing of foods. *Food Technol. 39*, 57-62, 64, 134.

Lee S.Y. and Krochta J.M. (2002) Accelerated shelf-life testing of whey-protein-coated peanuts analyzed by static headspace gas chromatography. *J. Agric. Food Chem. 50*, 2022-2028.

Lee S.Y., Trezza T.A., Guinard, J.-X., Krochta, J.M. (2002) Whey-protein-coated peanuts assessed by sensory evaluation and static headspace gas chromatography. *J Food Sci*. *67*, 1212-1218.

Malundo, T.M.M. and Resurreccion, A.V.A. (1992) A comparison of performance of panels selected using analysis of variance and cluster analysis. *J Sensory Stud*. *7,* 63-75.

Meilgaard M., Civille G.V. and Carr B.T. (1991) *Sensory Evaluation Techniques*, *2nd ed*. CRC Press, Boca Raton, FL. 354 p.

Muego-Gnanasekharan K.F. and Resurreccion A.V.A. (1992) Physicohemical and sensory characteristics of peanut paste stored at different temperatures. *J Food Sci*. *57*, 1385-1389.

Munoz, A.M. (ed.). (1997) Relating Consumer, Descriptive, and Laboratory data to better understand consumer responses. *ASTM Manual 30.* West Conshohocken, PA: American Society for Testing and Materials.

Plemmons, L.E. and Resurreccion, A.V.A. (1998) A warm-up sample improves reliability of responses in descriptive analysis. *J Sensory Stud 13*, 359-376.

Ramos A.A.T. (1995) Lipid Oxidation in roasted peanuts coated with edible films. M.S. Thesis, University of Georgia, Athens. p 14-68. 102 pp.

Schaub J. (1990) The peanut program and its effects. *FoodReview 13*(1), 37-40.

Shewfelt A.L and Young C.T. (1977) Storage stability of peanut-based foods: a review. *J Food Sci. 42*, 1148-1152.

Szczesniak, A.S., Brandt, M.A. and Friedman, H.H. (1963) Development of standard rating scales for mechanical parameters of texture and correlation between the objective and the sensory methods of texture evaluation. *J. Food Sci*. *28*, 397-403.

Tobias, R.D. (1997) *An introduction to partial least squares regression*. Cary, NC: SAS Institute.

Ward, C.D.W. (1995) Effects of physicochemical and sensory properties on functionality and consumer acceptance of snack chips formulated with cowpea, corn, and wheat flour mixtures. Ph.D. Dissertation. University of Georgia, Athens. pp.69-70.

Webb, R. and Labuza, T.P. (2002) Water activity of saturated salt solutions. Available from: http://www.users.bigpond.com/webbtech/salt.html. Accessed March 25.

TABLE 6.1.
STORAGE DAYS FOR ROASTED PEANUTS STORED AT EACH TEMPERATURE AND WATER ACTIVITY LEVEL

Treatment		Storage days[a]
Temperature	**Water Activity**	
23 °C	0.33	33, 91
	0.44	25, 68
	0.54	19, 53
	0.67	14, 37
	0.75	11, 31
30 °C	0.33	25, 69
	0.44	19, 52
	0.54	14, 40
	0.67	10, 29
	0.75	8, 23
35 °C	0.33	20, 56
	0.44	15, 42
	0.54	12, 32
	0.67	8, 23
	0.75	7, 19
40 °C	0.33	17, 46
	0.44	12, 34
	0.54	10, 26
	0.67	6, 15
	0.75	5, 13

[a]Days representing 40 and 110% of estimated shelf life for each treatment, respectively.

TABLE 6.2.
CALCULATED AND MEASURED WATER ACTIVITY OF SATURATED SALTS SLURRIES OF RELATIVE HUMIDTY STORAGE JARS AT VARIOUS TEMPERATURES

Water activity	Temperature	Saturated salt	Calculated water activity[1]	Measured water activity
0.33	23 °C	Magnesium chloride	0.33[a]	0.32
	30 °C	Magnesium chloride	0.33[a]	0.31
	35 °C	Magnesium chloride	0.32[a]	0.30
	40 °C	Magnesium chloride	0.32[a]	0.30
0.44	23 °C	Potassium carbonate	0.43[b]	0.42
	30 °C	Potassium carbonate	0.43[b]	0.45
	35 °C	Potassium carbonate	0.43[b]	0.44
	40 °C	Potassium carbonate	0.43[b]	0.41
0.54	23 °C	Magnesium nitrate	0.54[c]	0.53
	30 °C	Magnesium nitrate	0.53[c]	0.52
	35 °C	Sodium bromide	0.55[d]	0.55
	40 °C	Sodium bromide	0.53[d]	0.51
0.67	23 °C	Sodium nitrite	0.67[e]	0.63
	30 °C	Potassium iodide	0.68[f]	0.69
	35 °C	Potassium iodide	0.67[f]	0.66
	40 °C	Potassium iodide	0.66[f]	0.66
0.75	23 °C	Sodium chloride	0.77[g]	0.77
	30 °C	Sodium chloride	0.75[g]	0.76
	35 °C	Sodium chloride	0.74[g]	0.72
	40 °C	Sodium chloride	0.73[g]	0.79

[a]Using the equation: $\ln(a_w) = (151.0652/T)-1.6271$, where T= temperature in °K (Webb & Labuza, 2002)
[b]Using the equation: $\ln(a_w) = (-3.0240/T)-0.8300$, where T= temperature in °K (Webb & Labuza, 2002)
[c]Using the equation: $\ln(a_w) = (484.6993/T)-2.2670$, where T= temperature in °K (Webb & Labuza, 2002)
[d]Using the equation: $\ln(a_w) = (447.8054/T)-2.0575$, where T= temperature in °K (Webb & Labuza, 2002)
[e]Using the equation: $\ln(a_w) = (435.96/T)-1.88$, where T= temperature in °K (Labuza, 2001)
[f]Using the equation: $\ln(a_w) = (258.1545/T)-1.2388$, where T= temperature in °K (Webb & Labuza, 2002)
[g]Using the equation: $\ln(a_w) = (23.1092/T)-0.3607$), where T= temperature in °K (Webb & Labuza, 2002)

TABLE 6.3.
ATTRIBUTES AND DEFINITIONS USED IN THE DESCRIPTIVE ANALYSIS OF ROASTED PEANUTS

Attribute[1]	Definition	Reference standard	Intensity[2]
APPEARANCE			
Brown color[c,d]	The intensity of strength of brown color from light to dark brown[d]	white paper[b] (L=91.42, a=-0.22,b=0.04) dry cardboard[k] (L=49.71, a=5.77, b=16.01)	0 30
Moist	Amount of wetness on surface	wet cardboard	100
TEXTURE			
Crispness[h]	Amount of force needed and intensity of sound (high pitch) generated from chewing a sample with incisors[h]	corn chips[h] (Frito Lay, Plano, TX)	70
Fracturability[h]	The force with which the sample breaks[h]	corn chips (Frito Lay, Plano, TX)	53
Crunchiness[c,h]	The force needed and intensity of sound (low pitch) generated from chewing a sample with molar teeth[c,h]	corn chips[h,k] (Frito Lay, Plano, TX)	75
Hardness[d,h]	Amount of force needed to compress a food between molar teeth[d]	corn chips (Frito Lay, Plano, TX)	80
Chewvy[h,i]	The length of time in seconds required to masticate a sample at the rate of one chew per second in order to reduce it to a consistency satisfactory for swallowing[i]	raw peanuts	33
Tooth packing[c,h]	The degree to which product sticks on the surface of molars[c]	raw peanuts	80
FLAVOR			
Roasted peanutty[c,d,e]	The aromatic associated with medium-roast peanuts[c,d,e,h]	dark roasted peanuts (L=45.0±1.0)	84
Raw beany[c,e,f]	The aromatic associated with raw peanuts[c,d,f]	raw peanuts[b,k]	41
Oxidized[c,d,f]	The flavor associated with rancid fats and oils[c]	old vegetable oil[b,l] (Hunt-Wesson, Inc., Fullerton, CA)	37

(Continued on next page)

TABLE 6.3 (cont.)
ATTRIBUTES AND DEFINITIONS USED IN THE DESCRIPTIVE ANALYSIS OF ROASTED PEANUTS

Attributes[1]	Definition	Reference standard	Intensity[2]
Sweet aromatic[e]	The aromatics associated with sweet material such as caramel, vanilla, molasses, fruit[e]	caramel candy (Hershey Food Corporation, Hershey, PA)	60
Woody/hulls/skins[e]	The aromatics associated with base peanut character (absence of fragrant top notes) and related to dry wood, peanut hull, and skins[e]	peanut skins[k]	35
Cardboard[e,f]	The aromatic associated with somewhat oxidized fats and oils and reminiscent of wet cardboard[e,j]	wet cardboard[k]	24
Painty[e]	The aromatic associated with linseed oil, oil based paint[e]	boiled linseed oil[k] (Klean Strip, W. M. Barr & Co., Inc., Memphis, TN)	115
Burnt[e]	The aromatic associated with very dark roast, burnt starches, and carbohydrates, (burnt toast or espresso coffee)[e]	burnt peanuts[b,k] (lightness value L=40±1.0)	35
Earthy[e]	The aromatic associated with wet dirt and mulch[e]	wet soil[k] (Schultz Co., St. Louis, MO)	50
Fishy[e]	The aromatic associated with trimethylamine, cod liver oil, or old fish[e]	cod liver oil (E.R. Squibb & Sons, Inc., Princeton, NJ)	79
TASTES			
Salty[c,d,e]	The taste on the tongue associated with sodium chloride[c,d,e]	0.2% sodium chloride solution 0.35% sodium chloride solution 0.5% sodium chloride solution	25 50 85
Sour[e,g]	The taste on the tongue associated with citric acids[e,g]	0.05% citric acid solution 0.08% citric acid solution 0.15 % citric acid solution	20 50 100
Bitter[b,c,d,f,g]	The taste on the tongue associated with caffeine[b,c,d,f,g]	0.05% caffeine solution 0.08% caffeine solution 0.15% caffeine solution	20 50 100

(Continued on next page)

TABLE 6.3 (cont.)
ATTRIBUTES AND DEFINITIONS USED IN THE DESCRIPTIVE ANALYSIS OF ROASTED PEANUTS

Attributes[1]	Definition	Reference standard	Intensity[2]
Sweet[c,d,e,f]	The taste on the tongue associated with sugars[c,d,e,f]	2.0% sucrose solution	20
		5.0% sucrose solution	50
		10.0% sucrose solution	100
		15.0% sucrose solution	150
CHEMICAL FEELING FACTOR			
Astringency	The puckering of drying sensation of the mouth or tongue surface	grape juice (Welch's, Concord, MA)[f]	65

[a]Attributes are listed in the order perceived by the panelists
[b]Intensity ratings are based on 150 mm unstructured line scales
[c]Plemmons and Resurreccion (1998)
[d]Gills and Resurreccion (2000)
[e]Johnsen *et al.*(1980)
[f]Muego-Gnanasekharan and Resurreccion (1992)
[g]Meilgaard *et al.*(1991)
[h]Ward (1995)
[i]Szenesniak *et al.*(1963)
[j]Civille and Lyon (1996)
[k]Grosso and Resurreccion (2002)
[l]Divino *et al.* (1996)

TABLE 6.4.
RATINGS OF CONTROL SAMPLES[a] USED IN THE DESCRIPTIVE ANALYSIS OF STORED ROASTED PEANUTS

Attributes	Intensity[b]
APPEARANCE	
Brown color	23
Moist	0
TEXTURE	
Crispness	29
Fracturability	50
Crunchiness	60
Hardness	85
Chewy	15
Tooth packing	67
FLAVOR	
Roasted peanutty	74
Raw beany	0
Oxidized	0
Sweet aromatic	14
Woody/hulls/skins	12.5
Cardboard	0
Painty	0
Burnt	0
Earthy	5
Fishy	0
TASTES	
Sweet	12
Sour	0
Salty	12
Bitter	12
FEELING FACTOR	
Astringent	15

[a]Medium roasted Georgia Green medium runner peanuts (L=50.0 ± 1.0)
[b]Intensity ratings are based on 150-point unstructured line scales.

TABLE 6.5.
TREATMENTS AND TREAMENT CODE USED IN STORAGE STUDY OF ROASTED PEANUTS.

Treatment code	Storage water activity (a_w)	Storage Temperature (°C)	Storage Time (days)	Replication
1	0.33	23	0	1
2	0.33	23	33	1
3	0.33	23	91	1
4	0.33	30	25	1
5	0.33	30	69	1
6	0.33	35	20	1
7	0.33	35	56	1
8	0.33	40	17	1
9	0.33	40	46	1
10	0.33	23	33	2
11	0.33	23	91	2
12	0.33	30	25	2
13	0.33	30	69	2
14	0.33	35	20	2
15	0.33	35	56	2
16	0.33	40	17	2
17	0.33	40	46	2
18	0.44	23	25	1
19	0.44	23	68	1
20	0.44	30	19	1
21	0.44	30	52	1
22	0.44	35	15	1
23	0.44	35	42	1
24	0.44	40	12	1
25	0.44	40	34	1
26	0.44	23	25	2
27	0.44	23	68	2
28	0.44	30	19	2
29	0.44	30	52	2
30	0.44	35	15	2
31	0.44	35	42	2
32	0.44	40	12	2
33	0.44	40	34	2
34	0.54	23	19	1
35	0.54	23	53	1
36	0.54	30	14	1
37	0.54	30	40	1
38	0.54	35	12	1
39	0.54	35	32	1
40	0.54	40	10	1
41	0.54	40	26	1
42	0.54	23	19	2
43	0.54	23	53	2

TABLE 5 (Cont.)
TREATMENTS AND TREAMENT CODE USED IN STORAGE STUDY OF ROASTED PEANUTS.

Treatment code	Storage water activity (a_w)	Storage Temperature (°C)	Storage Time (days)	Replication
44	0.54	30	14	2
45	0.54	30	40	2
46	0.54	35	12	2
47	0.54	35	32	2
48	0.54	40	10	2
49	0.54	40	26	2
50	0.67	23	14	1
51	0.67	23	37	1
52	0.67	30	10	1
53	0.67	30	29	1
54	0.67	35	8	1
55	0.67	35	23	1
56	0.67	40	6	1
57	0.67	40	15	1
58	0.67	23	14	2
59	0.67	23	37	2
60	0.67	30	10	2
61	0.67	30	29	2
62	0.67	35	8	2
63	0.67	35	23	2
64	0.67	40	6	2
65	0.67	40	15	2
66	0.75	23	11	1
67	0.75	23	31	1
68	0.75	30	8	1
69	0.75	30	23	1
70	0.75	35	7	1
71	0.75	35	19	1
72	0.75	40	5	1
73	0.75	40	13	1
74	0.75	23	11	2
75	0.75	23	31	2
76	0.75	30	8	2
77	0.75	30	23	2
78	0.75	35	7	2
79	0.75	35	19	2
80	0.75	40	5	2
81	0.75	40	13	2

FIGURE 6.1
HUMIDITY CHAMBER DESIGN FOR STUDYING THE EFFECT OF WATER ACTIVITY ON ROASTED PEANUTS

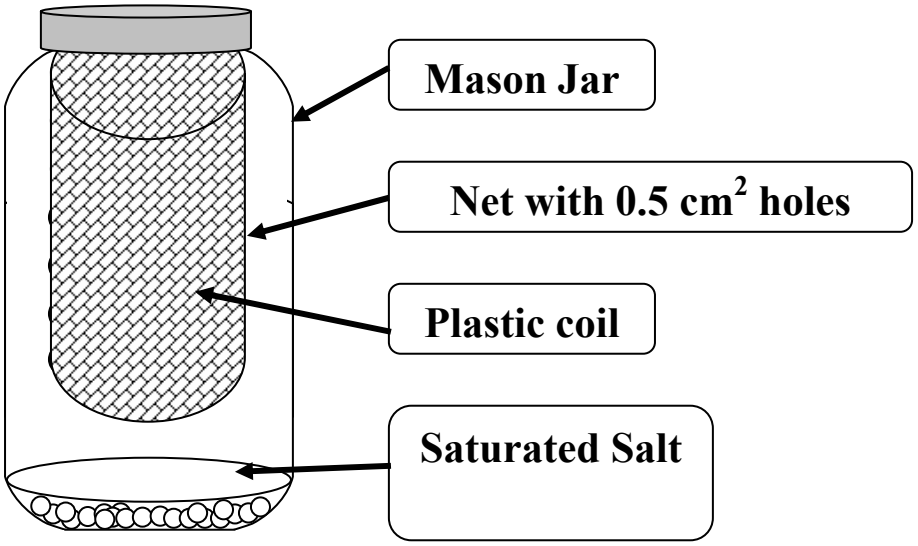

Mason Jar
Net with 0.5 cm^2 holes
Plastic coil
Saturated Salt

FIGURE 6.2
PRINCIPAL COMPONENT ANALYSIS LOADING PLOT OF THE FIRST AND SECOND PRINCIPAL COMPONENTS OF DESCRIPTIVE DATA. The first principal component (PC1) explains 55% of the variation in the data, and the second principal component (PC2) explains 14% of the variation in the data. The descriptive attributes (•) analyzed by PCA were brown color (bco), crispness (cri), fra (fracturability), crunchiness (cru), hardness (hardness), chewiness (che), tooth packing (too), roasted peanutty (rp), raw beany (rb), oxidized (oxi), sweet aromatic (sa), woody/hulls/skins (whs), cardboard (car), painty (pai), burnt (bur), earthy (ear), fishy (fis), salty (sal), sour (sou), bitter (bit), sweet (swe) and astringency (ast). Groupings of attributes in the PCA loading plots are enclosed with ellipses and labeled with 'peanutty', defect flavor', 'moist', 'crunchy' and 'other taste/flavor'

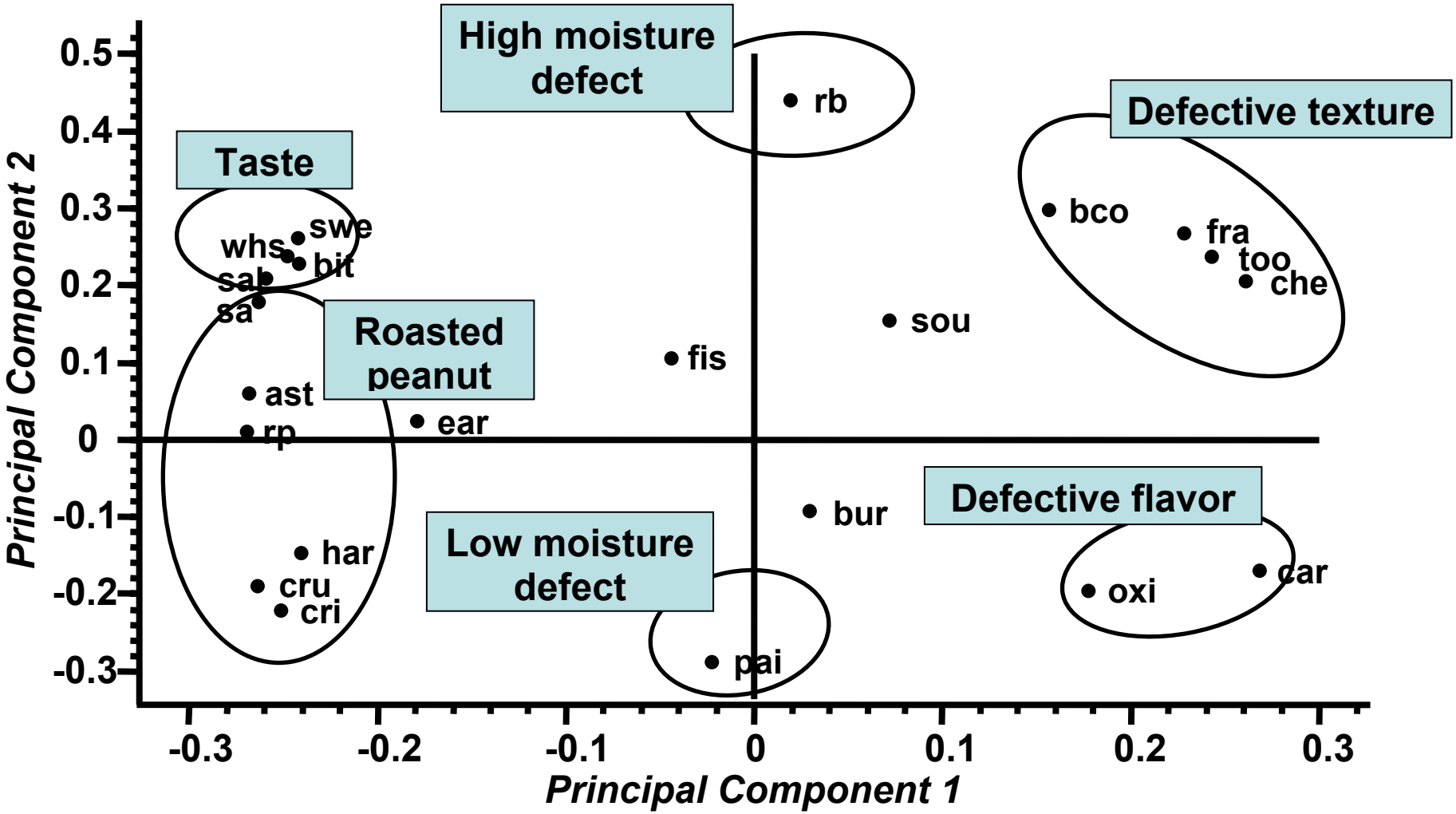

High moisture defect
rb
Defective texture
bco
fra
too
che
Taste
swe
whs
bit
sal
sa
sou
Roasted peanut
fis
ast
ear
rp
Defective flavor
bur
Low moisture defect
har
car
cru
oxi
cri
pai
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
Principal Component 2
Principal Component 1

FIGURE 6.3

PRINCIPAL COMPONENT ANALYSIS BI-PLOT OF LOADINGS WITH SCORES SUPERIMPOSED FOR THE FIRST AND SECOND PRINCIPAL COMPONENTS OF DESCRIPTIVE DATA. The descriptive attributes (•) analyzed by PCA were brown color (bco), crispness (cri), fra (fracturability), crunchiness (cru), hardness (hardness), chewiness (che), tooth packing (too), roasted peanutty (rp), raw beany (rb), oxidized (oxi), sweet aromatic (sa), woody/hulls/skins (whs), cardboard (car), painty (pai), burnt (bur), earthy (ear), fishy (fis), salty (sal), sour (sou), bitter (bit), sweet (swe) and astringency (ast). Groupings of attributes in the PCA loading plots are enclosed with ellipses and labeled with 'peanutty', defect flavor', 'moist', 'crunchy' and 'other taste/flavor'

1

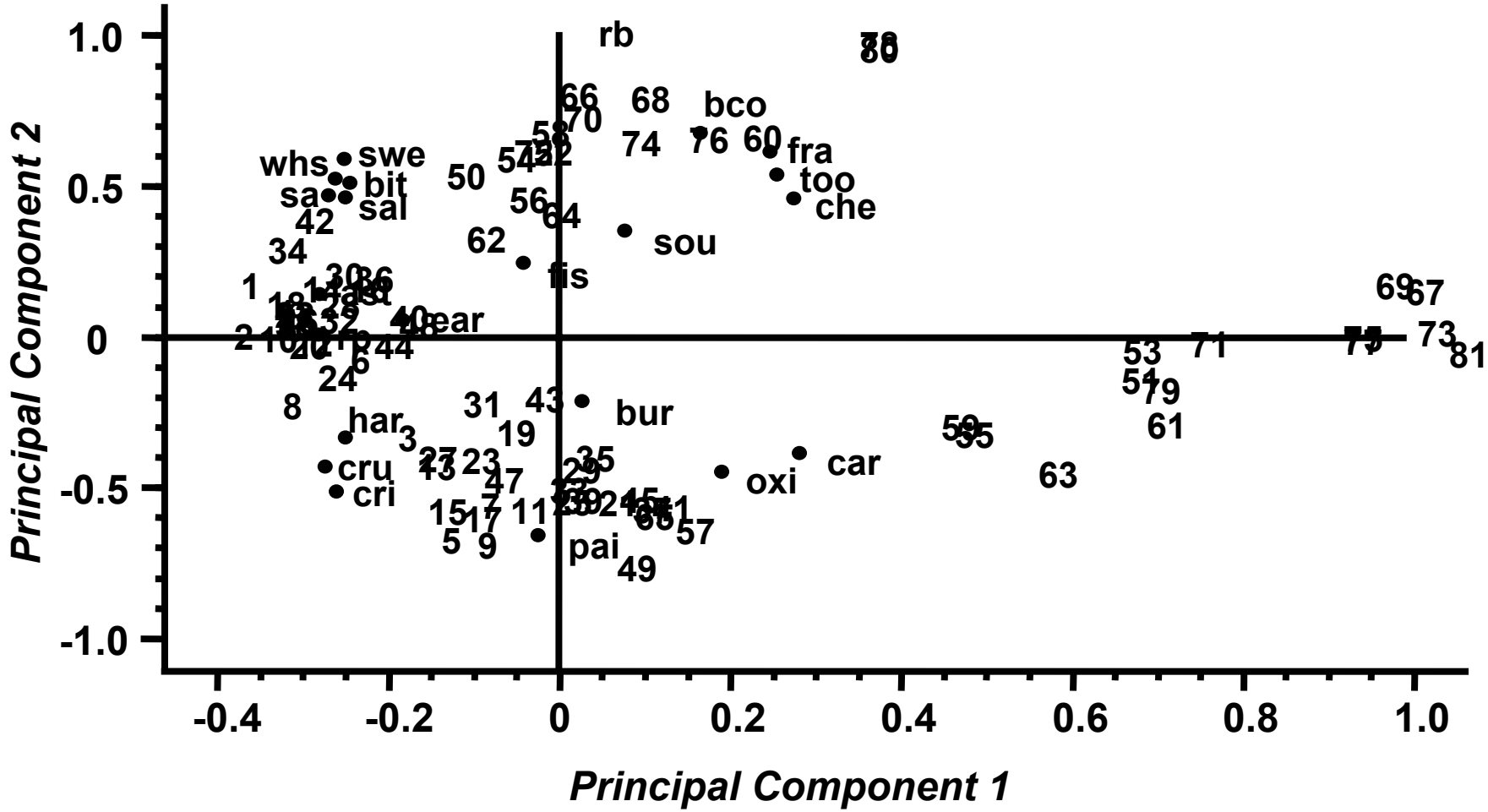

rb
bco
fra
too
che
sou
fis
swe
bit
sal
whs
sa
har
cru
cri
bur
car
oxi
pai
1.0
0.5
0
-0.5
-1.0
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1.0
Principal Component 2
Principal Component 1

FIGURE 6.4
PRINCIPAL COMPONENT ANALYSIS BI-PLOT OF LOADINGS WITH SCORES SUPERIMPOSED FOR THE FIRST AND SECOND PRINCIPAL COMPONENTS OF CONSUMER DATA. The consumer attributes (•) analyzed by PCA were overall (ctover), aroma (ctarom), flavor ctflav), appearance (ctappe), color (ctcolo) and texture (cttext) acceptance; and intensity attributes like roasted peanutty(ctrp), crunchiness (ctru), and stale/oxidized/rancid (csor). Groupings of attributes in the PCA loading plots are enclosed with ellipses and labeled with "liked" and "dislike"

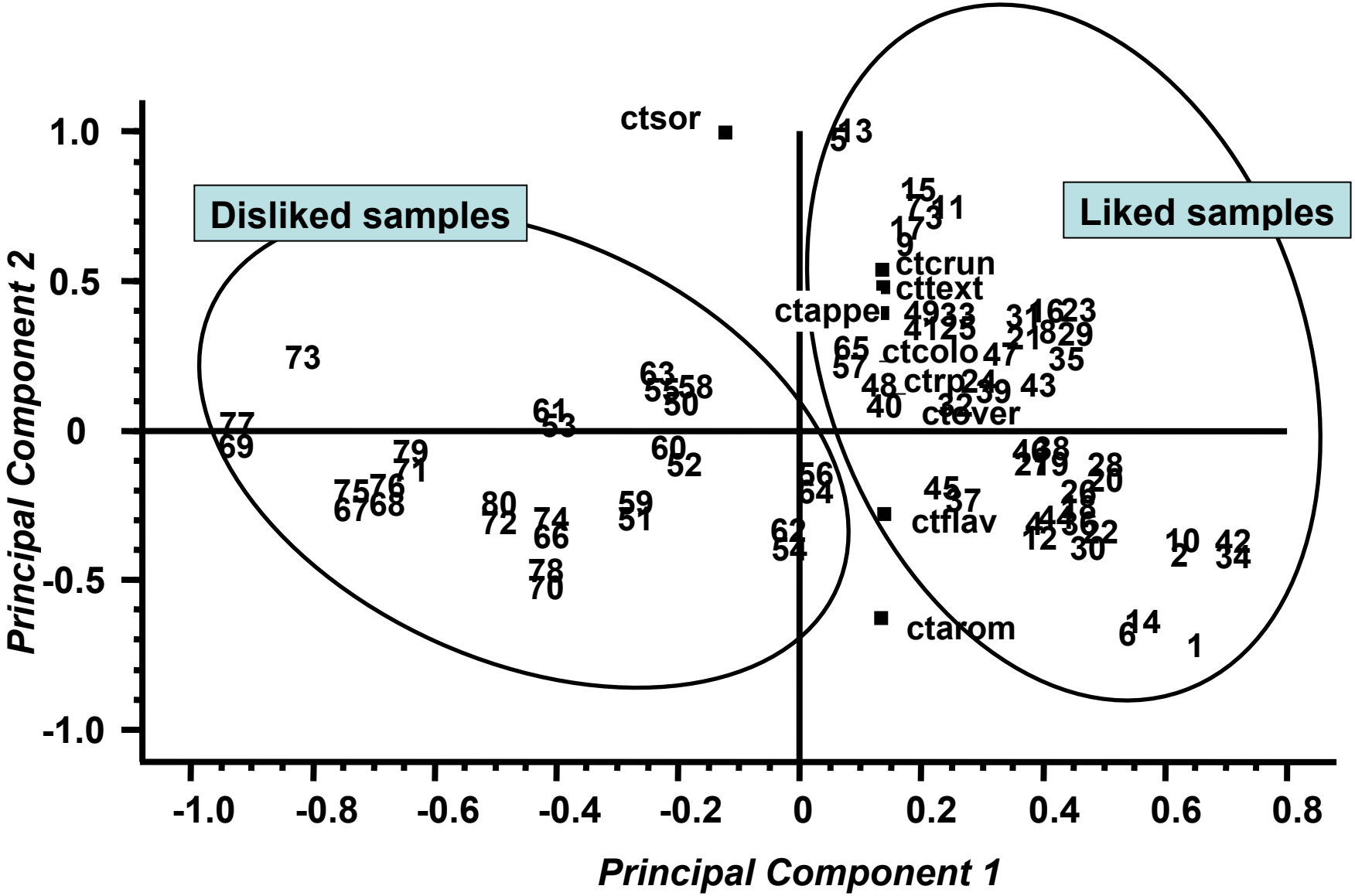
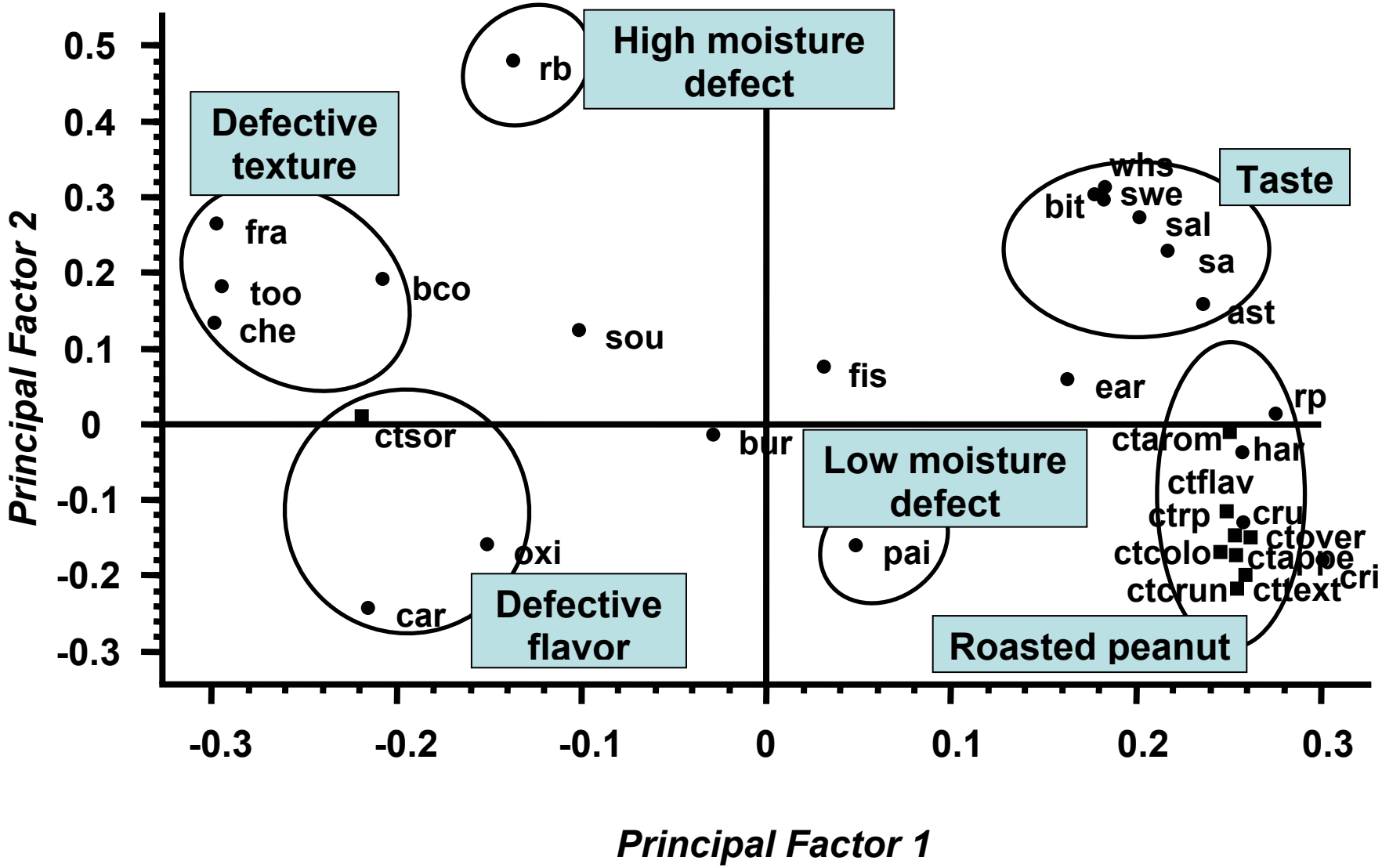

Disliked samples
Liked samples
ctsor
ctcrun
cttext
ctcolo
ctrp
ctover
ctflav
ctarom
Principal Component 2
Principal Component 1
1.0
0.5
0
-0.5
-1.0
-1.0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8

FIGURE 6.5

LOADING PLOT OF THE FIRST AND SECOND PARTIAL LEAST SQUARES REGRESSION (PLSR) FACTORS, BASED ON A PLSR ANALYIS ON DESCRIPTIVE DATA (X-MATRIX) AND CONSUMER ACCEPTANCE DATA (Y-MATRIX). The descriptive attributes (•) analyzed by PCA were brown color (bco), crispness (cri), fra (fracturability), crunchiness (cru), hardness (hardness), chewiness (che), tooth packing (too), roasted peanutty (rp), raw beany (rb), oxidized (oxi), sweet aromatic (sa), woody/hulls/skins (whs), cardboard (car), painty (pai), burnt (bur), earthy (ear), fishy (fis), salty (sal), sour (sou), bitter (bit), sweet (swe) and astringency (ast). Consumer acceptance attributes (■) were overall (ctover), aroma (ctarom), flavor (ctflav), appearance (ctappe), color (ctcolo), texture (cttext); and consumer intensity attributes (■) were crunchiness (ctcrun), roasted peanutty (ctrp), and stale/oxidized/rancid (ctsor).

1


High moisture defect
Defective texture
Taste
Low moisture defect
Defective flavor
Roasted peanut
rb
fra
too
che
bco
sou
whs
swe
bit
sal
sa
ast
fis
ear
rp
ctsor
bur
ctarom
har
ctflav
ctrp
cru
ctover
ctcolo
ctappe
cri
ctcrun
cttext
oxi
pai
car
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
Principal Factor 2
Principal Factor 1

SECTION VII

SUMMARY AND CONCLUSIONS

Roasted peanuts were stored under 20 different conditions consisting of four temperatures (23, 30, 35, 40°C) and five water activities (0.33, 0.44, 0.54, 0.67, 0.75 a_w). One hundred and twenty samples of roasted peanuts were evaluated in replicates after storing for 0, 20, 40, 60, 80, 100 and 110% of estimated shelf life (ESL), or between 0 to 91 days, for their descriptive profiles, instrumental texture properties, water activity, moisture and color. In addition, consumer acceptance and intensity ratings for sixty samples stored for 0, 40, and 110% ESL were determined.

Regression analysis indicated that increasing storage time and water activity resulted in most of the changes in roasted peanuts. Changes in the descriptive attributes included decreasing crispness, crunchiness, hardness, roasted peanutty, sweet aromatic salty, bitterness and sweetness, and increasing fracturability, chewiness, tooth packing, and cardboard flavor. Storage temperature was not significant ($p>0.05$) in contributing to the textural properties of stored roasted peanuts. In addition, the color lightness (*L*-value), water activity, and moisture of these samples also decreased with increasing storage time and water activity. Consumer ratings for overall, aroma, flavor, appearance, color and texture acceptance and that of crunchiness and roasted peanutty intensity decreased with increasing storage time and water activity. Intensity ratings of stale/oxidized/rancid flavor were predicted to increase with increasing storage time and water activity.

In addition to storage time and water activity, roasted peanuts flavor attributes, including descriptive roasted peanutty and cardboard flavor, consumer aroma and flavor acceptance, and consumer intensity ratings of staled/oxidized/rancid and roasted peanut flavor intensity were affected by storage temperature. Increasing storage temperature of stored roasted peanuts increased the rate of change of decreasing roasted peanuts and increasing cardboard flavor.

Roasted peanuts are bested stored at 23°C and in an atmosphere or manufactured with ingredients of water activities between 0.33 and 0.41 a_w, for a minimum change in sensory properties after 68 and 91 d, respectively. At 23 °C, the shelf life (consumer acceptance ≥ 5.0) of roasted peanuts stored between 0.33 and 0.75 a_w was determined by overall acceptance and the shelf life of roasted peanuts stored at 0.40, 0.50, 0.60, and 0.70 a_w were predicted to be 73, 40, 20 and 4 d, respectively. At accelerated temperatures of 30, 35 and 40 °C, shelf life of roasted peanuts was predominantly limited by flavor acceptance (≥5.0), and to a lesser extent, by aroma and overall acceptance. The shelf life of roasted peanuts stored at 0.40, 0.50, 0.60 and 0.70 a_w were predicted to be 50, 26, 13, 4 d at 30°C, 40, 22, 12, 4 d at 35°C, and 30, 15, 10, 3 d at 40°C, respectively. These estimates of shelf life will serve as guidelines for the industry in estimating the shelf life of roasted peanuts when formulated with ingredients of different water activities. While overall acceptance is typically used to evaluate product acceptability, results from this study also suggest that manufacturers should be concern with flavor acceptance in roasted peanuts when the storage temperature is expected to be above 23°C.

Moisture was the best predictor (R^2≥0.78) of descriptive texture attributes, while consumer ratings were best predicted (R^2≥0.75) by color and moisture measurement. Instrumental texture analysis, using a modified Kramer shear-compression cell or a cutting test, did not predict (R^2≤0.70) descriptive ratings or consumer ratings. Prediction models (R^2≥0.70) for descriptive and consumer ratings based on color or moisture measurements were established. Overall, instrumental measurements such as color, water activity and moisture were better predictors of consumer acceptance than were descriptive attribute ratings. Results from rapid measurement methods for color or water activity can be potential methods for a quick estimation of consumer acceptance in storage studies of roasted peanuts and or roasted peanut products.

Partial least square regressions showed that at low storage (0.33 to 0.54 a_w), samples stored up to 35 days were rated similar to control. Samples stored at high a_w (0.67 to 0.75 a_w) were oxidized and had a chewy texture. After prolonged storage of 5 to 13 days, high a_w treatments were chewy and had raw beany flavor, where as samples stored at low a_w for 25 to 91 days were oxidized and hard. Positive consumer acceptance was characterized by descriptive attributes grouped as "peanut flavor" and "desirable textures", and inversely related to "texture defects" and "oxidized flavors".

This research also illustrated the importance of using a sampling scheme that reflects the severity of treatment and estimating the sampling days using equations that takes into account of the effect of temperature and water activity. The sampling method can be employed by academic and industry researcher planning storage studies involving temperature and water activity effects.

The storage temperatures used in this study were chosen such that the range was narrow and a linear change in rate of reaction with increasing temperature was assumed. A single Q_{10} was sufficient in estimating the change in shelf life. However, the range of water activity was much larger, encompassing 0.33 to 0.75, or about 70% of the complete 0 to 1.0 a_w range. The author also found that the effect of water activity is not linear throughout the large spectrum studied. Any further research conducted involving water activity effect can be best planned with multiple assumed Q_a.