ABSTRACT

SHI, XIAOLEI. Effects of Different Roasting Conditions on Peanut Quality. (Under the direction of Dr. Lisa L. Dean and Dr. K.P. Sandeep).

In the U.S., a major portion of the peanut crop is converted from whole seed into value-added products. For such purposes, the peanut seeds are processed using a thermal operation as the first step in the manufacture of the final products, to achieve specific flavors, colors, and textures. Peanuts are typically processed by dry roasting or oil roasting (deep frying and blister frying). Comparisons among different dry roasting conditions and different roasting methods were made in this work regarding their effects on the quality-related properties of roasted peanuts.

On an industrial scale, peanuts are typically roasted to a specific color for quality control. Recent lab scale experiments demonstrated that peanuts roasted to equivalent surface colors at different time/temperature combinations could vary substantially in chemical and physical properties related to product quality. This study expanded that approach to a pilot plant scale roaster. Jumbo-size runner-type peanuts were systematically roasted at 5 temperatures (149-204 °C) to three Hunter L-values of 53.0, 48.5, and 43.0 using the same peanut bed depth and air flow. The flavor of medium dry roasted peanuts was superior to light and dark roasts, with higher roasted peanutty and sweet aromatic flavor notes. Total tocopherols of oil extracted from the roasted peanuts was greatest in peanuts roasted to darker colors, with the medium and dark oil showing no significant differences from the raw oil. Yield stress of pastes prepared from the roasted peanuts increased as the final color increased, regardless of roast temperature. This was attributed to decreased moisture content, lower oil fluidity, as well as increased degree of polymerization. Kinetics of color

development during peanut dry roasting were investigated. It was observed that the Hunter L values of the peanuts fitted well with either zero, first, or second order models (mean R^2>0.95). The activation energies calculated from the Hunter L and b values were 1.0-1.2×10^8 J/kg mol. High temperature roasting presented broader distributions of single seed color, indicating those roasts were less uniform in color development throughout the load, which indicated larger temperature differences among different locations within the roasting load.

Peanuts were also deep fried, blister fried, or dry roasted at 177 °C to Hunter L-values of 53.0 ± 1, 48.5 ± 1, and 43.0 ± 1, respectively. Peanut microstructure was most extensively damaged by blister frying, followed by deep frying, and then dry roasting. The moisture content decreased with darker surface colors, due to increased moisture loss for darker roasts. For light roasting, blister fried peanuts had significantly higher moisture content than the deep fried and dry roasted, while for medium and dark roasting, blister fried had lower moisture than the other two. Descriptive sensory analysis distinguished among the texture profiles of peanuts prepared by different roasting methods. Flavor profiles were more related to roast color than roasting method. In the storage test of 16 weeks, using peroxide value measurements, the blister fried had the longest shelf life, followed by the dry roasted, and then the deep fried. Descriptive sensory analysis ranked the shelf life length as deep fry > blister fry > dry roast.

The conditions and methods of roasting could potentially affect the physical, chemical, sensory, stability properties of roasted peanuts. From this research, the ideal way to compare different roasting conditions and methods should be based on the concept of

equivalent color roasting. The objective of this study was to compare the effects of different roasting conditions and methods on peanut quality related properties, including moisture content, tocopherols, yield stress, microstructure, sensory properties, and storability, as well as investigate the kinetics of peanut roasting to equivalent surface colors.

Effects of Different Roasting Conditions on Peanut Quality

by
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DEDICATION

I dedicate this work to my husband and my parents. Thank you for your continuous caring and love and always showing me support to achieve my goals.

BIOGRAPHY

Xiaolei Shi was born on August 11, 1987 in Rizhao, Shandong, P. R. China. She is the daughter of Jifu Shi and Jinying Xia of Shandong, China. Xiaolei graduated from Rizhao Yizhong high school, where she served as the deputy secretary of the student union. She continued her education at the Huazhong Agricultural University, Wuhan, China. She majored in Plant Protection for the first year and then transferred to Food Quality and Safety. There, Xiaolei obtained scholarships each year from 2007 to 2010 and was an active show hostess. Xiaolei earned a Bachelor of Science in May 2010 and then continued her education as a Masters student under the direction of Dr. Jack P. Davis in Food Science at North Carolina State University, Raleigh, NC, USA. She is an active member of the Food Science Club. In 2012, she won the 2012 Bimbo Pan-American nutrition, food science and technology award for a project "Improving the Value of Peanut Flour Using Enzymatic Hydrolysis". Upon graduation with a Master degree, she continued her education as a PhD student in Food Science, under the direction of Dr. Lisa L. Dean and Dr. K.P. Sandeep.

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CHAPTER 1

Literature Review

The Peanut

The peanut, *Arachis hypogaea*, is an annual legume grown in the tropics and temperate regions around the world (Bertioli, 2011). It probably originated in South America, as pottery made in South America in the shape of peanuts or decorated with peanuts as far back as 3,500 years ago has been found. Peanuts were first discovered by European explorers in Brazil and brought back to Spain. These explorers and traders spread peanuts to Asia and Africa. Peanuts in North America were introduced by Africans as early as the 1700's (APC, 2014). By the early 1800's, peanuts were extensively grown as a commercial crop in the United States. Previously, peanuts were regarded as feed for livestock and food for the poor and were considered too time and labor consuming to grow and harvest to be economically feasible. Peanuts were first grown in Virginia mainly for oil, food, and as a cocoa substitute. At the time of the American Civil War, peanuts became popular when Union soldiers found they liked them and brought them back to their homes in the Northern parts of the U.S. In the early 1900's, the peanut crop began to rival the economic position of the cotton crop in the South of United States (APC, 2014).

Global peanut production in 2014-2015 was 39.98 million tons, which was slightly less than the record crop for 2013-2014 year of 40.16 million tons (USDA, 2015). Unlike other countries where the end product is mainly peanut oil, most peanuts grown in U.S. are used for human consumption and the major value-added products of peanut are peanut butter, confections, and snack products (Tate, Chavan, Patil, & Kadam, 1990). The U.S. ranks as the world's third largest peanut producer, after China and India (Bertioli, 2011). Since most

of the Indian peanut crop is consumed locally, the U.S. is one of the world's leading peanut exporters. Other significant exporters are Argentina and China (USDA, 2015).

There are eight major producing regions in U.S. that produce 99% of all peanuts grown in U.S. The major production area is illustrated in **Figure 1.1** in red. In the crop year 2014, by weight, Georgia lead the ranking by producing 46.5% of all peanuts, followed by Florida (13%), Alabama (11%), Texas (9.0%), North Carolina (7.5%), South Carolina (8%), Mississippi (2%), and Virginia (1.5%) (APC, 2014; Tate, Chavan, Patil, &Kadam, 1990). Planted area and harvested area are estimated at 1.64 and 1.61 million acres in the 2012 crop year, an increase of 44 and 49 percent, respectively, from the previous crop year. Average yield was decreased by 69 pounds over 2013, reaching 3932 pounds per acre in 2014. The production of peanuts is estimated at a record to 5.2 billion pounds in 2015, which will be a 25 percent increase from previous year (**Table 1.1.**) (USDA, 2015).

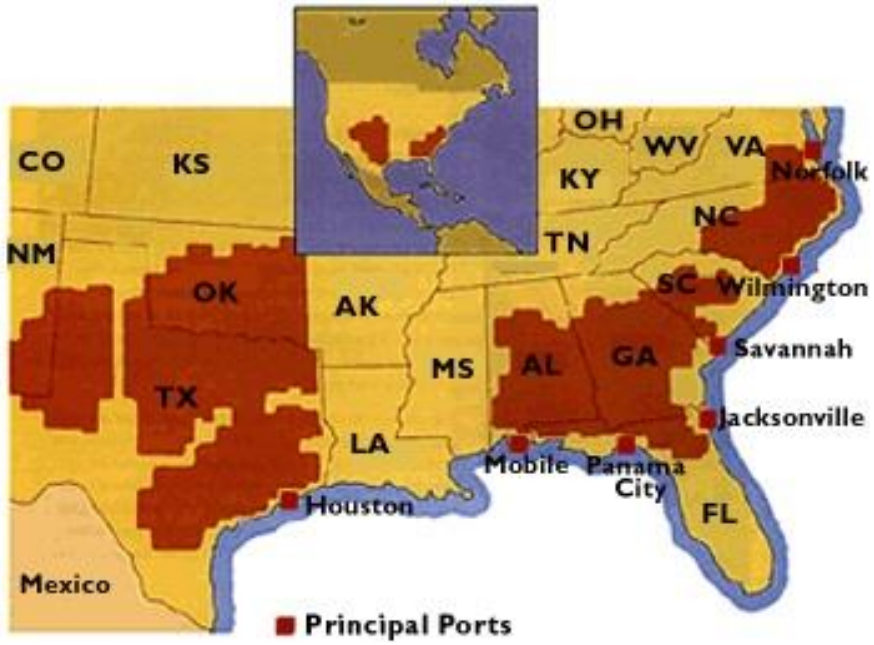

Figure 1.1. Peanut producing areas in U.S. (APC, 2014).

Table 1.1. Peanut crop production summary of U.S. from crop year 2012-2014. Table was taken from USDA crop production report (NPB, 2015).

State	Area planted			Area harvested		
	2012	2013	2014	2012	2013	2014
	(1,000 acres)	(1,000 acres)	(1,000 acres)	(1,000 acres)	(1,000 acres)	(1,000 acres)
Alabama	220.0	140.0	175.0	219.0	138.0	173.0
Florida	210.0	140.0	175.0	195.0	131.0	167.0
Georgia	735.0	430.0	600.0	730.0	426.0	591.0
Mississippi	52.0	34.0	32.0	49.0	33.0	31.0
New Mexico	10.0	7.0	5.0	10.0	7.0	5.0
North Carolina	107.0	82.0	94.0	106.0	81.0	93.0
Oklahoma	24.0	17.0	12.0	22.0	16.0	11.0
South Carolina	110.0	81.0	112.0	107.0	78.0	108.0
Texas	150.0	120.0	130.0	146.0	117.0	127.0
Virginia	20.0	16.0	19.0	20.0	16.0	19.0
United States	1,638.0	1,067.0	1,354.0	1,604.0	1,043.0	1,325.0

State	Yield per acre			Production		
	2012	2013	2014	2012	2013	2014
	(pounds)	(pounds)	(pounds)	(1,000 pounds)	(1,000 pounds)	(1,000 pounds)
Alabama	4,000	3,550	3,200	876,000	489,900	553,600
Florida	3,900	3,950	4,000	760,500	517,450	668,000
Georgia	4,580	4,430	4,100	3,343,400	1,887,180	2,423,100
Mississippi	4,400	3,700	4,000	215,600	122,100	124,000
New Mexico	2,600	3,100	3,100	26,000	21,700	15,500
North Carolina	4,030	3,900	4,300	427,180	315,900	399,900
Oklahoma	3,650	3,700	4,000	80,300	59,200	44,000
South Carolina	3,900	3,500	3,800	417,300	273,000	410,400
Texas	3,600	3,620	3,850	525,600	423,540	488,950
Virginia	4,100	3,950	4,350	82,000	63,200	82,650
United States	4,211	4,001	3,932	6,753,880	4,173,170	5,210,100

Four market types of peanuts are grown in the U.S.: Runner, Virginia, Spanish and Valencia (APC, 2014). Each type differs in size (**Figure 1.2.**). Runner peanuts are medium-size varieties which typically accounted for 80% of U.S. peanut production in the most recent decades due to their high yields and attractive seed size range. The majority of runners are processed into peanut butter. V irginia peanuts account for 15% of the U.S. production and are characterized by the largest seed size. The main products of virginia peanuts are in-shell roasted, and in shell salted roasted peanuts. Spanish-type peanuts account for 4% of U.S. production and are usually processed with their reddish-brown skin left intact (Stalker, 1997). This type is usually processed into peanut candy and confections. Valencia peanuts make up less than 1% of U.S. production. They typically have three or more small kernels in one pod

(Stalker, 1997). Since the seeds of this type are quite sweet, they are usually consumed as in-shell roasted as well as boiled peanuts (APC, 2014).

Figure 1.2. Four basic market types of peanut (NPB, 2013).

Peanut Components

By weight, peanuts are composed of approximately 44-56% lipid, 22-30% protein, 16-25% carbohydrates, and a lower percentage of ash, minerals, and vitamins (Pattee & Young, 1982). The components of peanut oil, protein, and carbohydrates are discussed in detail below. Peanuts are a good sources of some minerals and vitamins when compared to other nuts. Peanuts contain higher potassium than sodium, and they are also good sources of phosphorous and magnesium. Peanuts contain abundant vitamin E (tocopherols), and some of the B-complex vitamins. Four forms of tocopherols (α, β, γ and δ) have been identified in peanuts and their functionality will be discussed below in the section on peanut oil.

Thiamine (Vitamin B1), is relatively high with approximate 1.0 mg/100g of peanut seed (Pattee et al., 1982). Peanuts are also good sources of other B-complex vitamins, with noteable amounts of niacin (12.8-16.7 mg/100g) based on the dry weight of the cotyledons (Pattee et al., 1982).

Peanut Oil

Peanuts are naturally high in oil content, containing 44-56% (Pattee et al., 1982). Peanut oil consists of 96.1–96.4 % triglycerides, 2.4–2.9% phospholipids, 0.69–0.80% sterols, 0.1–0.4% free fatty acids and 0.10–0.14% glycolipids (Mondal, Badigannavar, & D'Souza, 2011). The fatty acid composition for peanuts is summarized in **Table 1.2** (Ahmed & Young, 1982). Since palmitic (C 16:0), oleic (C 18:1), and linoleic acids (C 18:2) constitute about 90% of peanut oil, proportions of these fatty acids are important from both the human nutrition perspective and for oil stability (Pattee et al., 1982). Oleic acid, as the main monounsaturated fatty acid in peanut, is reported to have health benefits in reducing the risk of cardiovascular disease, lowering low density lipids (LDL) cholesterol, preventing cancer, increasing insulin sensitivity, and mitigating inflammatory responses (Mondal et al., 2011). Oleic acid is less prone to oxidation and rancidity and high levels would be expected to extend the shelf life of peanut products (O'Keefe, Wiley, & Knauft, 1993). Linoleic acid, the main polyunsaturated fatty acid in peanut, has two double bonds and as a result, is more prone to lipid oxidation, thus limiting the storage life of peanuts (Bolton & Sanders, 2002). The ratio of oleic acid to linoleic acid (O/L) can serve as an indicator of the stability and shelf life of peanut products. The O/L ratio of normal peanut ranges from 0.9 to 2.5 with an

average of 1.5, depending on growth area, cultivar, and market grade (Mozingo, Coffelt, & Wynne, 1988; Sanders, 1980). High O/L peanut lines have been developed using traditional peanut breeding techniques and contain up to 80% oleic and as low as 3% linoleic acid (Braddock, Sims, & O'Keefe, 1995). An increase in shelf life of high oleic peanut paste has been reported from a normal value of 128 days to 300 days (Riveros et al., 2010).

Table 1.2. Typical fatty acid composition of peanut oil. (Ahmed et al., 1982).

Fatty acid	**Percentage**
Palmitic (C16:0)	10%
Stearic (C 18:0)	3%
Oleic (C 18:1)	45%
Linoleic (C 18:2)	35%
Behenic (C 22:0)	2%
others	5%

Like other vegetable oils, the typical production of peanut oil involves the processes of crushing, mechanical pressing, filtering, and refining. Refined peanut oil has been purified of the allergenic proteins, making it non-allergenic (Crevel, Kerkhoff, & Koning, 2000).

Low grade peanuts are generally used for oil, therefore, peanut meal, the by-product of peanut oil production, has a high potential for contamination with aflatoxin, which restricts its usage in human foods (Ellis, Smith, Simpson, Oldham, & Scott, 1991). Peanut oil is characterized as having a healthy fatty acid profile as there are no detectable *trans*-fatty

acid and about 80% of the fat is unsaturated (Davidson, Brown, & Landman, 1999). Peanut oil contains intermediate levels of saturated fat. These saturated fatty acids (C 16:0, C 18:0, C 20:0, C 22:0, and C 24:0) are characteristically located at the *sn*-1 and *sn*-3 positions of the glycerol skeleton of triglycerides, where the fatty acid can be easily cleaved by pancreatic lipase into free fatty acids, resulting in a limited influence on plasma lipids. Saturated fatty acids in peanut oil tend to remain in the solid form due to high melting points, thus reducing their absorption rate (Carrin & Carelli, 2010). It has been demonstrated that the consumption of peanut oil significantly reduced cholesterol and LDL cholesterol while producing no decrease in high-density lipoprotein (HDL) cholesterol and no increase in plasma triglycerides (Sanders, 2001).

In addition to triacylglycerol, native peanut oil also contains other minor components, including phospholipids, sterols, tocopherols, pigments and phenolic compounds, of which tocopherols and phenolic compounds are considered beneficial to human health due to their antioxidant capacity (Pattee et al., 1982). Tocopherols are a class of organic compounds that play an important role in maintaining human nervous system operation and fertility (Schneider, 2005). Additionally, tocopherols are a type of natural fat soluble antioxidant that can provide protection to against oxidation of other components of the peanut (Carrin et al., 2010; Schneider, 2005). The four forms of tocopherols that have been identified in peanut are α, β, γ and δ, with α-tocopherol having the highest nutritional vitamin activity in humans and being the most potent antioxidant *in vivo* (Carrin et al., 2010; Schneider, 2005). The primary forms of tocopherols in peanut are α- and γ-tocopherol and

together account for approximately 80-90% of the total tocopherols (Hashim, Koehler, & Eitenmiller, 1993). Industrial processing of peanuts into peanut butter showed the retention of total tocopherols during peanut butter production was 95% (Chun, Ye, Lee, & Eitenmiller, 2003). Although decreases in the tocopherols levels of peanuts were observed during roasting, the addition of peanut oil countered the roast loss of tocopherols. The addition of stabilizers, mainly partially hydrogenated vegetable oil, enhanced the tocopherols levels of peanut butter, as well as protected the tocopherols from degradation. Another study indicated roasting to a darker color resulted in slower degradation of tocopherols during storage which was attributed to higher amounts of other antioxidants formed during dark roasting that provided protection to the tocopherols (Davis, Dean, Price, & Sanders, 2010). The potential mechanisms of enhanced antioxidant capacity during roasting are the formation of Maillard browning compounds (Oliviero, Capuano, Cammerer, & Fogliano, 2009) and/or the release of previously bound polyphenolic compounds in the cellular matrix (Talcott, Passeretti, Duncan, & Gorbet, 2005).

Peanut Proteins and Amino Acids

Among regularly consumed nuts, which include tree nuts and peanuts, peanuts have the highest protein content at 25.8% (Venkatachalam & Sathe, 2006). The protein in peanut seeds falls into two categories: globulins (salt soluble) and albumin (water soluble) (Pattee et al., 1982; Singh & Singh, 1991). Globulins consist of arachin, conarachin and non-arachin. Arachin represents approximate 63% of the total protein while conarachin represents approximate 33% of the total protein. Arachin differs from conarachin mainly by the amount

of sulfur content: 0.4% for arachin and 1.9% for conarachin (Johns & Breese Jones, 1917). Conarachin can be further fractionated into conarachin I and II (Monteiro & Prakash, 1994). During roasting, the heating of peanuts causes changes to the proteins. One study suggested that protein solubility was reduced by nearly half after 1 hour of dry roasting at 145 °C; however, the major protein, α-arachin maintained its intact structure (Ory, Neucere, Singh, & St Angelo, 1970).

The amino acid profile of peanuts as reported by Monteiro et al. (1994) is summarized in **Table 1.3**. The total protein of peanut contains high amounts of glutamic acid, aspartic acid, and arginine, but is low in cysteine, methionine, and tryptophan. Arachin contains more glutamic acid, proline, histidine, and tryptophan than conarachin, whereas conarachin contains 6 times the amount of glycine than arachin, as well as more serine (Monteiro et al., 1994).

Table 1.3. Typical amino acid profile of peanut protein fractions (gram per 100 g of protein) (Monteiro et al., 1994).

Amino Acid	Total Protein	Arachin	Conarachin II	Conarachin I
Glutamic acid	23.01	23.01	21.43	22.24
Aspartic acid	12.91	12.29	12.68	7.95
Arginine	12.43	10.69	10.19	4.82
Leucine	6.25	6.42	7.22	4.26
Phenylalanine	5.41	6.87	6.27	6.07
Serine	5.22	4.60	5.55	7.97
Glycine	5.15	3.99	4.16	29.73
Proline	5.01	5.84	3.11	2.68
Tyrosine	4.12	4.13	2.38	5.69
Alanine	3.74	3.87	3.99	2.87
Valine	3.65	4.77	5.73	3.47
Lysine	3.12	3.06	5.46	7.13
iso-Leucine	2.83	3.61	4.12	2.40
Threonine	2.5	2.68	2.97	3.06
Histadine	2.22	3.50	2.81	2.54
Tryptophan	1.59	1.21	0.91	0.59
Methionine	0.52	0.71	0.78	0.34
half-Cysteine	0.33	0.33	0.19	0.23

Carbohydrates

Peanut seeds contain about 25% carbohydrates in the form of starch and sugars. The components of peanut carbohydrates have been shown to change during maturation as well as during curing, and to vary among the genotypes (Pattee, Johns, Singleton, & Sanders, 1974; Vercellotti, Chung, Bett, Vinyard, & Sanders, 1994). The starch content reaches a maximum beyond middle maturity then stays constant. The sugar content of peanut was

found to increase based on a per seed weight throughout the maturation, reaching the maximum sugar content at full maturity (Pattee et al., 1974). Six sugars, glucose, fructose, inositol, sucrose, raffinose, and stachyose, and one unknown sugar were reported to be present in peanuts, and it has been suggested that the sugar contents differed due to differences in genotypes and harvest times (Oupadissakoon, Young, Giesbrecht, & Perry, 1980; Pattee, Isleib, Giesbrecht, & McFeeters, 2000). The most abundant sugar is sucrose, regardless of cultivar, and glucose is present at lowest concentration (Holley & Hammons, 1968). Glucose tends to decrease throughout maturity, while fructose remains unchanged during maturation (Pattee et al., 1982).

The importance of sugars in peanut roasting is mainly due to their role in Maillard browning, where they serve as the precursors of Maillard compounds. The mechanism of Maillard browning will be elaborated below, but briefly it is due to interactions between the amino group of proteins and the carbonyl group of reducing sugars (Corzo-Martínez, Corzo, Villamiel, & del Castillo, 2012). Only reducing sugars can directly participate in Maillard browning, while non-reducing sugars and sugar alcohols are not substrates for this reaction. Glucose and fructose are the most common hexoses in food matrices and they serve as the substrates for Maillard browning. Fructose contains open chain structures, making it more prone to participate in the Maillard reaction than glucose. Although sucrose itself is not a reducing sugar, research clearly demonstrated that during roasting it undergoes hydrolysis into glucose and fructose (Newell, Mason, & Matlock, 1967). This theory has been confirmed by Mason, Johnson, & Hamming (1966) and it is considered the reason that in

some instances glucose and fructose are found to increase during roasting. As the role of sugars is as the precursor for browning reactions during thermal processing, the contents of these sugars are expected to affect the flavor of cooked peanuts. A relationship was expected to be found between the sugar content of 52 cultivars of peanut and the sensory attributes, including bitter, astringency, roast peanutty, sweet, and sweet aromatic; however, the expected relationship could not be applied across all market-types due to the complexity of chemical reactions contributing to the flavor, and the interrelationship among these flavor attributes, but a positive correlation between total sugars and sweetness was observed within varieties of Virginia, Runner, and fastigiate ($P < 0.05$) (Pattee et al., 2000).

Peanut Planting, Harvesting, Shelling, and Grading

Peanuts in U.S. are planted in April or May when the soil temperature has reached at least 20 °C. Peanuts are typically mechanically tilled once or twice for weed control. Peanut harvesting involves two stages: digging and combining (APC, 2014). Digging begins when approximate 70% of the pods have reached maturity. The digger loosens the plant and a shaker lifts the plant from the soil and the peanut pods are turned up to be exposed to the sun. The second stage is combining which includes separating the pods from the vines and the subsequent curing using solar energy, typically in windrows (Mills & Dickens, 1958). Trailer drying with air flow is used to further reduce moisture content of in shell peanuts to about 10%. This level of moisture content helps reduce the growth of postharvest *Aspergillus flavus*, resulting in decreased aflatoxin contamination during storage (Butts &

Sanders, 2002; Diao et al., 2015). Current marketing regulations require peanuts be cured until the seed moisture content is reduced to 10.5% wet basis or 11.7% dry basis before storage (PAC, 2000). After curing, peanuts are inspected and graded by the Agricultural Marketing Service of the U.S. Department of Agriculture (USDA/AMS) to determine the quality and value (APC, 2014). The locations for inspection and grading are usually at peanut buying points which are within a few miles of the peanut farms. The buying points receive, clean and dry, and then grade peanuts delivered from the growers. Once the overall quality (in aspects of the meal content, size of pods, damaged kernels, foreign material, and kernel moisture content) is established, the market value is determined from USDA price support schedules (APC, 2014).

After grading, peanuts are stored in warehouses for up to 1 year before being moved to the shelling operation. The first step of shelling is removal of the soil, stones, vines, and other foreign materials. After cleaning, the peanuts pass through updraft air columns that separate the seeds from the hulls and simultaneously remove the immature and light weight pods. The seeds and the unshelled pods are separated by specific gravity machines, which also remove any remaining immature pods and stems. The kernels are then passed over various perforated grading screens where they are pre-sorted by seed size into market grades (APC, 2014).

Value-added Peanut Products

With a farm value of more than one billion U.S. dollars, peanuts rank as the 12th most valuable cash crop grown in the United States (APC, 2014). Processing of peanuts creates a variety of value-added products. In the early 1800's, peanuts began to be extensively imported into Europe due to a shortage of other oil crops. In America, there was also an increase in peanut importation; however, unlike other countries where peanuts were mainly used for oil production, the use of peanuts in the U.S. for oil decreased during and after the Civil War in the 1860's. Currently, peanuts in the U.S are consumed in the form of peanut butter, peanut flour, whole kernels, and ingredients in candies and confectionaries. Peanut butter production uses approximate half of the U.S. total market share (APC, 2014). Whole kernels, candies, and confectionaries represent about 35% of U.S. consumption, with oil consumption making up less than 15% of the total market (APC, 2014). The value added peanut products in U.S. market are summarized in **Table 1.4** (AgMRC, 2014; Chang, Sreedharan, & Schneider, 2013).

Table 1.4. Peanut products in U.S. market (AgMRC, 2014; Chang et al., 2013).

Peanut Products	Description
Peanut Butter	Prepared from roasted peanuts, peanut butter can be eaten as is or added to a variety of food items
Whole Kernels, Candies, Confectionaries	Different coatings can be applied to the peanuts prior to and after roasting to provide a variety of products including such flavors as honey, smoked, sweet, hot and spicy, and salty. Used as roasted whole nuts or crushed ingredients in candies or chocolate products.
Peanut Flour	Defatted roasted peanut flour is a gluten-free source of protein. Used as thickening agent, coating material, and fortifier for breads and pastries
Oil	Refined peanut oil: frying oil; does not absorb food flavors and has a high smoke point Unrefined peanut oil: salad dressings, cosmetics
Others	Biodiesel nonedible products

Peanut butter is made from ground dry-roasted peanuts, to which may be added seasoning and stabilizers (Chang et al., 2013). A minimum content of 90% peanuts with less than 55 percent oil in peanut butter is required to meet the standards by U.S. FDA Standard of Identity (FDA, 2015). One challenge for natural peanut butter or peanut paste without stabilizers is the phase separation, i.e. the peanut oil separates from the solid phase of peanut paste and rises to the top of the container during storage. Stabilizers, primarily partially hydrogenated vegetable oils, have been added to commercial peanut butters to prevent phase separation (Hartel & Hartel, 2008). Additionally, salt is added as a flavor enhancer and sugar as a sweetener. As a soft, sticky, and easy to chew food product, the characteristic stickiness

of peanut butter is mainly due to the high content of protein that pulls the moisture out of the mouth when chewed. On the other hand, the oil provides lubrication and counters the stickiness of peanut butter (Hartel & Hartel, 2008).

Another use of peanuts in the food industry is to make whole seed snacks, such as salted roasted peanuts, salted in shell peanuts, and blister fried peanuts. Peanuts require roasting, boiling, or frying for safety and sensory aspects. Peanut can also be used as an ingredient in candies, and confectionaries, such as nutritional bars and protein bars. For these products, peanuts are used in the form of whole seed or powder-like ingredients. Peanut flour, peanut concentrates, and peanut isolates are the three main protein-enriched food grade peanut materials obtained from peanut seeds (APC, 2014). Peanut concentrates and isolates are usually prepared by the simultaneous separation of peanut protein and oil from raw peanut seeds using an aqueous medium (Rhee, Natarajan, Cater, & Mattil, 1977). The main difference between concentrates and isolates is that isolates are further purified to remove the non-protein components, and thus are higher in total protein than concentrates.

Roasting and Browning Reactions

Most peanuts are consumed after thermal processing, which is important for both food safety and food quality as it inactivates food borne pathogens and enhances palatability by creating a desirable flavor and texture for the consumer (Baker et al., 2003; Poirier, Sanders, & Davis, 2014). Thermal processing also has the potential to inactivate natural

toxins and enzymes, improve storability and digestibility, as well as enhance antioxidant and antimicrobial capacity; however, some negative consequences, such nutrients loss, carcinogen (mainly acrylamide) production, or undesired flavor formation, may be the result of improper thermal processing (van Boekel et al., 2010). An understanding of thermal processing is important to make use of the benefits and to minimize the negative consequences.

The most dominant method of peanut thermal processing is roasting, which can be further categorized into dry roasting and oil roasting (also called deep frying). For dry roasting, the heat is transferred by hot air, whereas the heat is transferred by hot oil in oil roasting. Temperatures above 150 °C are used for peanut roasting in order to produce roasted peanut flavors and to start browning chemical reactions (Davidson, et al., 1999). Other thermal processing methods include boiling, and blister frying, which is also known as water blanching (APC, 2014). Blister frying has not been scientifically defined but according to accessible cooking instructions, this process involves boiling blanched peanuts in water for a certain time, draining the excessive water, and then deep frying the pre-soaked kernels in vegetable oil, resulting in a highly crispy and highly crunchy snack with blisters on the kernel surface. Blister fried peanuts are also known as water blanched-deep fried peanuts. The peanuts were prepared by water soaking (95 °C, 5 min), air cooling, deep frying (150 °C, 12-13 min), and seasoning, resulting in a snack food (Miyagi, 2013). Like dry roasted and deep fried peanuts, blister fried peanuts have enhanced flavors, a crunchy texture, and golden-brown color due to the process. Color development, textural changes, as

well as flavor and aroma formation during nut roasting are mainly related to drying and non-enzymatic browning (Ozdemir et al., 2001).

The two main forms of non-enzymatic browning reactions that occur in foods, such as bakery foods, coffee beans, and nuts, are the Maillard browning reaction (MBR) and caramelization (Purlis, 2010). In peanuts, the formation of specific flavors, aromas, texture, and colors are mainly contributed by MBR, and to a lesser extent, caramelization. A considerable number of studies have focused on Maillard browning, but the mechanism of the reaction is still a controversial issue as it is complex and involves various reactants and products with high reactivity which are quickly converted to other compounds (Purlis, 2010). The reaction requires the participation of the carbonyl group from a reducing sugar and the free amino group from an amino acid such as the ε-amino group of lysine in proteins (**Figure 1.3**) (Perez-Locas & Yaylayan, 2010). Three steps are involved in Maillard browning. The first step is a condensation reaction between the carbonyl group of the sugar and the amine group of the protein, forming N-glycosylamine. As the N-glycosylamine loses water, a Schiff base is formed which is then reversibly converted into an N-substituted glycosylamine. The N-substituted glycosylamine is then rearranged to form the Amadori rearrangement product (1-amino-1-deoxy-2-ketose), which is then subsequently degraded into different compounds through three pathways mainly depending on the pH value of the food system. At pH levels between 4 and 7, which is the normal range for peanuts, hydroxymethylfurfural (HMF) or 2-furfural are known to be formed via the pathway of enolization. Another pathway is the through the ketoenolization, where the Amadori

rearrangement products are converted to dehydroreductones, which can be further converted into reductones through reverse ketoenolization. The third pathway involves sugar dehydration and fragmentation, followed by Strecker degradation, which is a chemical reaction that converts α-amino acids into aldehydes containing the side chain, by way of an imine intermediate. The final stage involves the polymerization of the intermediate products formed in the second stage with an amino compound. The melanoidins and heterocyclic compounds formed give a pleasant flavor, aroma, and color to processed food (Amarowicz, 2009; Davies & Labuza, 1997; Davis et al., 2010; Manzocco, Calligaris, Mastrocola, Nicoli, & Lerici, 2000; Perez-Locas & Yaylayan, 2010; Purlis, 2010).

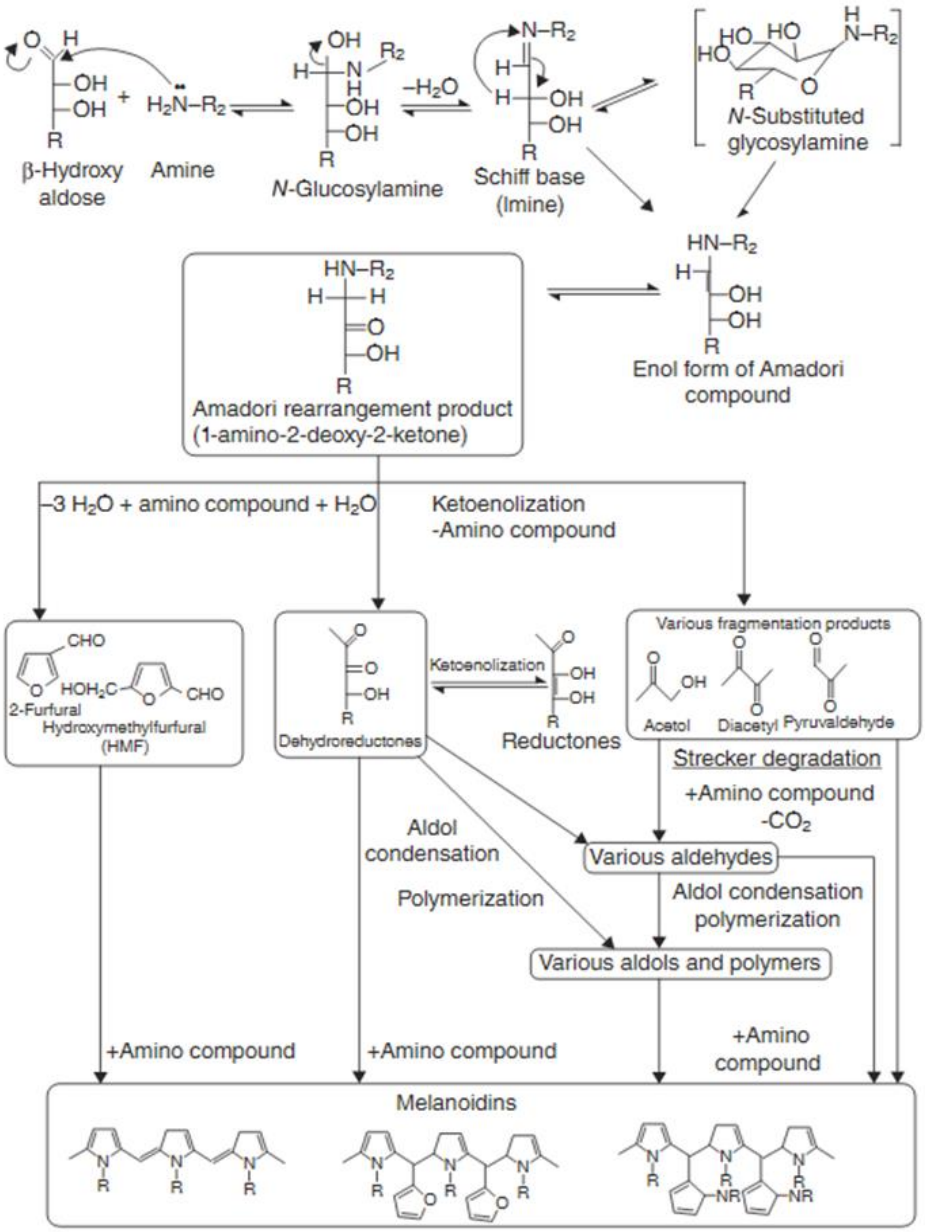

Figure 1.3. Summary of the Maillard browning reaction (taken from Perez-Locas et al., 2010).

Flavor and color development during peanut roasting is mainly affected by thermal processing conditions; however, other factors such as peanut variety, maturity, and post-harvesting conditions may also influence peanut flavor (Rodriguez, Basha, & Sanders, 1989; Sanders, Vercellotti, Crippen, & Civille, 1989). As sugars and free amino acids are the substrates for Maillard browning, their type and contents are important for the flavor and color formation during roasting. Immature peanuts typically contain higher concentrations of reducing sugars than mature peanuts, and thus they will roast faster than immature peanuts to the same color than mature peanut (Sanders et al., 1989). Mature peanuts typically contain higher amounts of free amino acids, which promote the development of roasted peanut flavor (Rodriguez et al., 1989). The breakdown of the polypeptide bonds and release of free amino acids from proteins and peptides during roasting allow free amino acids to participate in the MBR by combining with the reducing sugars such as glucose and especially fructose that are also present (Newell et al., 1967). The amino acids, aspartic acid, glutamic acid, glutamine, histidine, asparagine, and phenylalanine have been established as precursors of typical roasted peanut flavor, whereas threonine, tyrosine, lysine, and arginine has been reported as precursors of atypical flavors (Newell et al., 1967). The effects of roasting conditions on the sensory properties, such as color, flavor, and texture, will be further discussed in the sensory quality section.

Peanuts can be roasted in either batch or continuous systems. Batch roasters provide more flexibility in process control and settings, whereas continuous roasters are designed to meet high hourly capacity (Perren & Escher, 2013). For dry roasting, the most commonly

used industrial roaster is a continuous belt roaster, as illustrated in **Figure 1.4** (Poirier, et al. 2014). This continuous belt roaster is assembled with one or more than one roasting units, with each unit consisting of up-flow and down-flow zones, and a cooling zone. Peanuts are loaded to a specific bed depth and transferred on a perforated belt moving at a defined speed. The air flow rate is controlled to 0.7–1.3 m/s, usually at 1.0 m/s (Poirier, et al. 2014). With highly controlled systems of temperature, air flow, air flow direction, and bed depth, batch roasting can produce consistent products as long as all parameters are kept constant (Perren et al., 2013). The well controlled system of a batch roaster allows for duplicating the conditions of the industrial continuous belt roaster as well as minimizing the operational differences between batch and continuous roasters (Perren et al., 2013). One type of batch roaster used to simulate the design of continuous belt roaster is described as shown in **Figure 1.5** (Poirier, et al. 2014). As the controlled systems of this batch roaster have the potential to minimize the operational differences between batch and continuous system, the information derived in a batch scale study would be very useful for manufacturers to scale up the process into industrial roasting, aiming to optimize quality of roasted peanuts (Perren et al., 2013; Poirier, et al. 2014).

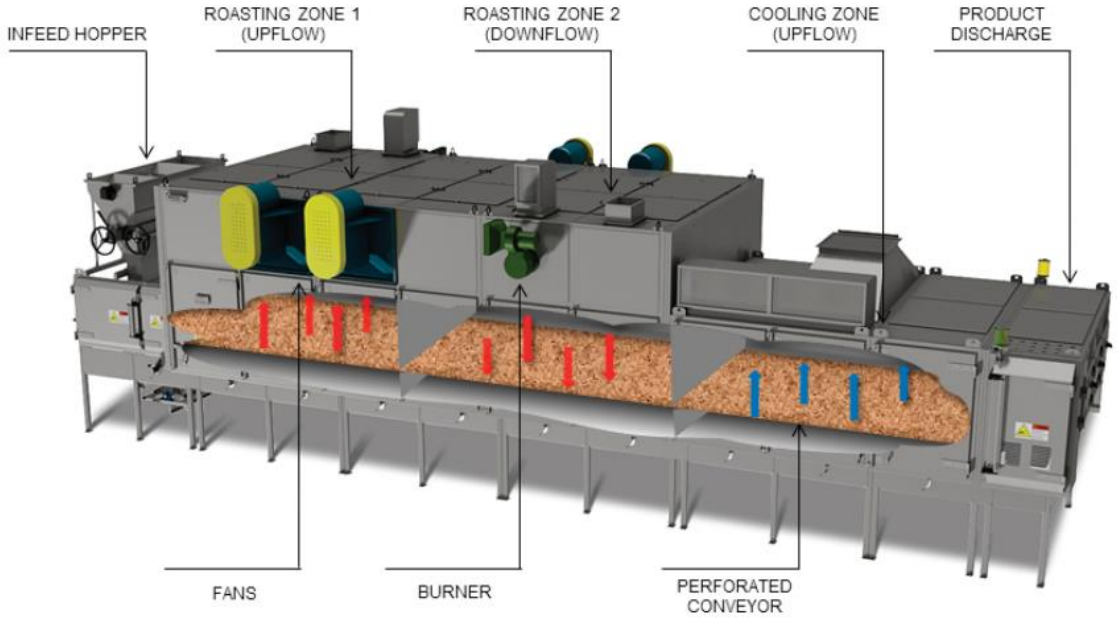

Figure 1.4. Industrial dry roaster (taken from Poirier, et al. 2014).

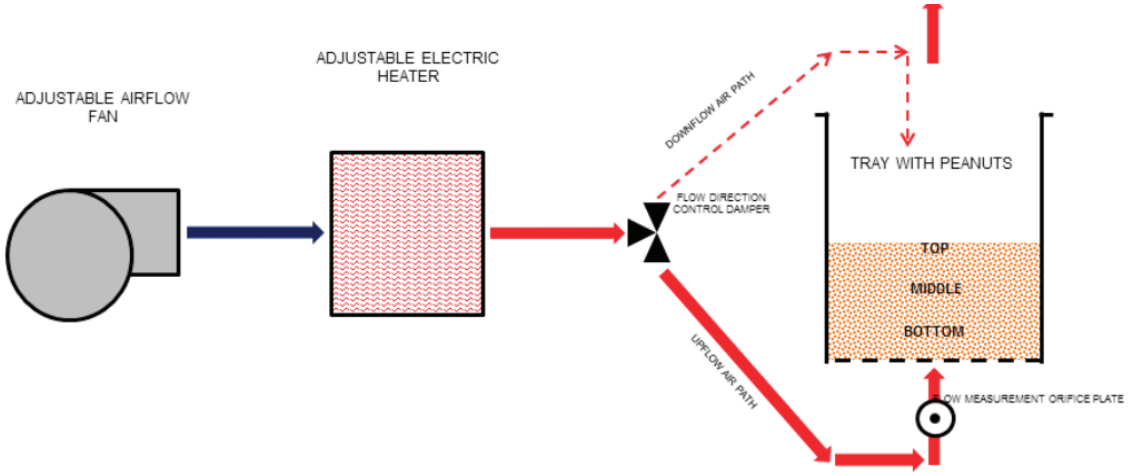

Figure 1.5. Schematic of a batch dry roaster (taken from Poirier, et al. 2014).

Deep frying is one of the most widely used method of preparing food. The main characteristic of deep frying is the formation of a crispy crust on the outside of a food, which appeals to many consumers. As a unit operation of thermal processing, deep frying involves immersing a food into hot oil, with a temperature typically in the range of 175 to 205 °C. During deep frying, rapid moisture loss occurs at the surface of food, resulting in formation of crust that prevents the further moisture loss and substance transfer. This crust typically gives deep-fried products their unique crispiness and crunchiness (Mallikarjunan, Ngadi, & Chinnan, 2009). Like dry roasting, deep frying can be conducted using either a continuous or a batch fryer. One type of the industrial fryer is the continuous fryer (**Figure 1.6**) (Mallikarjunan, Ngadi, & Chinnan, 2009). This type of fryer is designed for long continuous

use and large scale production. Briefly, the food is conveyed by a belt moving at a certain speed to pass through the hot oil, and the speed of the belt determines the deep frying time. The internal construction varies with the type of food to be deep fried. Batch fryers are similar to commercial kitchen style fryers. They are not typically used for large scale productions, but are commonly used in restaurants and other food service establishments.

Figure 1.6. Continuous industrial deep fryer (taken from Mallikarjunan, Ngadi, & Chinnan, 2009).

Different roasting schedules, i.e. different time/temperature combinations, are used to achieve roasting goals of certain food products, such as roasted coffee beans, peanuts, and hazelnuts (Wieland et al., 2012; McDaniel, White, Dean, Sanders, & Davis, 2012; Demir, Celayeta, Cronin, & Abodayeh, 2002). The roasting goals include achieving a certain level of inactivation in microbial, enzymes, or toxins, meeting requirements of food quality attributes, or reaching a desired color or degree of roast (Jinap, Rosli, Russly, & Nordin,

1998; Wieland, et al., 2012). In general, the dry roasting protocols can be categorized into two types, namely high temperature/short time (HTST) and low temperature/long time roasting (LTLT), depending on the applied roasting temperature and time. One example of the differences in the temperature profiles of the two protocols is shown in **Figure 1.7**, which was derived from a coffee roasting study **(**Baggenstoss, Poisson, Kaegi, Perren, & Escher, 2008**)**. A LTLT roasting protocol can be considered more of an isothermal process as the majority of the roasting occurs at a constant temperature with a relatively short "come-up" phase. HTST roasting features with a relatively long "come-up" phase throughout the roasting and thus it is considered as non-isothermal process (Demir, et al., 2002). These two roasting systems have been extensively compared with regard to the resulting sensory properties, chemical compositions, and microstructure changes of roasted coffee beans. One study suggested HTST roasting (260 °C/160 seconds) was prone to produce a low density high yield coffee product and higher intensities of roasted flavor and aroma, whereas LTLT roasting (220 °C/600 seconds) tended to produce a more balanced flavor (Schenker et al., 2002). The selection of a coffee bean roasting protocol is based on the flavor and quality requirements (Baggenstoss et al., 2008; Schenker et al., 2002). There have been some scientific studies of peanut roasting (Baker at al., 2003; Bolton & Sanders, 2002; Mason et al., 1966; McDaniel et al., 2012; Newell et al., 1967; Rodriguez et al., 1989; Smyth et al., 1998; Warner et al., 1966). The influence of roasting temperature and time on the sensory quality of peanuts will be discussed in the next section.

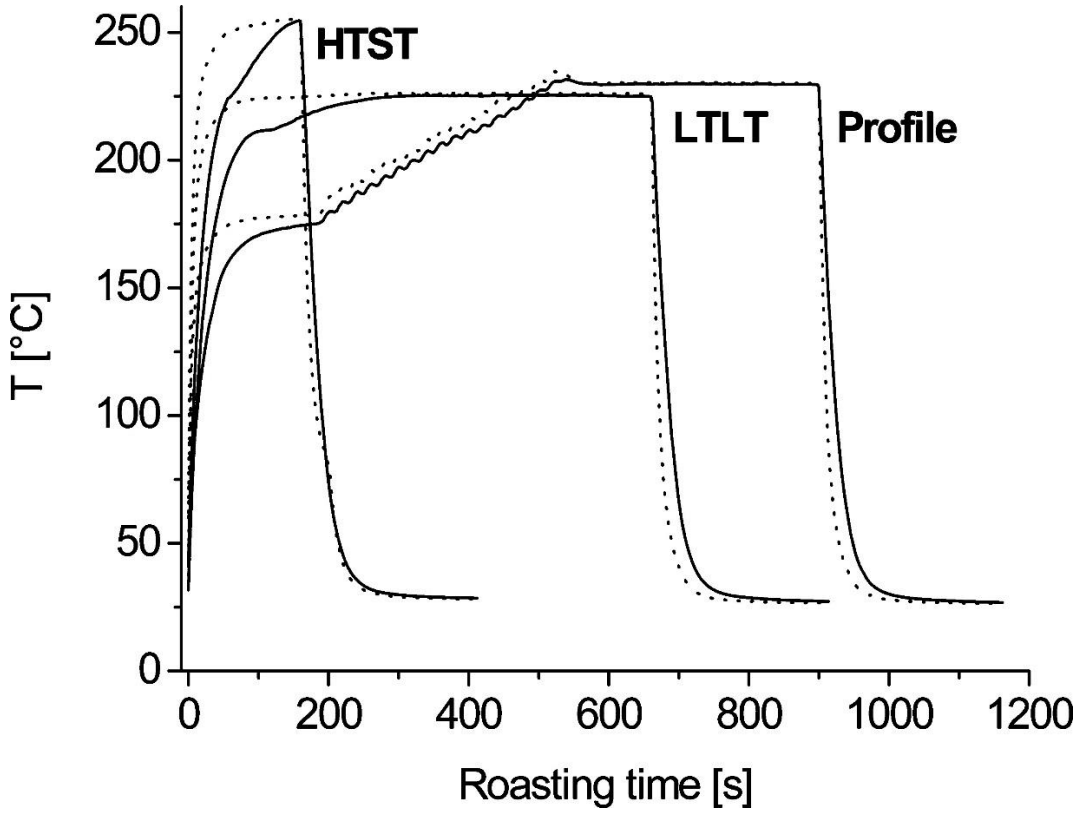

Figure 1.7. Evolution of the coffee bean core (——) and bulk (• • •) temperature during roasting with the fluidizing bed hot-air laboratory roaster (taken from Baggenstoss et al., 2008).

Sensory Quality

Color

Color development is generally used as a method of measuring the degree of roast because it is a fast, easy and nondestructive testing method (Manzocco et al., 2000), as well

as an indicator of final peanut flavor (Smyth et al., 1998). Coffee producers use roast color as an indicator of final product quality (Baggenstoss, et al., 2008). The development of color is mainly a function of non-enzymatic browning, and more specifically the Maillard Browning Reaction (MBR) (Newell et al., 1967; Saklar, Katnas, & Ungan, 2001). The colored pigments, namely the melanoidins, produced during Maillard browning contribute to the characteristic brown-yellow color of roasted goods or bakery product. Recent studies also indicated that melanoidins are composed of high molecular weight (>10kDa), intermediate molecular weight (3.5-10 kDa), and low molecular weight (<3 kDa) fractions (Ćosović, Vojvodić, Bošković, Plavšić, & Lee, 2010; Faist, Lindenmeier, Geisler, Erbersdobler, & Hofmann, 2001; Summa et al., 2008). In roasted coffee, approximately 60% of the melanoidins are high molecular weight (>12 kDa). It has also been reported that the molecular weight of melanoidins, i.e. the degree of polymerization, increased as roasting was continued (Bekedam, Loots, Schols, Van Boekel, & Smit, 2008a; Bekedam, Roos, Schols, Van Boekel, & Smit, 2008b). Although the melanoidins produced by high temperature roasting are primarily high molecular weight, some processing conducted under low temperatures may produce primarily low molecular weight melanoidins. Studies of glucose and alanine/glycine mixtures heated to 95 °C for 4 hours, and glucose/fructose and amino acid mixtures heated to 100 °C for 2 hours suggested the melanoidins formed under such low temperature were primarily low molecular weight compounds (< 3.5 kDa) (Hofmann, 1998; Kim & Lee, 2008). Differences in colors and appearance are seen due to the unique absorbance of the melanoidins produced. As the high molecular weight fraction of melanoidins (>10 kDa) exhibits a stronger adsorption in comparison to the low molecular

weight fraction (<3 kDa) of the same melanoidins, either high temperature roasting or long time roasting can promote the color enhancement during roasting (Ćosović et al., 2010).

Industrially, peanuts are typically roasted to a specified color, as these measurements are rapid and color is well correlated with quality optimization, including flavor (Mason, Johnson, & Hamming, 1966; Pattee, Giesbrecht, & Young, 1991). The final color of peanut pods and peanut butter can be described by Hunter L a b-values and CIELAB L* a* b* values (Hodge, 1953; Pattee, et al., 1991). Both scales are based on the assumption that the human eye perceives colors as pairs of light-dark, red-green, and yellow-blue. The formulas are calculated differently with Hunter using square roots and CIELAB is calculated using cube roots of CIE XYZ (HunterLab, 2013). The 3D distribution of the two scales have been compared (HunterLab, 2013). Theoretically, both scales could be used to describe the color change of peanut, but the predominant color measurement method reported for peanut and peanut butter is through Hunter L a b scale (Pattee et al., 1991). Among the three components of L, a, and b, the Hunter L value is commonly used as the parameter to monitor color changes during roasting due to its highest sensitivity to the time and temperature change (Demir, et al., 2002; Sanders et al., 1989). Pattee et al. (1991) described a simple equation, Hunter L = CIELAB L* - 7, to convert the values between the two scales in the L* range 52-65 for roasted peanuts. Hunter L values has been used to describe the degree of roast with a Hunter L value of 48.5-49 defined as the ideal surface color of blanched roasted peanut kernels for peanut butter. Pasting was found to increase the L value as the interiors of the roasted peanuts were usually higher than the surface (Sanders et al., 1989). Another study

defined Hunter L values of 43±1, 48.5±1, and 53±1 as corresponding to dark, medium, and light roasts, respectively (McDaniel et al, 2012). In industry, peanuts are typically roasted to a specific surface color for quality control; however, recent lab scale experiments suggested that peanuts roasted to equivalent surface colors at different temperature/time combinations can vary substantially in compositional (moisture content, sugar contents, and tocopherols profile) and sensory properties (McDaniel et al, 2012). In industry, defined roasting conditions combined with color information, sensory analysis, and chemical compositions are needed to make a high quality peanut product.

Flavor

Previously, the major compounds responsible for roasted peanut flavors were considered to be pyrazines and other volatile heterocyclic nitrogen containing compounds (Mason et al., 1966; Newell et al., 1967), but more recent studies using advanced technologies such as gas chromatography−mass spectrometry−olfactometry analysis combined with the reconstitution model method indicated no one class of volatiles is the basis for this primary flavor attribute (Schirack, Drake, Sanders, & Sandeep, 2006a; Schirack, Drake, Sanders, & Sandeep, 2006b; Chetschik, Granvogl, & Schieberle, 2008; Chetschik, Granvogl, & Schieberle, 2010). In roasted peanut oil, it has been reported that the three categories of aromatic volatiles that may contribute to the roasted peanut flavor and aroma are non-heterocyclic compounds, N-heterocyclic or heterocyclic compounds containing nitrogen, and O-heterocyclic or heterocyclic compounds containing oxygen (Liu et al., 2011). The non-heterocyclic chemical classes consisted of aldehydes, ketones,

alcohols, acids, alkenes, alkanes, and esters compounds. The main flavor and aroma contributors were aldehydes, which generally contributed undesirable flavors, such as green, painty, or rancidity. Additionally, some non-heterocyclic compounds, mainly aldehydes, ethanol, ketones, and esters, are reported to be associated with off flavors of high temperature cured peanuts (Pattee, Beasley, & Singleton, 1965). Within the N-heterocyclic category, pyrazine compounds were considered the main contributors to "nutty" and "roasty" with some eliciting earthy or potato like comments, but there were no descriptions for individual pyrazine compounds. During peanut roasting, pyrazine compounds, mainly in the form of methylpyrazine, dimethylpyrazine, and methylethylpyrazine, were found to be correlated highly with roasted flavor and aroma (Baker et al., 2003). That study indicated 2,5-dimethylpyrazine was most highly correlated (R^2>0.87) to roasted flavor and aroma. However, a more recent study reported that the added pyrazines that were previously characterized by GC-O did not show an impact on the overall flavor of pan fried peanuts (Chetschik et al., 2010). Within the O-heterocyclic category, furan derivatives were considered as contributors to thermally processed flavor, including caramel-like, fruity, and nutty flavors (Liu et al., 2011; Vranova & Ciesarova, 2009).

The instrumental analysis of associated volatile compounds aids in interpreting and predicting flavor perception, but cannot be used alone for sensory description. Sensory analysis is defined as a scientific method used to evoke, measure, analyze, and interpret those responses to products as perceived through the sense of sight, smell, touch, taste, ad hearing (Stone & Sidel, 2004). A sensory evaluation is a quantitative test that is conducted to answer

the questions about human responses to food and drink. For quantitative analyses, sensory tests are commonly classified into three categories, namely discrimination, descriptive, and affective analysis, according to their primary purpose and most valid use (Stefanowicz, 2013). Discrimination testing distinguishes whether products are different. The panelists involved in this type are screened for sensory acuity, and sometimes training is required for the panelists. Another analytical type is descriptive sensory analysis, which is used to describe how products differ in defined sensory attributes, by giving scores to the intensity of attribute. This type requires trained panelists that are screened for sensory acuity and motivation. The last type of sensory evaluation is the affective test, which is a type of hedonic test. An affective test answers the question of how well products are liked or which products are preferred. The panelists for this category are screened for product use but are not necessarily trained (Stefanowicz, 2013).

The sensory focus of this literature review is descriptive sensory analysis (DSA). DSA is conducted by well-trained panelists who quantitatively describe sensory attributes of a consumer product (Murray, Delahunty, & Baxter, 2001). The typical size of DSA panel is 8-12 panelists, and each panelist functions as a single instrument (Meilgaard, Carr, & Civille, 1999). For the DSA panel of a specific consumer product, a lexicon with all the sensory components of interest must be available in order to evaluate the product (Johnsen, Civille, Vercellotti, Sanders & Dus, 1988). The current peanut sensory terms and intensity scales were developed by Johnsen et al. (1988), with modifications by Sanders et al. (1989), and later addition of ashy and total off notes (Schirack et al., 2006a). The peanut flavor lexicon

(**Table 1.5**) includes a group of terms to describe both desirable and undesirable flavor attributes using an intensity scale from 0 to 15. This lexicon for roasted peanut flavor consists of three categories, they are aromatics, including roast peanutty, raw beany, dark roast, light roast, sweet aromatic, woody/hulls/skins, and off flavors, such as ashy, cardboard, and painty, and the basic tastes on the tongue, including sweet, bitter, sour, and salty, and chemical feeling factors, i.e. metallic and astringency.

Table 1.5. Lexicon for peanut flavor (Adapted from Johnsen et al., 1988; Sanders et al., 1989; Schirack et al., 2006a).

Attribute	Description
Aromatics	
Roast Peanutty (RP)	Aroma associated with medium-roast peanuts and having fragrant character such as methylpyrazine
Dark Roast (DR)	Aroma associated with dark-roasted peanuts and having very browned or toasted character
Raw Beany (RB)	Aroma associated with light-roasted peanuts and having legume like character
Sweet Aromatic	Aroma associated with sweet material such as caramel, vanilla, molasses, fruit
Woody/Hull/Skins	Aroma associated with base peanut character and related to dry wood, peanut hulls, and skins
Tongue and Throat Burn (TTB)	Burning sensation on back of tongue or throat immediately following ingestion or expectoration
Ashy	Aroma associated with very dark roast (espresso)
Cardboardy/Stale	Aroma associated with oxidized fats and oils
Painty	Aroma associated with linseed oil, oil based paint
Earthy	Aroma associated with wet dirt and mulch
Plastic Chemical	Aroma associated with burnt plastics
Fruity Fermented	Aroma associated with floral, fermented, rotten garbage
Total Off-notes	Combination of all off-notes perceived (does not necessarily add up to scores from all other off-notes)
Taste	
Sour	Basic taste associated with acids
Sweet	Basic taste associated with sugars
Bitter	Taste on tongue associated with bitter agents such as caffeine or quinine
Chemical Feeling Factors	
Metallic	The chemical feeling factor on the tongue associated with iron and copper
Astringency	The chemical feeling factor on the tongue associated with tannins and alum; causing puckering or dry mouth sensations

Descriptive sensory evaluation can be correlated with instrumental data, shelf life tests, and other research, to better allow quality optimizations of current product and/or product development (Riveros, et al., 2010; Silva, Martinez, Casini, & Grosso, 2010; Warner, Dimick, Ziegler, Mumma, & Hollender, 1996). The current quality standards used to estimate roasted peanut flavor are based on the color and/or moisture content of roasted peanut; however, recent lab scale experiments suggested different temperature/time combinations can achieve equivalent color but different sensory properties (McDaniel et al., 2012). Other than roasting conditions, peanut flavor can also be affected by other factors such as peanut variety, maturity, harvesting, and post-harvest processing (Sanders et al., 1989). A more accurate prediction of peanut flavor for a specific genotype can be achieved by including volatile compounds levels, along with roast color, roasting conditions (temperature and time), and other potential parameters (Baker et al., 2003). Previous studies stated pyrazines were the major components contributing to the roasted flavor of peanuts (Baker et al., 2003; Mason et al., 1966; Mason et al., 1969), but this statement has become controversial recently with the use of advanced technologies. Gas chromatography (GC), GC- mass spectrophotometry (GC-MS), solid-phase microextraction (SPME), and GC-olfactometry (GC-O) have been used to identity and quantify the volatile compounds associated with peanut flavors (Chetschik et al., 2010; da Conceicao Neta, 2012). It has been reported that the added pyrazines that were previously characterized by GC-O did not show an impact on the overall flavor of pan fried peanuts (Chetschik et al., 2010). Another study examined the effect of 30 potential contributors on roasted peanut aroma by combining different concentrations of selected volatile compounds into 5 recombinant models. The

potential contributors were screened either by aroma extract dilution analysis or based on their high intensity scores on the GC-O analysis. The results indicated that pyrazines did not have a major effect on the aroma of model mixture (da Conceicao Neta, 2012). The information collected from these instrumental methods can be used in combination with DSA to determine the contribution of these compounds to the flavor and aroma of roasted peanut.

Texture

In some foods, the perceived texture is the most important attribute of the product. These include nuts, crackers, potato chips, peanut snacks, and similar products. The peanut texture lexicon has not been exclusively established but it refers to terms derived from other oilseeds and nuts (Tunick et al., 2013; Varela, Salvador, & Fiszman, 2008; Vickers, Peck, Labuza, & Huang, 2014; Wanlapa & Jindal, 2006). Most oilseeds and nuts are comparable in composition in that they are high in oil (40-70%), high in protein (10-25%), and low in moisture content (Venkatachalam & Sathe, 2006), resulting in similar textures. Texture perception can be divided into auditory and tactile perceptions. Auditory texture is sound related responses during breaking or chewing, whereas tactile texture is the feel related responses when manipulating a food by mouth or hand (Lawless, 1998). The commonly used terms of auditory texture attributes of oilseeds and nuts texture are crispiness and crunchiness, crackliness, brittleness, and hardness (Vickers, 1982). The definition of crispness and crunchiness is controversial. It is thought that crispiness is acoustically more related to a relatively larger proportion of high pitched sounds with frequencies higher than 1.9 kHz, while a larger proportion of low pitched sounds, with frequencies less than 1.9 kHz,

is related to crunchiness (Vickers, 1984). Another evaluation of crispiness and crunchiness examined the time sequence of breakage on application of chewing force by molars. Crispiness is associated with the sound in a single breakage stage, while crunchiness is about the sound in several successive stages (Szczesniak, 1991). The term hardness has also been used to evaluate the texture of crisp food. Unlike crispiness and crunchiness, oral tactile sensations are more useful than auditory sensations for the evaluations of hardness in most cases (Vickers, 1982, 1984). Hardness of peanuts was defined as the measure of the force needed to bite completely through the sample with the front teeth or molars (Smyth et al., 1998). Another term for tactile texture that describes the attributes of brittle food is breakdown. Breakdown describes the dynamic process involving grinding ingested food into a fine state, mixing with saliva, bringing to mouth temperature to prepare for swallowing; however, when breakdown is used as a term for texture description, it is mainly associated with how easily the food crumbles during mastication (Lenfant, Loret, Pineau, Hartmann, & Martin, 2009).

The moisture loss and changes in storage protein are considered as the main factors in texture development of roasted peanuts, resulting in increased crispiness, crunchiness, hardness, and looseness of particles than is seen in raw peanuts. When peanuts were stored in a high relative humidity environment, they absorbed moisture and became soggy in texture (Metwalli, Zoueil, Mohamed, & El-Zalaki, 1975; Smyth et al., 1998). Although there is improved texture due to roasting, high intensity roasting may cause a crumbling effect on peanuts, making them too brittle in texture due to excessive moisture loss and thermal

modifications (Hung & Chinnan, 1989; Smyth et al., 1998). A similar association of moisture loss with texture development has been found in other oilseeds and nuts such as hazelnuts (Demir & Cronin, 2004, 2005), pecans (Anzaldua-Morales, Brusewitz, & Maness, 1998), cashews (Lima, Campos, & Goncalves, 2000; Lima, Goncalves, Silva, Campos, & Garcia, 1998; Wanlapa & Jindal, 2006), and almonds (Vickers et al., 2014).

Another textural property associated with peanut products is the spreadability of peanut butter. Spreadability is a subjective, textural term related to how easy it is to create a uniform distribution of food material over a surface (Shakerardekani, Karim, Ghazali, & Chin, 2013). Peanut butter can be considered a concentrated suspension system, such as ketchup, yogurt, chocolate, and purees. Specifically, peanut butter, and also its base peanut paste, is a multiphase system consisting of a concentrated suspension of non-colloidal small peanut particles in peanut oil (Corradini & Peleg, 2005). Peanut butter is a spreadable food that is usually consumed after being spread over a surface through the back and forth motion of a knife. The spreadability of peanut butter can be well assessed by yield stress, which is a mechanical measure of the minimum shear stress to initiate the flow or deformation of a food material (Liddell & Boger, 1996). A strong link between spreadability and yield stress has been established for spreadable foods (Daubert, Tkachuk, & Truong, 1998). To eliminate the potential of wall slipping in the oscillatory rheometer, the vane method was applied under a controlled relatively low (< 1 rpm) shear rate and is a well-established method for yield stress measurement (Cheng, 1986; Daubert et al., 1998; Sun & Gunasekaran, 2009). The yield stress measured with the vane method was able to identify specific changes in yield stress

when the levels of ingredients of spreadable food varied (Truong & Daubert, 2001). Daubert et al. (1998) distinguished the yield stress of peanut butter (approximately 1700 Pa) and reduced fat peanut butter (approximately 2500 Pa) using the vane method conducted at 0.5 rpm. In general, the magnitude of the yield stress of food suspensions increased with increasing particle volume fraction (the volume occupied by the particles in relation to the total volume) and particle-particle forces; however, the mechanisms of how these factors affect the yielding behavior of food suspensions were not clear (Genovese, Lozano, & Rao, 2007).

Kinetics

Basic Kinetic Equations

A broad definition of food quality is meeting the expectation of consumers (van Boekel, 2008). One challenge for food manufacturers is to make a connection between quality requirements and process design. Instead of fuzzy control of food processing with trial and error, a systematic modeling that simulates industrial processing but built at smaller scales provides a more precise method of processing with the aim of better control of food quality (van Boekel, 2008; van Boekel et al., 2010). Kinetic modeling provides a way to quantitatively relate the indicators of food quality, such as color, composition, and microorganism kill, to process design. This type of model can be built at lab and/or pilot

plant scales that simulate the industrial scale described by a series of mathematic equations (Holdsworth & Simpson, 2007; van Boekel, 2008).

Kinetic models are widely used in thermal processing for safety and quality control (Holdsworth, 1985). The successful thermal processing of packaged food products requires sufficient heat treatment for microbial inactivation, to kill both pathogenic and spoilage microorganism. Understanding the heat resistance of microorganisms is essential to establishing a time- temperature schedule for achieving this objective. Kinetics are most widely used in microbial kill prediction using time-temperature profiles; however, the model can also be used for studying the chemical reactions, enzyme inactivation, degradation of certain components, and the effects of cooking on a food (Holdsworth, 1985). The most general equation for studying the kinetics of reactions, is given by **Equation 1** and can be linearized to **Equation 2**, with c being the concentration of reacting species at time t; k_n being the specific reaction rate, and n being the reaction order (Holdsworth & Simpson, 2007). The order of reaction can be determined by plotting ln (-dc/dt) versus ln (c). The slope of the linear line is the reaction order and the intercept is ln (k_n).

$$-dc/dt = k_n c^n \qquad \textbf{Equation 1}$$

$$\ln(-dc/dt) = \ln k_n + n \ln c \qquad \textbf{Equation 1}$$

In a chemical system, the reaction usually obeys zero or first order rate (Holdsworth et al., 2007; Ozdemir & Devres, 2000; Simsek, 2007; van Boekel et al., 2010; Wang & Lim, 2014; Yilmaz & Toledo, 2005), with exceptions obeying the second order rate. The kinetic

equations can be simplified to **Equation 3** (n=0), **Equation 4** (n=1), or **Equation 5** for the zero, first, or second order reactions. Two examples for zero order reaction are caramelization of sugar and vitamin C degradation in a food system. The reactions that fall under the first order reaction are microbial kill, nutrient destruction, and enzymatic inactivation. A typical example of second order reaction is the thiamin destruction in milk (Horak & Kessler, 1981).

$$c = c_0 - k_0 t \qquad \textbf{Equation 3}$$

$$c = c_0 e^{-k_1 t} \qquad \textbf{Equation 4}$$

$$1/c_0 - 1/c = -k_2/t \qquad \textbf{Equation 5}$$

The kinetics of color change during thermal processing were reported to be represented by either zero order or first order within a certain temperature range (Kaftan, 2012; Ozdemir et al., 2000; Wang et al., 2014). The second order was also found between color changes and roasting time of coffee beans (Somporn, Kamtuo, Theerakulpisut, & Siriamornpun, 2011). The purpose of the reaction kinetics of color change is to determine the processing time required to achieve specific colors at a certain temperature, as well as to predict the color change under a designated temperature and time combination (Demir et al., 2002). In an industrial setting, the validation of the model formula allows for processing design and product quality control.

Arrhenius Relationship

The Arrhenius Relationship is a model describing the temperature dependence of simple chemical reactions (van Boekel, 2008). It is an empirical model derived to relate the reaction rate *k* defined above to the absolute temperature. A mathematical formula is used to describe the temperature dependence of reaction rates as **Equation 6**, which can be linearized to **Equation 7**, where *A* is the pre-exponential factor (also called collision number or frequency number) in the unit of s^{-1}, *Ea* is the activation energy in the unit of J/kg mol, and *R* and *T* are respectively, the universal gas constant (=8314 J/kg mol K) and absolute temperature in the units of degrees Kelvin. The activation energy *Ea* is the minimum energy which molecules must have for the reaction to occur and the exponential term $exp^{-Ea/(RT)}$ is the fraction of molecules that collectively have the minimum energy (Goldblith, 1961; Singh & Heldman, 1984). According to **Equation 7**, a linear curve can be plotted of lnk versus 1/*T* with a series of known k and *T*. The pre-exponential factor can be calculated through the exponential function of the intercept and the activation energy can be derived through the absolute value of the slope multiplied by *R*. The magnitude of activation energy is related to the temperature dependency of the reaction. A higher order of E_a usually corresponds to a stronger temperature dependency of the reaction. In other words, the reaction takes place relatively fast at high temperatures, while the reaction runs much slower below a certain temperature.

$$k = A \exp\left(-\frac{E_a}{RT}\right) \qquad \textbf{Equation 6}$$

$$\ln k = \ln A - \frac{E_a}{RT} \qquad \textbf{Equation 7}$$

When the reaction rates are known at two temperatures (T_1 and T_2), the application of **Equation 7** results in two equations with k_1 and T_1 and k_2 and T_2, which can be integrated into **Equation 8** and further into **Equation 9** as seen below. If a proper reference temperature T_{ref} is assigned to this equation with known k_{ref}, the reaction rate at another temperature can be calculated without knowledge of the pre-exponential factor *A*.

$$\ln\left(\frac{k_1}{k_2}\right) = -\frac{E_a}{RT}\left(\frac{T_2 - T_1}{T_1 T_2}\right) \qquad \textbf{Equation 8}$$

$$\frac{k_1}{k_2} = \exp\left[\frac{E_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right] \qquad \textbf{Equation 9}$$

One important usage of kinetics is to optimize the product and process design. Food safety and food quality are two aspects needed to be considered for thermal process design. As there is a difference in the temperature sensitivity between food quality indicators and microorganisms, the temperature dependency differs in chemical reaction and microbial inactivation as illustrated by **Figure 1.8** (van Boekel, 2008). The process should be designed by selecting the combination of time and temperature that can meet the requirement of microbial inactivation, while minimize quality loss. The so called UHT (ultra-high temperature) region is characterized by time/temperature combinations that can achieve sufficient microbial kill and limited quality change (Goldblith, 1961; Singh & Heldman, 1984).

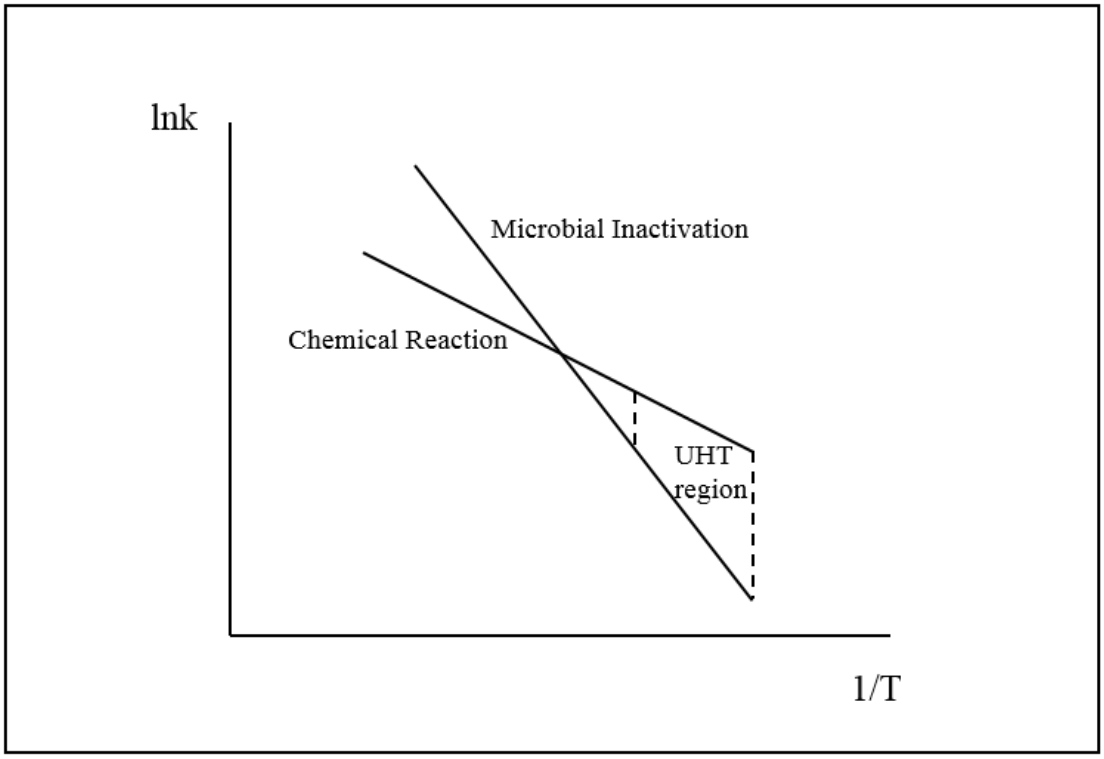

Figure 1.8. Graphic illustration of the temperature dependence of microbial inactivation and a chemical reaction (taken from van Boekel, 2008).

Kinetic Parameters

In addition to the parameters described above, that is, reaction rate, order, and energy activation factors, there are other parameters commonly used to describe the temperature dependency. The parameters discussed in this section are primarily used for describing microorganism reduction during food process, but have been extended to quality changes, such as chemical composition, color, and even texture attributes (Demir et al., 2004, 2005; Kaftan, 2012; Ozdemir et al., 2000; Wang et al., 2014; Yilmaz & Toledo, 2005). The

concentration of a chemical compound, the intensity of color, or the extent of texture attributes is represented by factor *c*. The parameter D is the decimal reduction value, which is the time required to achieve one common logarithm (log) change of *c* at reference temperature. The D value is the inverse of the reaction rate. Another parameter, z value is defined as the temperature change for one log change in the D value, in other words, z value describes the temperature change that would increase the reaction rate by one log. To distinguish the z value from microbial kill, z_c value is used for quality changes. The magnitude of z_c is usually in a much higher order than the z value for microorganism, as chemical composition, color, and texture, etc. are usually more resistant to processing than microbes (van Boekel, 2008).

The ratio of *k* at two temperatures is referred to as the quotient indicator (Q). When the temperature difference is 10 °C, the ratio is referred to as the Q_{10} value as described by **Equation 10**. The parameter Q_{10} is strongly temperature dependent and should be reported with a temperature range (van Boekel, 2008).

$$Q_{10} = \frac{K_{T+10}}{K_T} = \frac{D_T}{D_{T+10}} = 10^{10/z_c} \qquad \textbf{Equation 10}$$

To facilitate the comparison of the lethal effect of different processes for microbiologists, the concept of integrated lethality, also known as the F value (in the unit of minutes), was introduced (Ball & Olson, 1957) as described in **Equation 11**, where t is the processing time, T is the temperature in Celsius, T_{ref} is the reference temperature, and the z

value is as described above. The factor, F-value is the integration of lethal rate (LR), as described in **Equation 12**. The concept of F value is referred to as the time of processing at the reference temperature that yields the same amount of microbial kill as in the process. The F value gives a measure of microbial inactivation that can be used to compare the lethal effect of different processes, where a higher F value represents a better sterilization effect.

$$F = \int_0^t 10^{(T-T_{ref})/z}\, dt \qquad \textbf{Equation 11}$$

$$LR = 10^{(T-T_{ref})/z} \qquad \textbf{Equation 12}$$

The concept of lethality of microbial inactivation can be extended to food quality changes. The "lethality like" value for food quality is designated as cook value (C) as expressed in **Equation 13**, where z_c is the z value for quality change (Holdsworth, 1985). Cook value makes it possible to compare the quality changes in different processes by relating each process to the reference process.

$$C = \int_0^t 10^{(T-T_{ref})/z_c}\, dt \qquad \textbf{Equation 13}$$

For a constant temperature process, the formula of F value and C value can be simplified to **Equation 14** and **Equation 15**. In practice, the temperature is usually measured and recorded with a time interval, during which the temperature can be considered as constant as long as the time interval is reasonably small. With every increase of Δt, the F or C value increases with a value of $10^{(T-T_{ref})/z}$. As F and C values are cumulative in a continuous value, it is possible to calculate the F or C value of whole process by summing

the F or C value for each time interval. For a non-isothermal process over time t_n, the conservative F and C values can be determined based on using the minimum temperature for each time interval. The formulas of conservative F and C values are listed as **Equation 16** and **Equation 17** (Goldblith, 1961; Singh & Heldman, 1984). The use of a conservative calculation prevents the overestimation of lethality effects for the F value, which decreases risks of insufficient processing. Conservative calculations for C value prevents the overestimation of quality degradation, thus decreases the risk of under cooking.

$$F = 10^{(T-T_{ref})/z}\ \Delta t \qquad \textbf{Equation 14}$$

$$C = 10^{(T-T_{ref})/z_c}\ \Delta t \qquad \textbf{Equation 15}$$

$$F = \sum_0^{t_n}[\Delta t \times 10^{\frac{min(T_{t-\Delta t}, T_{\Delta t}) - T_{ref}}{z}}] \qquad \textbf{Equation 16}$$

$$C = \sum_0^{t_n}[\Delta t \times 10^{\frac{min(T_{t-\Delta t}, T_{\Delta t}) - T_{ref}}{z_c}}] \qquad \textbf{Equation 17}$$

Microstructure

Peanuts (and other tree nuts) store all the energy required for germination and the first phase of growth of a new plant in their kernels (Perren et al., 2013). Fat as unsaturated fatty acids are the major forms of stored energy inside peanut kernels. Due to the high levels of unsaturated lipids in peanuts, it is a challenge to prevent lipid oxidation (Perren et al., 2013). The highly compartmentalized microstructure of peanut kernel tissue protects the lipid from

degradation. Triglycerides inside the oil bodies are encapsulated by a bilayer of phospholipids with embedded oleosin protein, assembled as compartments known as oleosomes. Methods of light microscopy (LM), scanning electron microscopy (SEM), and transmission electron microscopy (TEM) have been used to elucidate peanut structure. The effects of maturity and food processing on the microstructure change of peanut seeds have been investigated using microscopy (Young et al., 2004; Young & Schadel, 1990, 1991; Young, Schadel, & Heertje, 1993). In terms of the anatomy and cytology of a peanut seed, the peanut cotyledon is composed of epidermal, vascular, and parenchyma tissues. The epidermal tissue is a single layer of outermost cells covering the rounded outer surface and the curved inner surface of cotyledon (**Figure 1.9**) (Young, Pattee, Schadel, & Sanders, 2004). The epidermal cells of the outer surface are characterized by their rectangular shape and smaller size than the parenchyma cells. The inner surface epidermal cells are shaped irregularly and have guard cells and stomata. The vascular tissue is composed of bundles and only represents a small portion of the total cotyledon (**Figure 1.10**) (Young et al., 2004). The largest volume of the cotyledon is occupied by parenchyma cells, which are relatively large, isodiametric cells (**Figure 1.11**) (Young et al., 2004; Young & Schadel, 1990, 1991). Both epidermal and parenchyma cells are defined and restricted by the spherical cell walls at the microscopic level. The network surrounding the subcellular organelles (protein bodies, starch grains, and lipid granules) is the cytoplasmic network (**Figure 1.11**) (Young et al., 2004). Young and Schadel (1990) characterized the smaller granules as lipid bodies at about 1-2 μm in diameter, and the bigger granules as protein and starch bodies with sizes of 5-12

and 4-15 μm in diameter, respectively. The protein and starch bodies cannot be distinguished from each other using SEM, but they are distinct in the vision of TEM (Young et al., 2004).

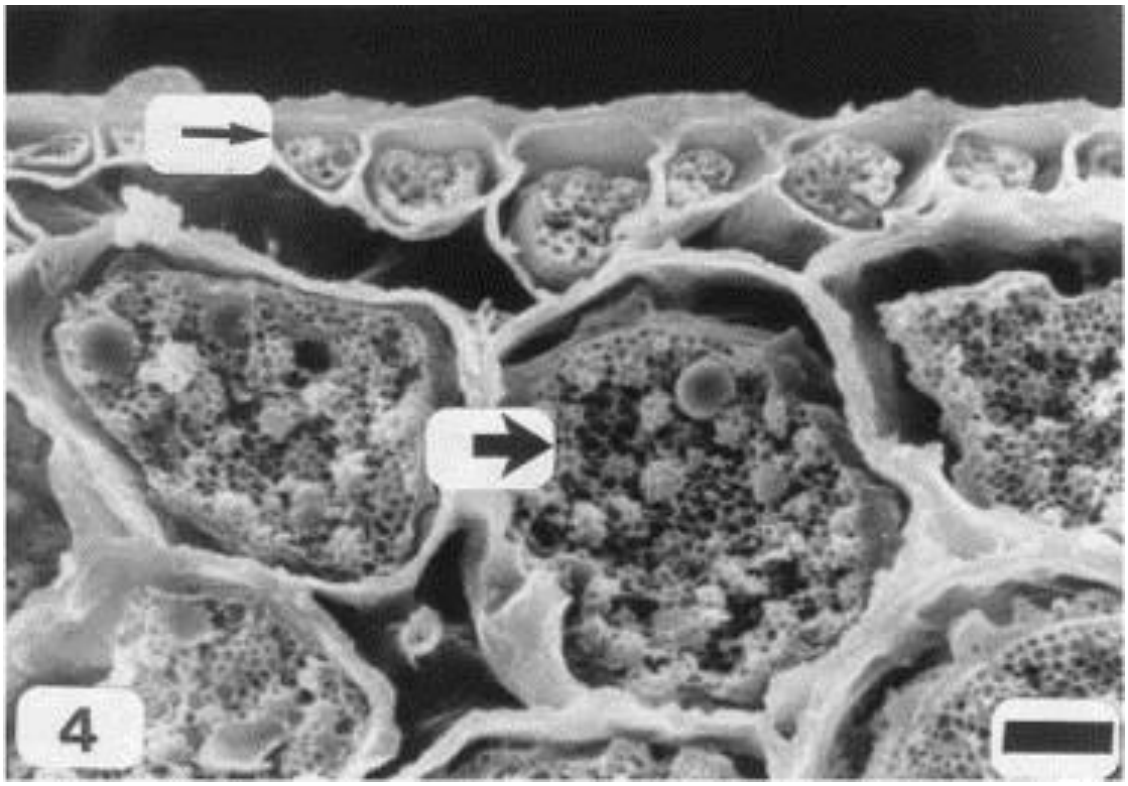

Figure 1.9. The SEM of cross-section of outer surface of epidermal cells (small arrow) and parenchyma cells (large arrows) of a mature peanut (taken fromYoung et al., 2004).

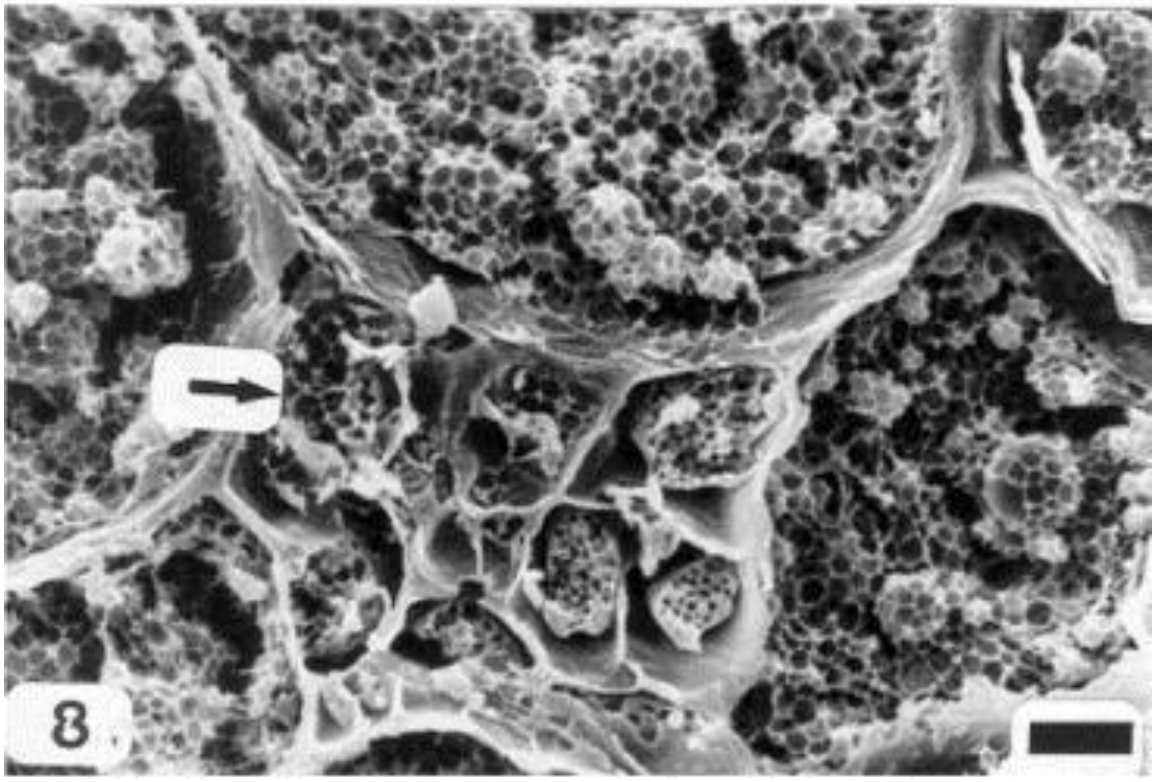

Figure 1.10. The SEM of the cross-section of provascular tissue bundle (arrow) in a mature peanut (taken from Young et al., 2004).

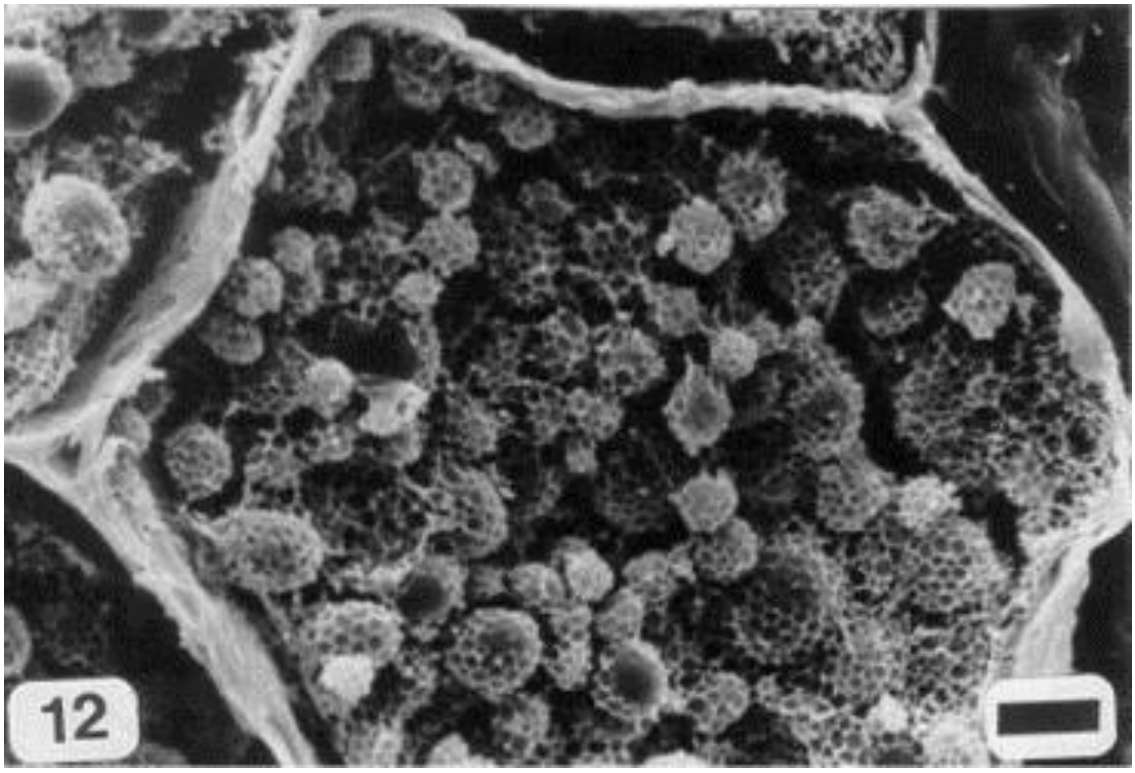

Figure 1.11. The SEM of the cross section of mid-region of parenchyma in a mature peanut (taken from Young et al., 2004).

Examination of the peanut seed microstructure is important in that physical changes at this level are associated with the maturity of peanut seed, the environmental conditions, as well as the processing procedures (Young & Schadel, 1990). Observing the microstructural changes during peanut processing aids in the understanding of the thermal modifications, such as cell wall rupture, protein and starch body distension, and cytoplasmic network disruption, of the peanut seed cotyledon (Young & Schadel, 1990). The thermal

modifications (i.e. cell wall rupture, protein and starch body distension, and cytoplasmic network disruption) of oven roasted and oil cooked peanut cotyledon have been described. Oven roasting at 160 °C consistently induced similar thermal modifications more slowly than oil roasting at the same temperature (Young et al., 1993). The details of thermal modifications of dry and oil roasted peanut cotyledon are summarized in **Table 1.6**.

The loss of cell structure and release of substances from damaged cell compartments enhances the mass transfer and facilitates access and migration of oxygen into the peanut tissue. Thus roasting has the potential to accelerate the lipid oxidation (Perren et al., 2013); however, the relationship between roasting conditions and lipid stability is more complex. This will be discussed in the next section on shelf life.

Table 1.6. Thermal modification of dry and oil roasted peanut cotyledon (Young et al., 1993).

	%Cytoplasmic Network Distrupted	Protein Body Distension	Cell Wall Separation
Raw			
Outer epidermal cross section	0	None	Absent
Mid-region cross section	0	None	Absent
Inner epidermal cross section	0	None	Absent
Oven Roasted (160 °C/7min)			
Outer epidermal cross section	<10	None	Absent
Mid-region cross section	0	None	Absent
Inner epidermal cross section	<10	None	Absent
Oven Roasted (160 °C/13min)			
Outer epidermal cross section	<10	Mild	Absent
Mid-region cross section	<10	Mild	Absent
Inner epidermal cross section	<10	Mild	Absent
Oven Roasted (160 °C/16min)			
Outer epidermal cross section	<50	Moderate	Present
Mid-region cross section	<50	Moderate	Absent
Inner epidermal cross section	<50	Moderate	Absent
Oven Roasted (160 °C/19min)			
Outer epidermal cross section	>50	Severe	Present
Mid-region cross section	<50	Moderate	Absent
Inner epidermal cross section	<50	Severe	Present
Oil Roasted (160 °C/4min)			
Outer epidermal cross section	<50	Mild	Absent
Mid-region cross section	<10	None	Absent
Inner epidermal cross section	<10	None	Absent
Oil Roasted (160 °C/8min)			
Outer epidermal cross section	>50	Moderate	Present
Mid-region cross section	<10	Mild	Absent
Inner epidermal cross section	<50	Moderate	Absent
Oil Roasted (160 °C/10min)			
Outer epidermal cross section	>50	Severe	Present
Mid-region cross section	<50	Moderate	Absent
Inner epidermal cross section	<50	Moderate	Absent
Oil Roasted (160 °C/12min)			
Outer epidermal cross section	>50	Severe	Present
Mid-region cross section	<50	Moderate	Absent
Inner epidermal cross section	<50	Severe	Present

Shelf Life

Lipid Oxidation

Oxidation in food products leads to a reduction in the quality and shelf-life. Factors such as environmental stresses from harvesting or curing, exposure to light, heat and air can all cause different forms of oxidation (Burton & Ingold, 1986). Lipid oxidation is the main problem in the storage of high oil foods as it causes off-flavors and nutrient loss. The associated negative flavors in peanuts include rancidity, cardboard, stale, and other undesirable flavors (Warner, et al., 1996). Even under refrigerated conditions, foods can undergo lipid peroxidation by the mechanism of free radical chain reactions (Burton et al., 1986). **Figure 1.12** depicts the main steps of free radical chain reactions during lipid oxidation: initiation, propagation and termination (Burton et al., 1986). The initiation step is the spontaneous abstraction of a hydrogen atom from a lipid molecule and production of carbon centered radical R• (**Figure 1.12 (1)**). The propagation involves the direct addition of an oxygen molecule to a double bond to generate hydroperoxide compounds (ROO•) (**Figure 1.12 (2)**). The ROO• formed reacts with the organic material (RH) to produce ROOH and release R• (**Figure 1.12 (3)**). This propagation step is continued as R• can be oxidized into a free radical (ROO•) and then released to produce more free radicals. This chain reaction is terminated when two free radicals produce a non-radical molecule (**Figure 1.12 (4)**) (Wasowicz et al., 2004). Both enzymatic and non-enzymatic catalyzed oxidation may occur in raw and roasted peanut during storage; however, considering the effect of enzyme inactivation during high temperature roasting, the greater rate of lipid oxidation for roasted

peanuts is probably caused by lipid oxidation catalyzed by metalloproteinase (Agbo, Anderson, & Singh, 1992). Previous studies claimed particular transition metals, such as iron, may promote the lipid oxidation in food system (McClements & Decker, 2000; Lorrain, Dangles, Loonis, Armand, & Dufour, 2012).

Initiation

$RH \rightarrow$ Production of $R\cdot$ (1)

Propagation

$R\cdot + O_2 \rightarrow ROO\cdot$ (2)

$ROO\cdot + RH \rightarrow ROOH + R\cdot$ (3)

Termination

$ROO\cdot + ROO\cdot \rightarrow$ molecular products (4)

Figure 1.12. Steps of oxidation free radical chain reaction, where RH = lipid molecule and R• = carbon centered radical (Burton et al., 1986).

The commonly used indicators of lipid oxidation are peroxide value (PV) and thiobarbituric acid reactive substances (TBARS). As the primary reaction products of lipid oxidation are peroxides (ROOH), their concentration can be used as an indicator of the process of oxidation. The most commonly used method (AOAC 965.33) utilizes the ability of ROOH to liberate iodine (I_2) from potassium iodide (KI) (AOAC, 2010). The I_2 formed can be reduced to I^{-1} by adding the sodium thiosulfate ($Na_2S_2O_3$). The complete reduction of I_2 to I^{-1} can be reflected by the color change of solution from blue to colorless using starch as

the indicator (Crowe & White, 2001). An issue in the use of the PV method lies in the fact that peroxides are primary products that are decayed in the latter stage of lipid oxidation. A lower PV may represent the very initial or the final stages of oxidation. An alternative method to measure the extent of lipid oxidation is to use the thiobarbituric acid test, which measures the products of hydroperoxide degradation (Kanner & Rosenthal, 1992). This method depends on the color products formed from the condensation of thiobarbituric acid with malonaldehyde, which is presumably formed in the oxidized lipids. This method is limited as other food components may react with thiobarbituric acid causing similar color formation (Kanner & Rosenthal, 1992).

Due to their high oil content and high ratio of unsaturated fatty acids, peanuts are susceptible to lipid oxidation. Lipid oxidation is the major cause of the degradation of pleasant flavors and presence of unpleasant off flavors, such as painty, rancity, and cardboard, during peanut storage (Riveros et al., 2010). The association between the peroxide value (PV) results and developed rancidities has been established (Agbo et al., 1992). Both chemical and sensory analysis were used to assess peanut storability in shelf life tests (Agbo et al., 1992; Lima et al., 1998; Riveros et al., 2010). Additionally, positive correlations (R^2 >0.6) were determined between chemical analysis results (PV, conjugated dienes, and p-anisidine values) and oxidized and cardboard flavors, whereas negative correlation exists between roasted peanutty flavor and chemical analysis (PV, conjugated dienes, and p-anisidine values) (Riveros et al., 2010). In the literature, the shelf life of medium roasted peanut pastes (Hunter L=50±1) prepared from normal peanuts was 128 days

when stored at room temperature (23 °C), based on a PV threshold of 10 meqO_2 kg^{-1}; however, the shelf life of pastes made from high oleic peanuts was 300 days (Riveros et al., 2010).

Factors Influencing Peanut Shelf Life

Flavor fade in peanuts has been defined as the loss of positive attributes associated with the flavor of fresh roasted peanuts such as roasted peanut and sweet aromatic accompanied by development of off flavors (such as, cardboardy, painty, and other oxidized flavors) during storage (Abegaz, Kerr, & Koehler, 2004). The formation of off flavors is mainly due to the formation of various undesirable volatile aldehydes during storage, such as hexanal, heptanal, octanal, and nonanal. These sub-products of lipid oxidation may interact with roasted peanut flavor compounds, ultimately leading to loss of roasted peanut flavors. Also, large quantities of aldehydes formed during lipid oxidation may mask the roasted peanut flavors (Warner et al., 1996; Williams, Duncan, Williams, Mallikarjunan, & O'Keefe, 2006). In one study, tocopherols, peroxide value, and sensory attributes were tested in roasted peanuts after storage at 40 °C for 88 days (Silva, et al., 2010). Tocopherol contents of roasted samples decreased with storage time, but peroxide value increased with time, showing a negative correlation between the two. Positive sensory attributes of roasted peanuts decreased with storage time, while cardboardy, painty, and oxidized flavors increased.

Many factors influence the lipid oxidation of peanut products, including variety, maturity, seed size, moisture content, water activity, processing, and storage and packaging conditions (moisture content of environment, processing, temperature, light, and oxygen) (Agbo et al., 1992; Anzaldua-Morales et al., 1998; Baker, Sims, Gorbet, Sanders, & O'Keefe, 2002; Chun, Lee, & Eitenmiller, 2005; Riveros et al., 2010). It is known that high oleic peanuts are more resistant to lipid oxidation than normal peanuts, as the higher ratio of oleic acid to linoleic acid decreases the unsaturation of the lipids. Riveros et al. (2010) claimed that the shelf life of high oleic peanut paste was extended to 300 days from 128 days, which is the shelf life of normal peanut paste. Increases in moisture content resulted in decreased lipid oxidation rates up to the water activity of 0.40; however, further increases in water activity increased the oxidation rate as expected (Evranuz, 1993). Lipid oxidation occurs even at low temperatures, and the rate of oxidation reaction is accelerated with increased temperature (Evranuz, 1993). It has been found that the best strategy to control lipid oxidation of peanut paste is the prevention of oxygen contact with peanut pastes and utilizing low temperature for storage (Agbo et al., 1992). Also, addition of some additives, such as a metal chelator (EDTA) or an antioxidant (mainly tocopherols), showed the potential to retard lipid oxidation reactions (Agbo et al., 1992).

As previously described, the Maillard reaction is thought to generate compounds called Maillard reaction products (MRP) with strong antioxidant properties (Amarowicz, 2009; Manzocco, et al., 2000). Enhanced antioxidant capacity resulted from the formation of Maillard compounds, such as melanoidins, and/or release of previously bound polyphenolic

compounds, such as p-coumaric acid, which could protect tocopherols from heat degradation during roasting (Amarowicz, 2009; Oliviero, et al., 2009; Talcott et al., 2005). In the case of coffee roasting, the differences in the antioxidant activity of brewed coffee were highly dependent on the degree of roast (the darkness of roasted bean color) rather than on the type of coffee (Baggenstoss, et al., 2008). The radical-scavenging activity of the non-phenolic fraction of brewed coffee increased with the degree of roasting along with the accumulation of MRP; however, dark roasted coffee showed reduced radical-scavenging activity compared to medium-roasted coffee. This was attributed to the degradation of the polyphenols formed via the earlier stages of Maillard browning.

The relationship between roasting conditions and storability is complex in the case of peanuts. Dry roasting was found to cause microstructure damage to the oleosomes, which allows the access of oxygen into the cell tissue, which can promote the lipid oxidation during storage (Perren et al., 2013). The damaged cell structure was seen to compromise the shelf life of roasted peanuts compared to the unroasted. Another aspect of the shelf life of roasted peanuts, roasting intensity, was considered the primary factor determining the storability. Although heat degradation of tocopherols during peanut roasting was observed, formation of MRP with high antioxidant capacities could protect the tocopherols from deterioration (Chun, et al., 2003). Storage tests suggested tocopherol contents of roasted samples had a negative correlation with the peroxide value (Silva, et al., 2010; Chun et al., 2005). Both studies found that α-tocopherol showed the least stability in roasted peanuts compared to the other tocopherols under storage conditions. Roasted peanuts showed enhanced total

antioxidant capacity (McDaniel et al., 2012; Talcott et al., 2005), which increased as peanuts were roasted to darker colors (Davis, et al., 2010). Roasting to darker colors resulted in slower degradation of tocopherols during storage, attributed to higher amounts of MRP with antioxidant capacity formed during dark roasting that provide protection to the tocopherols (Davis et al., 2010).

In a previous study, peanuts were roasted at 166 °C from 0 to 77 min in a lab-scale oven and crude (unrefined) peanut oil was subsequently mechanically pressed and placed in open beakers at 85 °C to accelerate oxidation (Davis et al., 2010). The most liable tocopherol, i.e. α-tocopherol, showed the greatest decreases in samples roasted for 7 and 21.5 min, whereas degradation of this antioxidant was substantially less with higher roast intensities. Similar trends were observed for the total tocopherols. The final concentration of tocopherols in roasted peanuts or peanut oil was a balance between heat degradation and indirect heat stabilization via the formation of MRP with high antioxidant capacity (Davis et al., 2010).

In a study by Chun et al. (2005), runner peanuts were roasted in a two zone gas fired roaster at 135 °C in the 1st zone and at 190 °C in the 2nd zone to a medium roasts (Hunter L=49±1). A storage study was conducted at 21±1 °C for 38 weeks for raw and roasted peanuts either under vacuum, or under ambient air conditions. When air was present, the peroxide value for the roasted peanuts reached 47 meq/kg by 12 weeks. Under vacuum, lipid oxidation was significantly suppressed ($p<0.05$) compared to storage when air was present. It was noted in that study that regardless of ambient air or vacuum condition, the roasted

peanuts always had higher peroxide values than the unroasted raw peanuts (< 2 med/kg), as roasting causes microstructure damages that promote lipid oxidation (Perren et al., 2013). In both studies, α-tocopherol was the least stable tocopherol isoform during roasting (Davis et al., 2010; Chun et al., 2005).

Conclusions and Areas for Future Research

Industrially, peanuts are typically roasted to a specified color, as the color measurements are rapid and it is well correlated with peanut quality, including flavor (Mason et al., 1966; Pattee et al., 1991). Recent lab scale experiments demonstrated that peanuts roasted to equivalent surface colors at different temperature/time combinations can vary substantially in chemical and physical properties related to product quality (McDaniel et al, 2012). The oven used in most published studies, however, was not simulated to the industrial roaster as there was no air flow and bed depth. There is opportunity to expand that approach to a pilot plant scale roaster that simulates the configurations of one of the most common industrial type roaster, a multi-zone belt roaster, with adjustable air flow and bed depth (Poirier, et al. 2014). Also, although there are several commercial peanut products prepared by dry roasting, deep frying, and blister frying, the scientific comparison of different roasting methods has not been reported, which gives the opportunity to compare the quality related properties of roasted peanuts prepared by different methods in equivalent colors.

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CHAPTER 2

The Effects of Different Dry Roast Parameters on Peanut Quality using an Industrial, Belt Roaster Simulator

The Effects of Different Dry Roast Parameters on Peanut Quality using an Industrial, Belt Roaster Simulator

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Abstract

Recent lab scale experiments demonstrated that peanuts roasted to equivalent surface colors at different temperature/time combinations can vary substantially in chemical and physical properties related to product quality. This study expanded that approach to a pilot plant scale roaster that simulates the configurations of one of the most common industrial type roaster, a multi-zone belt roaster. Jumbo-size runner-type peanuts were systematically roasted at 5 temperatures (149-204 °C) to 3 Hunter L-values (53±1, 48.5±1, and 43±1), corresponding to light, medium, and dark roast. Moisture content was lower in samples roasted at 149 °C, and tocopherol concentrations were not significantly different among medium and dark roast samples from all temperature treatments. Seed moisture decreased with darker roast color and total tocopherols were higher in peanut oils from darker roasts. Yield stress of peanut pastes prepared from the roasted samples increased in darker colored pastes, indicating that spreadability correspondingly decreased with darker roast colors. Intensity of the roast peanut flavor as evaluated using descriptive sensory analysis was highest in the medium roast samples.

Keywords: Peanut roasting, sugar, tocopherols, sensory, yield stress

Highlights:

- The pilot plant roaster with well-controlled systems of air flow and bed depth simulated industrial continuous multi-zone, belt roasters.
- Equivalent colors were achieved with different temperature/time combinations, but some quality-related properties were different.
- Moisture content was lower in samples roasted at 149 °C, whereas tocopherol concentrations did not significantly differ among medium and dark roast regardless of temperature treatment.
- Yield stress increased with darker roast color.
- The highest roast peanut flavor intensity was found in the medium roasted peanuts.

Introduction

Industrially, peanuts are typically roasted to a specified color, as these measurements are rapid and color is well correlated with quality optimization, including flavor (Mason, Johnson, & Hamming, 1966; Pattee, Giesbrecht, & Young, 1991). The pigments contributing to the characteristic color of roasted peanuts are mainly produced from two non-enzymatic browning reactions, Maillard browning and to a lesser extent, caramelization (Hodge, 1953). Maillard browning results from heat induced reactions among the amino groups of the amino acids present with the carbonyl groups of reducing sugars. For a long period of time, the primary flavor compounds producing the flavor descriptor, roasted peanut, were considered to be pyrazines and other semi-volatile heterocyclic nitrogen containing compounds (Mason et al., 1966; Newell, Mason, & Matlock, 1967; Baker et al., 2003). Correlations among roasted peanut flavor and headspace pyrazines identified by GC and other instruments were often observed; however, recent studies using advanced technologies combined with reconstitution model methods, indicated that no single class of volatiles, including pyrazines was the basis for this primary flavor attribute (Schirack, Drake, Sanders, & Sandeep, 2006a; Schirack, Drake, Sanders, & Sandeep, 2006b; Chetschik, Granvogl, &Schieberle, 2008; Chetschik, Granvogl, &Schieberle, 2010). Chetschik et al. (2010) indicated that the addition of a range of pyrazines did not contribute to roasted peanut flavor. Roast color can be quantified using a colorimeter using convertible Hunter Lab or CIELAB (L* a* b*) coordinates (Pattee et al., 1991). Of these the L or L* value is most commonly used to monitor the color change during roasting due to its high sensitivity to the roast time and temperature change (Demir, Celayeta, Cronin, & Abodayeh, 2002). The L

and L* values decrease as roast color darkens. An empirical equation L=L*-7 was established to convert the values between the two scales in the L* range 52-65 for roasted peanuts (Pattee et al., 1991). The ideal color for roasted peanuts after pasting were reported as L* values of 58-59 or L values of 51-52 for peanut paste; while L values of 47.5-49.5 were stated to be the ideal surface color for medium roasted, blanched kernels (Pattee et al., 1991; McDaniel, White, Dean, Sanders, & Davis, 2012). Color development is generally used as a method of measuring the degree of roast because it is a quick, inexpensive testing method (Manzocco, Calligaris, Mastrocola, Nicoli, & Lerici, 2000). Coffee roast color had been established to determine the degree of roast of coffee beans, and the roast degree was used as an indicator of the roasted coffee bean quality (Baggenstoss, Poisson, Kaegi, Perren, & Escher, 2008). Moisture content and water activity are parameters related to the development of chemical/sensory properties of roasted peanuts, as their association has been established with Maillard browning and the texture of roasted peanut (Lee & Resurreccion, 2006). Due to the primary role of reducing sugars as precursors of nonenzymatic browning reactions central to peanut roasting, changes in sugar concentrations should provide an understanding of roasting conditions and final product quality; however, the concentrations of fructose and glucose rarely decreased during roasting as sucrose was also hydrolyzed into glucose and fructose during roasting (Mason et al., 1969). As sucrose is abundant in peanuts, even minor hydrolysis can significantly impact the fructose and glucose contents without causing significant changes of sucrose contents (Mason, Newell, Johnson, Koehler, & Waller, 1969; Oupadissakoon & Young, 1984).

Peanut butter and peanut paste, are multiphase systems consisting of a concentrated suspension of small peanut particles in peanut oil (Corradini & Peleg, 2005). Peanut butter is typically consumed after being spread over the surface of bread, crackers, or fruit, among other things, making it a typical spreadable food. Spreadability is a sensory term related to the ease of creating a uniform distribution of food material over a surface (Shakerardekani, Karim, Ghazali, & Chin, 2013). The spreadability of food relates to the mechanical measurement of yield stress, which measures the minimum shear stress needed to initiate the flow or deformation of a material (Liddell & Boger, 1996; Daubert, Tkachuk, & Truong, 1998). A strong link between spreadability and yield stress has been established for spreadable foods (Daubert et al., 1998). The vane method applied under a controlled low shear rate (<1 rpm) is a well-established method for yield stress measurement as it eliminates the potential wall slipping of oscillatory rheometry (Cheng, 1986; Daubert et al., 1998; Sun & Gunasekaran, 2009). The vane method differentiated specific changes in yield stress when the levels of ingredients of key spreadable foods, including peanut butter, cream cheese, margarine spread, were varied. (Daubert et al., 1998; Truong & Daubert, 2001). The yield stress of commercial regular peanut butter was approximately 1700 Pa compared to 2500 Pa for commercial reduced fat peanut butter (Daubert et al., 1998).

Tocopherols are natural fat soluble antioxidants found in oilseeds, nuts, and other plant oils (Carrin & Carelli, 2010). Four tocopherol isomers (α, β, γ, and δ) have been identified in peanut oil (Cobb & Johnson, 1973). Tocopherols often contribute to shelf life, as they provide protection from lipid oxidation (Chun, Lee, & Eitenmiller, 2005). After the industrial processing of roasted peanuts into peanut butter, more than 95% of tocopherols

remained (Chun, Ye, Lee, & Eitenmiller, 2003). Although decreases in the tocopherol levels were observed during roasting, the addition of peanut oil as an ingredient to peanut butter mediated the roast loss of tocopherols and even enhanced the tocopherols (Chun et al., 2003). A previous study indicated roasting to a darker color resulted in slower degradation of tocopherols during storage, probably due to higher amounts of other Maillard reaction product antioxidants formed during dark roasting that provided protection to the tocopherols (Davis, Dean, Price, & Sanders, 2010).

Flavor is a primary attribute of food quality, and flavor can be described and quantified through descriptive sensory analysis (DSA) (Stone, Sidel, Oliver, Woolsey, & Singleton, 1974). DSA is conducted using trained panelists (n>6) (Meilgaard, Civille, & Carr, 1999; Stefanowicz, 2013). The panel qualitatively, quantitatively, and objectively describes flavor attributes of a food product using an established lexicon. The terminology of the lexicon promotes communication among researchers, producers, and manufacturers for quality control and product development. The current peanut sensory terms and intensity scales were developed by Johnsen, Civille, Vercellotti, Sanders, & Dus (1988), with additions by Sanders, Vercellotti, Crippen, & Civille (1989), and later addition of ashy and total off notes during microwave processing of peanuts (Schirack et al., 2006a). The lexicon for roasted peanut flavor consists of the three categories, aromatics, including roast peanutty, sweet aromatic, raw beany, dark roast, woody/hulls/skins, and off flavors, such as ashy, cardboard, and painty, and the basic tastes on the tongue, including sweet, bitter, sour, and salty, and the chemical feeling factors metallic and astringency. Evaluation by DSA can be correlated with instrumental data and shelf life tests, to better allow quality optimizations of

current products and/or product development (Riveros et al., 2010; Silva, Martinez, Casini, & Grosso, 2010; Warner, Dimick, Ziegler, Mumma, & Hollender, 1996).

To date, only one study has examined the effects of roasting conditionson on the quality-related properties of roasted peanuts on a pilot plant scale (Poirier, Sanders, & Davis, 2014). A recent small oven study suggested most flavor attribute intensities were comparable among different roast conditions prepared to the ideal paste color L*=58 to 59; however, the roasted peanutty intensities tended to be higher for higher temperatures (177 and 204 °C) than at the lower temperature of 163 °C (Smith, Perry, Marshall, Yousef, & Barringer, 2014a). In another earlier study, the roasted peanut flavor and aroma was optimized at 175 °C/15min for the four peanut genotypes (Baker et al., 2003). A lab scale study indicated that dry roasting at different temperature/time combinations produced equivalent surface colors; however different compositional and mechanical properties were determined. That optimized lab scale roast processing could not be directly applied to industrial roasting as the oven was of a different design from the industrial roaster (McDaniel et al., 2012). The current investigation used a pilot plant roaster that simulates the design of an industrial continuous belt dry roaster by adding air flow and bed depth parameters, in order to identify the important process factors and their influence on market quality related properties so that process optimization becomes possible. A well-controlled pilot plant system allows for duplication of the conditions of the industrial continuous belt roaster as well as minimizes the operational differences between batch and continuous roasters (Perren & Escher, 2013). The information derived from this research is expected to be comparable to that of the continuous

roaster, thus it could be used to scale up the process into industrial roasting to optimize the quality of roasted peanuts.

Materials and Methods

Materials

Jumbo grade size (>21/64 in slotted screen) peanuts of the Georgia 06G cultivar, large-seed, runner-type variety, were obtained from the 2012 US peanut harvest delivered by National Peanut Research Lab (Dawson, Georgia). The peanuts had been grown, harvested, cured, shelled, sized and stored utilizing standard industry practices prior to delivery to the USDA ARS Market Quality & Handling Research Unit at North Carolina State University (Raleigh, NC). Shelled peanuts were stored in sealed containers under refrigeration until immediately prior to roasting, at which time a sample was removed and tempered to room temperature. Studies were completed within 18 months of harvest. The average moisture content prior to roasting was 7.9% as determined by loss on drying using a forced air oven at 130 °C (Young et al., 1982).

Peanut Roasting

The pilot plant roaster used in this study simulate the typical industrial continuous dry roaster that is commonly utilized for the dry roasting of peanuts. Such an industrial roaster consists of a perforated steel belt that conveys material through the roaster for a specified

residence time. A continuous dry roaster is divided into independent roasting zones with alternating air flow through the perforated belt, and a final up-flow cooling zone. The continuous roaster has one or more roasting units, with each unit consisting of the up-flow and down-flow zones. A pilot plant scale batch roaster as described by Poirier, Sanders, & Davis (2014), was specifically built by Bühler Aeroglide Corp (Cary, NC) to simulate such commercial dry roasters was used. The parameters used in this study (airflow rate, airflow direction, bed depth, and air temperature,) were selected to simulate common industrial continuous dry roaster conditions. The air flow rate was set at 1.0 m/s (airflow is usually set at 0.7–1.3 m/s for continuous dry roaster) and the bed depth was fixed at 76.0 ± 2.5 mm for all roasting treatments, again bracketing depths common in an industrial practice. A higher air flow of 1.3 m/s was also used in preliminary experiments at roast temperatures of 177 and 191 °C (**Figure 2.1**). The air flow direction was changed from up-flow to down-flow at the half waypoint of the roasting time to simulate industrial practice (Poirier et al., 2014). The dimensions of the roasting tray and the configurations of the thermocouples in the pilot plant dry roaster are shown in **Figure 2.2**. Four thermocouples were fixed in the roasting tray at the center of the top (T), middle (M), and bottom (B) locations of peanuts in the tray, and inside of an individual peanut seed that was located at the center of the middle location (P). Unblanched peanuts (2078 g) were roasted in triplicate in the pilot plant scale roaster at 5 different temperatures (149, 163, 177, 191, and 204 ºC). Immediately following roasting, the roasting tray containing peanuts was placed onto a forced air blower and peanuts rapidly cooled to ambient temperature. Peanuts were then blanched (skins removed) and the surface color of the blanched seed was determined with a Hunter Lab DP-9000 colorimeter

(HunterLab, Reston, VA). For this study, blanched seeds having L values of approximately 53±1, 48.5±1, and 43±1 were regarded as light, medium, and dark roasted, respectively. Roasting temperatures were set and roasting times were determined by linear regression of Hunter L-value versus roast time curves derived from preliminary roasting trials. The Hunter L values of blanched seeds were plotted in linear regression with roasting times for each temperature (**Figure 2.3**).

Oil Extraction and Preparation of Defatted Solids

Peanuts were coarsely ground, wrapped with cheese cloth, and compressed using a Carver press (Carver, Wabash, IN) at 8000 kilograms for 15 minutes. The co-product of this process, partially defatted solids, was then completely defatted with hexane in a Soxhlet apparatus for 6 hours. The defatted solids were stored at -18 °C in 50 ml plastic tubes for future analysis. The pressed oil was used immediately for tocopherols analysis.

Moisture Content (MC)

Unblanched whole peanut seeds from each treatment (triplicate) were dried in a forced air oven at 130 ºC for 6 hours (Young et al., 1982). The weight differences before and after oven drying were used to calculate moisture content (MC; % dry weight).

Tocopherol Analyses

Tocopherols were analyzed using high performance liquid chromatography (HPLC) initially described by Hashim, Koehler, Eitenmiller, & Kvien (1993), with later modifications (Dean, Hendrix, Holbrook, & Sanders, 2009). In brief, 200 mg oil was analytically weighed and diluted with 0.8 mL of 1% (v/v) isopropanol in hexane. Twenty μL of the diluted sample was injected onto the HPLC system configured with a Luna silica column (5μ, 250 mm length, 4.60 mm I.D.) (Phenomenex, Torrance, CA) and a Waters 2487 Dual Wavelength Absorbance Detector (Waters, Milford, MA) set to 294 nm. A mobile phase of 1% (v/v) isopropanol in hexane was used at a flow rate of 1.2 mL/min. Peak areas of prepared samples were compared to authentic isomer tocopherol standards (Sigma, St. Louis, MO) diluted in mobile phase.

Sugars Analysis

Defatted peanut solids were analyzed for sugar content using a Dionex BioLC HPLC system (Dionex Corporation, Sunnyvale, CA) with a Pulsed Amperometric Detector (PAD) at a controlled temperature of 30 °C (Pattee, Isleib, Giesbrecht, & McFeeters, 2000). The column used was a Dionex PA-1, 250 mm length and 4 mm i.d., fitted with a Dionex PA-1 Guard column. In brief, analytically weighed defatted peanut meal (100 mg) was suspended in 15 ml of extraction solvent (60/25/15 (v/v/v)) methanol/chloroform/deionized water), then sonicated for 20 min. After centrifugation, the supernatant was decanted into a beaker and evaporated. Internal standards of lactose and cellobiose in water were then added to dissolve

the residue from the beaker. Fifty μL of the sample solution were then diluted to 2 mL with deionized water, vortexed and decanted to a syringe fitted with a Dionex OnGuard ® II H Filter. An external standard solution was prepared containing *myo*-inositol, glucose, fructose, sucrose, raffinose, stachyose and the internal standards. Sugars were identified by comparison with retention times of unknown samples to the known standards. Sugar contents based on dry meal weight were calculated from the peak heights relative to the internal standards and the dilution factor. The results of these analyses are presented in **Table 2.1.**

Descriptive Sensory Analysis (DSA)

Descriptive sensory panels were conducted at the USDA Market Quality and Handling Research Unit (Raleigh, NC). Roasted, blanched peanuts were homogenized to a paste using a Robot Coupe Blixer 3 mixer (Robot Coupe, Ridgeland, MS) and sealed in glass jars and stored at -26 ºC for sensory analysis. Prior to testing, samples were equilibrated to ambient room temperature. Duplicates of the roasted samples were evaluated by well-trained panelists (n>6) in randomized order. A peanut lexicon based on Johnsen et al. (1988) with modifications by Sanders et al. (1989) and Schirack et al. (2006a) was used. The Spectrum^{TM} analysis (Sensory Spectrum, Inc., Chartham, NJ, USA) method was used for training and evaluation sessions. Result of the panel evaluations are presented in **Table 2.2.**

Yield Stress

Peanut pastes stored in glass jars were tempered to 76 ± 1 °C for 15 min in a water bath and then gently shaken to remove the trapped air and to homogenize the paste. The pastes were then cooled overnight to ambient room temperature. Yield stress was analyzed using a Haake VT550 rheometer (Thermo Fisher, Waltham, MA) configured with a vane with four vertical blades that was 4mm in diameter (Daubert et al., 1998). The vane was immersed into the peanut paste to a depth of 30mm. The trails were conducted using a constant rotation rate of 1 rpm for 30.0 s and torque was measured over time. The maximum torque was recorded for yield stress calculation based on the equation, $\sigma_0 = \frac{6M}{\pi d^2(3h+d)}$, where σ_0 is the yield stress in Pa, M is the maximum torque in N·m, h and d are the immersed depth of the vane and the vane diameter in units of meters (Steffe, 1996).

Statistical analysis

Results from triplicate experiments were analyzed using JMP PRO 10.0 (SAS, Cary, NC). Factorial analysis of variance (ANOVA) and least-squares means (LSMEANs) Student's t test were conducted on the moisture content, tocopherols, sugars, and yield stress. One-way ANOVA was performed on the results of sensory analysis. A significance standard at α=0.05 was used for all tests.

Result and Discussion

Roast Temperature History

The temperature profiles of peanuts roasted at 149, 177, and 204 °C to produce a roast color of L=48.5 (medium roast color) are presented in **Figure 2.4**. The temperature profiles of 163 and 191 °C were not shown as their profiles shared high similarity with 177 and 204 °C, respectively. Temperature was recorded at the center of the top (T), middle (M), and bottom (B) layers of the peanut load, as well as inside the peanut kernels (P) in the geometric center of the load (**Figure 2.2).** The higher the temperature, the greater the observed temperature differences among the different locations of the peanut load. Air flow rate highly affected the color development. Both air flow rates of 1.0 and 1.3 m/s were used in preliminary experiments at roast temperatures of 177 and 191 °C. The faster air flow at 1.3 m/s typically reached a darker surface color when roasted for the same time, but burnt peanuts were observed at the top layer for high temperature (191 °C) roasting (**Figure 2.1.**). The air flow rate of 1.0 m/s was selected for this study as it allowed for a better uniformity of observed color development throughout the load. With up-flow air, the temperature at the bottom of the bed was higher than the middle, followed by the top of the bed temperature. The peanut temperature (P) was lower than the temperature in the middle before the change of air flow direction. Upon shifting the air flow direction to down-flow, temperature differences among different locations sharply narrowed at 149 and 177 °C, while the temperature difference remained obvious at 204 °C, but changed to the order of top>middle>bottom> peanut. The temperature difference between locations for high

temperature roasting was due to the heating air temperature decrease through the inlet to the outlet of the peanut load. Low temperature/long time roasting protocols, like those roasted at 149 °C, gave a relatively long temperature plateau and a relatively short temperature increase phase. This is consistent with a previous report that temperatures above 150 °C are used for peanut roasting in order to produce roasted peanut flavors and brown colors (Davidson, Brown, & Landman, 1999). For this low temperature long time roasting schedule, the majority of the quality changes during roasting took place during this isothermal plateau period as previously reported (Demir et al., 2002). Roasting at 177 °C and similarly at 163 °C (data not shown) resulted in a larger portion of the temperature change being in the temperature increase phase with a less wide plateau than at the lower roast temperature of 149 °C. At the higher roasting temperature of 191 °C (data not shown) and 204 °C in the same figure, the temperatures constantly increased due to shorter roasting times required. As the required roast time is much shorter and the roasting temperature is constantly rising throughout the process, the quality changes took place over a broader temperature range (Demir et al., 2002). For the trials of high temperature/short time roasting, as the entire load was not at the same temperature at all times, the internal resistance of the peanut load to heat transfer is not negligible. In this case, it was necessary to consider temperature profiles, load size, convection heat transfer coefficient of the loaded peanuts, and other factors influenced by the heat penetration to analyze heat transfer of this protocol.

Moisture Content (% dry weight) (MC)

Moisture contents (MC) of the unroasted peanut seeds and all the 15 roasted samples are presented in **Figure 2.5**. MC of the roasted samples varied from 0.74-1.60% compared to an average moisture content of 7.9% before roasting. Final roast MC correlated with both surface color ($P<0.0001$) and roasting temperature ($P<0.0001$). At a given roast temperature, the MC decreased with darker surface colors, as darker roasted samples were exposed to heat for longer times. For each roast color, the MC tended to be higher with increased temperature as shorter roasting times were used. The trends of the MC changes in this study were consistent with the findings previously reported by McDaniel et al. (2012) for peanuts roasted in a lab scale oven. Light and medium roasts at 149 °C had lower MC than the equivalent roasts at other temperatures, due to more moisture loss during longer roasting time at such low temperatures. In the temperature range of 163-204 °C, there was no statistical difference in MC among different temperatures for each roast color. In a food matrix, MC is a critical factor that influences the rate of numerous chemical and physical reactions, such as Maillard browning, lipid oxidation, microstructure damage, among others, thus it may be related to other chemical/texture properties. Correlations were examined among MC and various quality related properties as discussed below.

Tocopherols

Tocopherol contents were analyzed immediately after roasting and blanching. In the oils extracted from the samples, α- and γ- tocopherols comprised 90-93% of the total

tocopherols with levels of α- being 1.28-1.55 times higher than those of γ- for both raw and roasted oils, while β- and δ- tocopherol composed the remainder. In general, the retention of tocopherols during roasting was high, especially for medium and dark roasted peanuts, as no significant decreases in tocopherols were observed from the initial concentrations in raw peanuts. This observation is consistent with previous reports that tocopherols were very resistant to degradation during roasting and manufacturing (Chun et al., 2005; Chun et al., 2003). It was also observed that the loss of tocopherols which occurred during roasting was mainly contributed by degradation of the alpha and gamma isomers, as they were the major types of tocopherols in peanuts (Chun et al., 2005; McDaniel et al., 2012). Tocopherol contents of the extracted peanut oils were more correlated with the surface color ($p=0.0008$) than the temperature of roasting ($p=0.2238$). There was no significant difference in tocopherols among different roasting temperatures with exceptions of light and medium roasts at 149 °C (**Figure 2.6A)**. All roasts at 149 °C were comparable to the raw peanuts in tocopherols contents, probably due to negligible tocopherols losses at such low temperatures. At a given temperature, the tocopherols losses were less for darker roasted peanuts. One explanation is the enhanced antioxidant capacity at darker roasts via the formation of Maillard compounds and/or the release of previously bound polyphenolic compounds which could protect tocopherols from heat degradation during roasting (Oliviero, Capuano, Cammerer, & Fogliano, 2009; Talcott, Passeretti, Duncan, & Gorbet, 2005). Roasted peanuts showed enhanced total antioxidant capacity (McDaniel et al., 2012), which increased as the peanuts were roasted to darker colors (Davis et al., 2010).

The correlation between MC and total tocopherols (R^2=0.78) is shown in **Figure 2.6B**. This observed correlation is consistent with the previous small oven roasting study (McDaniel et al., 2012). As the peanuts were roasted to darker colors, the MC decreased, and the retention of tocopherols increased. This could be explained by the present of water accelerating tocopherol degradation during roasting (Katherine & Theodore, 1992). As tocopherol and moisture contents are both important factors influencing the stability of roasted peanuts, the established negative relationship made it possible to design a process that can increase the retention of tocopherols and simultaneously decrease the MC for a potentially longer shelf life; however, a roasting schedule that could increase the storability may compromise the flavor of roasted peanuts. It is necessary to consider the overall shelf life stability and sensory properties for a selecting a roasting protocol.

Sugars

The sugar contents after roasting are summarized in **Table 2.1** on a dry weight basis. For both raw and roasted peanuts, sucrose was the most abundant sugar, accounting for approximately 78% of total identified sugars followed by stachyose at 19%, while glucose and fructose together represented less than 0.5%. As reducing sugars are important substrates involved in Maillard browning (Oupadissakoon & Young, 1984), they are expected to decrease during roasting, but in this study, only slight changes of sugar concentrations were observed. Sugar concentrations of each sugar type did not change significantly during roasting, with the exception of the glucose and fructose in the medium roasts that were actually significantly higher than the raw and other roasts, as the sucrose was

hydrolyzed into glucose and fructose during roasting (Mason et al., 1969). As sucrose is abundant in peanuts, even minor hydrolysis can significantly increase the fructose and glucose contents without causing significant changes in sucrose contents (McDaniel et al., 2012). The joint action of browning reactions and sucrose hydrolysis together determined the final contents of fructose and glucose.

Yield Stress

A strong link between the sensory concept of spreadability and the mechanical measurement of yield stress has been established for spreadable foods (Daubert et al., 1998). Yield stress is highly temperature and time dependent, which can affect reproducibility (Cheng, 1986). The comparison of the yield stress of the samples was conducted under ambient temperature. Statistical analysis of this data indicated that the paste yield stress was correlated with surface color ($p<0.0001$) but not roasting temperature ($p=0.9297$). The correlation of yield stress and MC was low ($R^2=0.39$), indicating the moisture was not the only factor influencing the yield stress. In general, the magnitude of the yield stress of food suspensions increases with increasing particle volume fraction that is, the volume occupied by the particles in relation to the total volume, and particle-particle forces; however, the mechanisms of how these factors affect the yield stress of peanut pastes and other food suspensions are not clear (Genovese, Lozano, & Rao, 2007). In **Figure 2.7**, the paste yield stress increased as surface color became darker, which indicated a higher spreadability of the peanut paste prepared from lighter roasted peanuts. In other words, less force was needed to initiate the deformation of the lighter roasted peanut paste. Darker roasting may have

resulted in more extensive cell damage within the peanut seed, thus more denaturation of protein structure, and more release of the major substances, proteins, carbohydrates, and lipids from the cell structure during pasting (Young, Schadel, & Heertje, 1993). Also, darker roasting was considered to produce higher molecular weight polymeric compounds than lighter roasting. All these changes during darker roasting may increase the particle volume fraction and strengthening the particle interaction (Young et al., 1993). Further examination of the microstructure of the samples may lead to better insight and explanation of these results.

Descriptive Sensory Analysis (DSA)

As a primary attribute of food quality, flavor can be described and quantified through descriptive sensory analysis (DSA) (Stone et al., 1974). Intensity data for the ten sensory attributes of roasted peanuts were statistically analyzed (**Table. 2.2)**. Roasted peanutty (RP) and sweet aromatic attributes are generally associated with pleasant flavor, and thus are considered as positive attributes (Schirack et al., 2006a). Total off notes are the panel estimation of all off flavors (cardboard, earthy, painty, plastic chemical, metallic, fermented, and bitter), and are perceived as negative attributes (Schirack et al., 2006a). Roasted peanuts with the highest positive attributes and minimal off flavors including ashy were considered here to have the optimized overall flavor. Dark roast, raw beany, woody, sweet taste, bitter taste, and astringency are inherent in roasted peanuts and a certain intensity of each is needed for full peanut flavor; however, the panel found that in some cases, too high or too low intensities of these attributes contributed to unpleasant flavor. Excessive bitterness and

astringency are also considered to negatively affect the overall flavor. Statistical analysis suggested the RP intensity was significantly correlated with surface colors in the order of intensity as medium>light>dark. At medium and dark colors, the lowest RP scores were always observed at 149 ºC, but RP was not found to be different for higher temperatures (163, 177, 191, 204 °C). At light roast colors, the RP was higher at 149 and 204 °C. Another positive flavor attribute, sweet aromatic, followed the same correlations with surface color as the intensity decreased in the order of medium>light>dark ($p<0.0001$). The highest intensities of sweet aromatic were observed from medium roasts made at 163, 177, and 204 ºC. A positive correlation ($R^2=0.91$) of the two positive attributes of RP and sweet aromatic was observed, showing consistency with a previous study (Smith et al., 2014a). Dark roasted and raw beany attributes were correlated with both surface color and roasting temperature. At a given temperature, the dark roast attribute increased with the increase in roasting temperature, while the raw beany followed a reverse trend. Woody and sweet taste were more correlated with surface color than roasting temperature. In general, woody increased with darkening surface color, while sweet taste decrease with the increase in color. This study also showed, for a given temperature, bitterness and astringency increased with the surface color and there was a positive correlation between the two attributes ($R^2=0.91$). A correlation between the bitterness and astringency was also previously reported for dry roasted virginia peanuts prepared at 160 °C for varied roasting times ($R^2=0.65$) (Pattee, Isleib, Giesbrecht, & McFeeters, 2000). A previous study also observed a positive correlation between dark roast and bitterness (Schirack et al., 2006a). At each surface color, bitterness was minimized at 177 ºC, while astringency was not distinguished by roasting

temperature. The negative attributes ashy and total off notes were more closely correlated with surface color than roasting temperature. In general, at each temperature, ashy and total off notes increased with darker surface colors. At each surface color, the highest intensity of total off notes was observed at 149 °C, while the lowest was at 177 °C.

For light roasted samples, RP and sweet aromatic were affected by roasting temperature and tended to be the highest at 204 °C. For medium roasting, overall positive sensory attributes, were more intensive at 163 °C and above, as these conditions maximized the RP and sweet aromatic. Medium roasting at the lowest temperature (149 °C) diminished RP and sweet aromatic as well as increased the bitterness, astringency, ashy, and total off note, probably due to the dissipation of volatile flavor and aromatic compounds during the long roasting time. High temperatures (191 and 204 °C), achieved comparable RP and sweet aromatic intensities with 177 °C but also increased ashy and total off notes over that of 177 °C. For dark roasting at 177 °C, the highest scores of RP and sweet aromatic and lowest intensities of ashy and total off notes were produced. Of all the treatments, the highest RP and sweet aromatic intensities were produced at 163 °C/24.5min, 177 °C /15min, and 204 °C/9min for the medium roast samples and the off flavor intensity scores were not significantly different between the first two treatments. These two treatments were considered optimized for the roasting process. At 177 °C, the time required to achieve the same color was less than that at 163 °C, thus the treatment of 177 °C is superior to 163 °C considering its higher hourly capacity. The optimized process (177 °C /15min) determined by this study regarding flavor properties was very close to the optimal protocol (175

°C/15min) in the laboratory oven roasting study that achieved the highest intensities of roasted flavor (Baker et al., 2003). A recent study also suggested medium runner peanuts with same color had different volatile levels, and the highest level of volatiles was achieved by oven roasting at 177 °C for 15min; however, a darker color (L*=49-52, corresponding to Hunter L=42-45) was reached than that in our roasting using the same temperature /time combination, probably due to the differences in peanut characteristics (Smith, & Barringer, 2014b).

Conclusions

This study demonstrated that the compositional properties, moisture, sugars, tocopherols, and yield stress were highly related to surface color, especially within the temperature range of 163-204 °C; however, the sensory properties were correlated with both surface color and roasting temperature. Optimized flavor was achieved for medium roasted peanuts. As the well-controlled systems of this roaster has the potential to minimize the operational differences between batch and continuous system, the information derived in this study is useful to scale up these parameters into industrial roasting, aiming to optimize quality of roasted peanuts.

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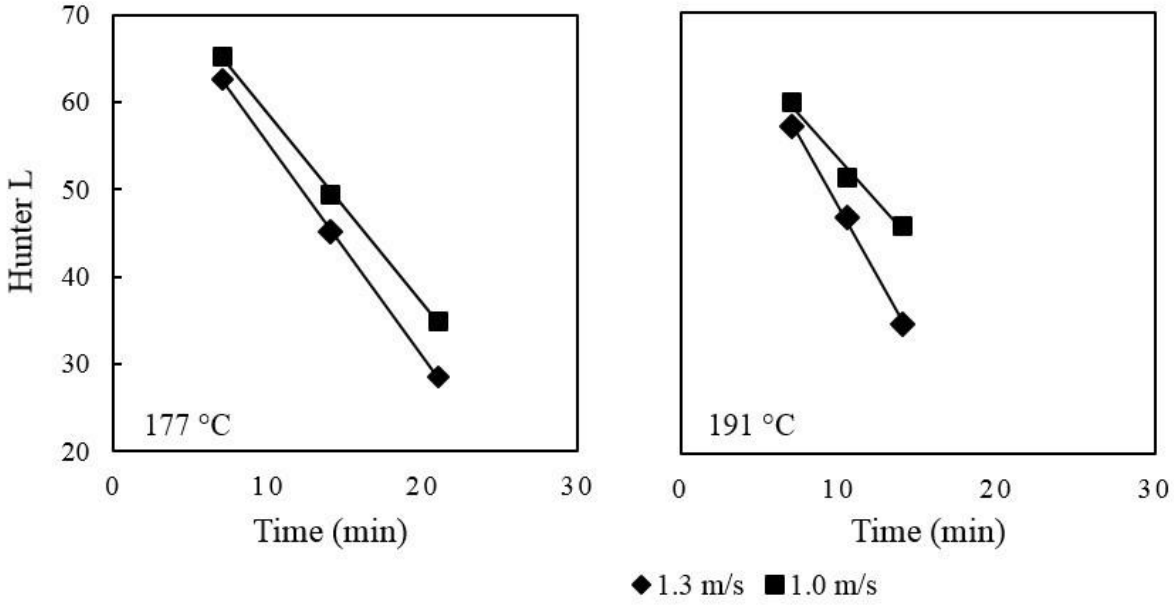

Figure 2.1. Surface color (Hunter L values) of peanuts roasted at 177 and 191 °C for different times at air flow rates of either 1.3 m/s or 1.0 m/s.

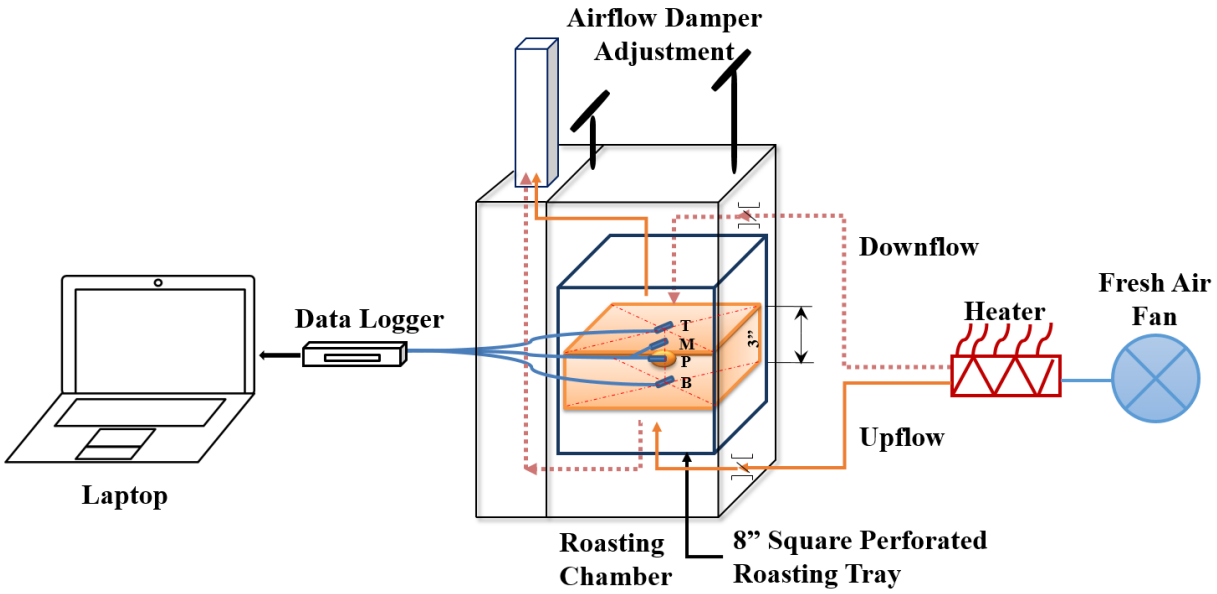

Figure 2.2. A schematic of the industrial, multi-zone, belt roaster simulator used in this study. The roasting tray had a perforated bottom. Four thermocouples were configured in the roasting tray at the center of the top, middle, and bottom locations of the product.

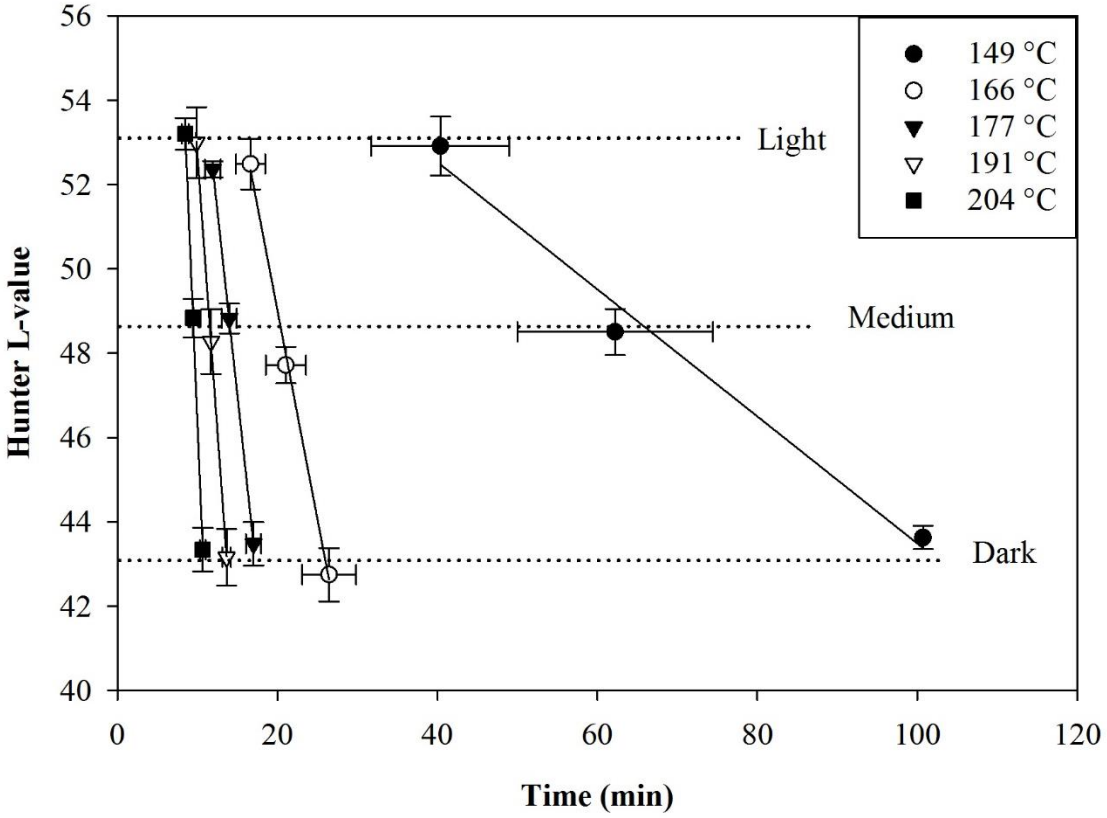

Figure 2.3. Surface Hunter L-values of peanuts roasted at 149, 163, 177, 191 and 204 °C for different times, all at an air flow rate of 1.0 m/s. Solid lines represent best linear fits of data. Dashed, horizontal lines represent Hunter L-values associated with surface colors (Light=53, Medium=48.5, Dark=43).

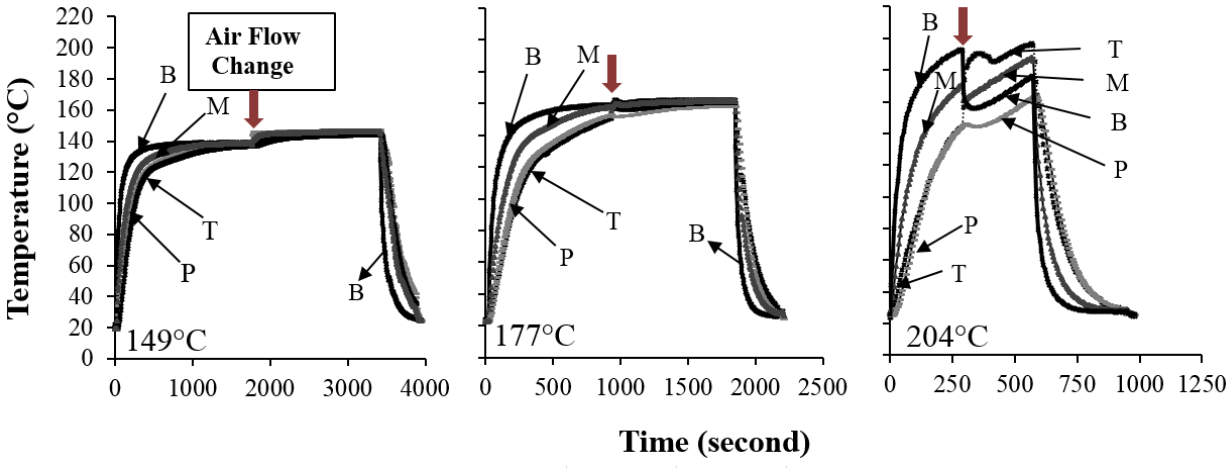

Figure 2.4. Temperature history from within the product bed for peanuts roasted at 149, 177, and 204 °C to a medium color. Thermocouples were centered at the top (T), middle (M), and bottom (B) locations of the product bed. A thermocouple was also imbedded within a peanut (P) and placed at the center of the roasting tray. The bold arrows represent the point when the air flow direction was changed from bottom-up to top-down.

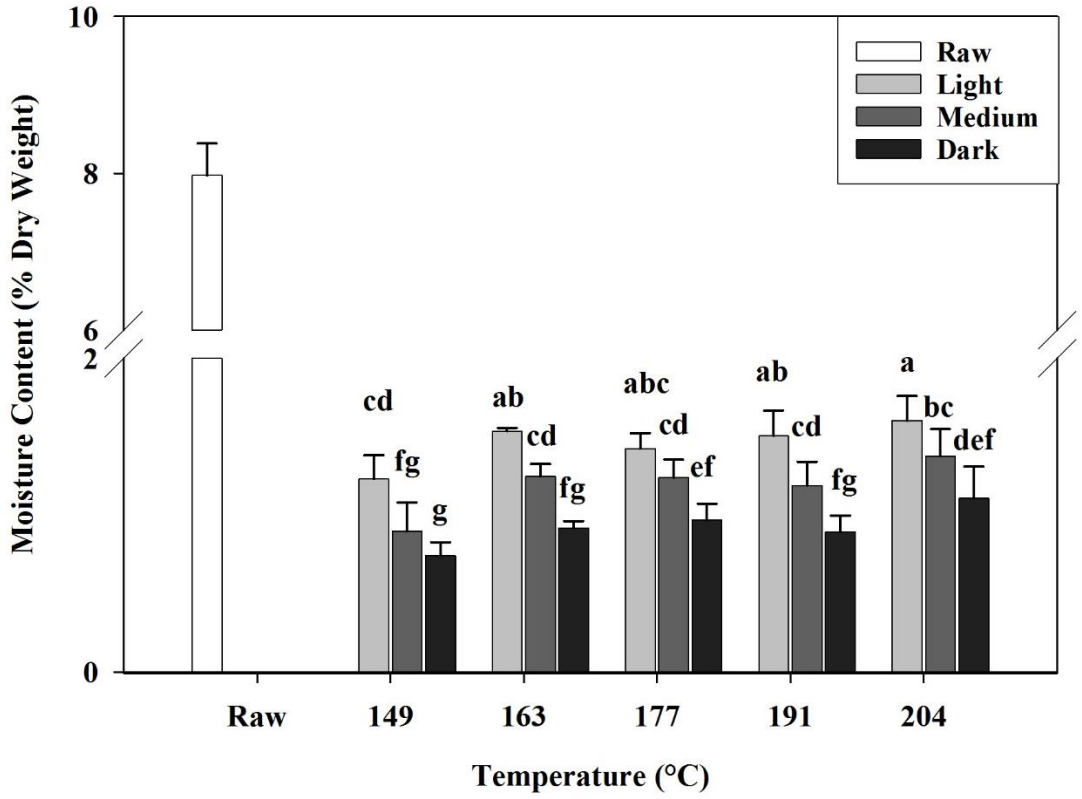

Figure 2.5. Moisture content (% dry weight) of unroasted peanut seed (raw) and peanuts roasted to the three target surface colors as a function of roasting temperature. Bars represent means ± standard deviations. Bars labelled with different letters are significantly different ($p<0.05$).

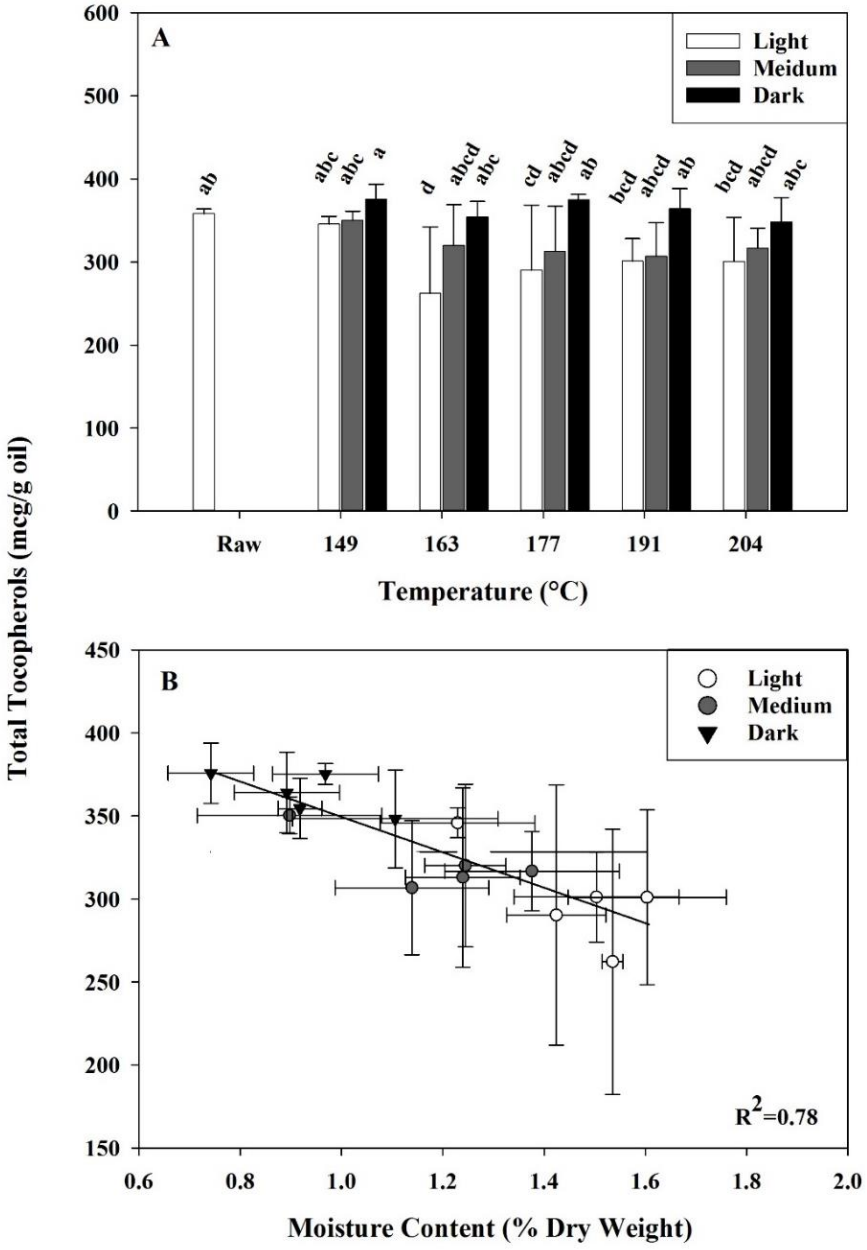

Figure 2.6. Total tocopherol content (μg/ml) of raw and roasted peanuts at three surface colors as a function of roasting temperature (A) and total tocopherol content (μg/ml) versus moisture content (% dry weight) of roasted peanuts (B). Bars and points represent means ± standard deviations. Bars labelled with different letters are significantly different ($p<0.05$).

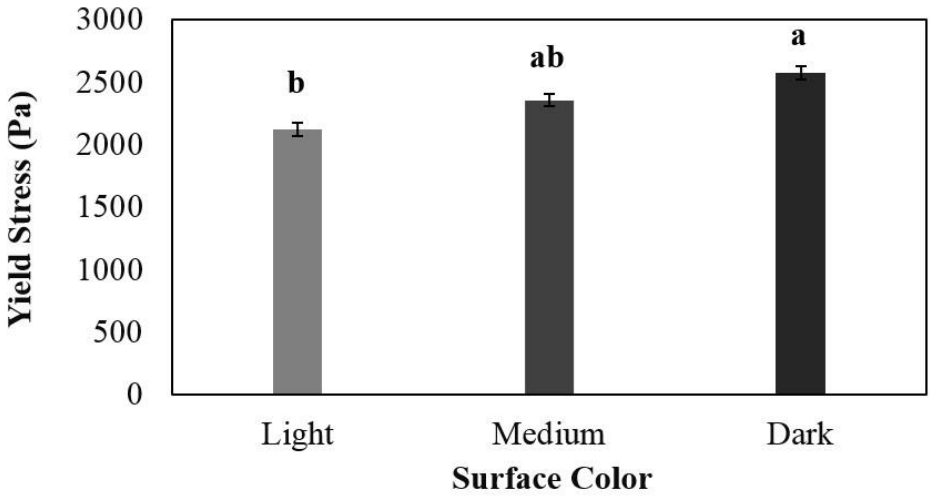

Figure 2.7. Yield stress (Pa) of pastes prepared from roasted peanuts at the three target surface colors. All roast temperature treatments are included for each target color. Bars represent means ± standard deviations. Bars labelled with different letters are significantly different ($p<0.05$)

Table 2.1. Mean values ± standard deviations of sugar concentrations (µg/g dry meal) of raw peanuts and peanuts roasted to equivalent colors averaged across all roast temperatures. Values followed by different letters are significantly different ($p<0.05$) in the same roast colors.

	Inositol	**Glucose**	**Fructose**	**Sucrose**	**Raffinose**	**Stachyose**
Raw	285±19a	96±24b	33±29b	37617±1778a	1202±120a	9153±1267a
Light	279±27a	107±21b	57±23b	36589±3254a	1107±156a	8606±842a
Medium	297±41a	135±25a	78±18a	37893±6398a	1125±160a	8548±887a
Dark	288±15a	103±22b	63±31ab	37033±1591a	1200±103a	9186±815a

Table 2.2. Mean values ± standard deviation of descriptive sensory analysis attributes for peanut paste of equivalently roasted peanut based on a 15 point sensory Spectrum® scale. Values followed by different letters within the same column are significantly different ($p<0.05$).

	T (°C)	RP	Sweet Aromatic	Dark Roast	Raw Beany	Woody	Sweet Taste	Bitter	Astringency	Ashy	Total Off Note
	149	4.9±0.6^{cde}	3.1±0.3^{cde}	2.4±0.6^{g}	2.5±0.5^{bc}	2.9±0.4^{f}	2.6±0.3^{abc}	2.0±0.4^{gh}	1.1±0.2^{cde}	0.0±0.2^{f}	0.3±0.7^{def}
	163	4.5±0.7^{f}	3.0±0.5^{de}	2.1±0.6^{h}	2.9±0.5^{a}	2.8±0.4^{f}	2.6±0.3^{ab}	2.0±0.5^{gh}	1.0±0.2^{de}	0.0±0.2^{f}	0.3±0.7^{ef}
L	177	4.7±0.6^{def}	3.0±0.4^{de}	2.2±0.6^{gh}	2.7±0.6^{ab}	2.8±0.5^{f}	2.7±0.3^{a}	1.9±0.4^{h}	1.0±0.1^{e}	0.0±0.1^{f}	0.1±0.3^{f}
	191	4.6±0.7^{f}	3.0±0.5^{def}	2.2±0.7^{gh}	2.7±0.6^{ab}	2.8±0.5^{f}	2.7±0.3^{ab}	1.9±0.4^{gh}	1.0±0.1^{de}	0.1±0.3^{f}	0.1±0.4^{ef}
	204	5.0±0.3^{bc}	3.2±0.3^{abc}	2.6±0.5^{f}	2.4±0.4^{cd}	2.9±0.4^{ef}	2.7±0.3^{a}	2.0±0.4^{gh}	1.0±0.1^{cde}	0.0±0.3^{f}	0.2±0.5^{ef}
	149	4.9±0.3^{cd}	3.1±0.4^{cde}	3.2±0.6^{d}	1.9±0.6^{fg}	3.2±0.2^{bc}	2.3±0.3^{e}	2.5±0.5^{cd}	1.1±0.3^{bc}	0.4±0.6^{de}	1.4±1.6^{bc}
	163	5.2±0.5^{ab}	3.3±0.3^{ab}	3.0±0.4^{e}	2.1±0.5^{ef}	3.0±0.3^{cd}	2.5±0.3^{c}	2.2±0.3^{ef}	1.1±0.1^{cde}	0.2±0.4^{ef}	0.3±0.6^{def}
M	177	5.3±0.5^{a}	3.3±0.3^{ab}	2.8±0.4^{ef}	2.3±0.4^{de}	3.0±0.3^{de}	2.5±0.2^{bc}	2.1±0.3^{fg}	1.1±0.2^{cde}	0.0±0.2^{f}	0.1±0.4^{f}
	191	5.3±0.4^{a}	3.2±0.4^{bcd}	3.3±0.6^{d}	1.7±0.7^{h}	3.2±0.3^{b}	2.3±0.2^{de}	2.4±0.3^{de}	1.1±0.2^{bcd}	0.6±0.8^{d}	0.6±0.8^{d}
	204	5.3±0.5^{a}	3.3±0.3^{a}	3.2±0.3^{d}	1.8±0.5^{gh}	3.1±0.2^{bcd}	2.4±0.3^{cd}	2.2±0.3^{ef}	1.0±0.2^{cde}	0.4±0.6^{e}	0.5±0.7^{de}
	149	4.2±0.6^{g}	2.7±0.4^{g}	4.6±0.6^{a}	0.4±0.6^{k}	3.5±0.5^{a}	1.9±0.3^{g}	3.3±0.7^{a}	1.3±0.4^{a}	1.63±0.7^{a}	2.3±1.2^{a}
	163	4.5±0.7^{f}	2.9±0.4^{f}	4.2±0.7^{b}	0.8±0.7^{j}	3.5±0.4^{a}	2.1±0.3^{f}	2.9±0.6^{b}	1.3±0.4^{a}	1.38±0.7^{b}	1.6±0.8^{b}
D	177	4.7±0.6^{ef}	3.1±0.3^{cde}	3.9±0.7^{c}	1.2±0.7^{i}	3.4±0.3^{a}	2.1±0.2^{f}	2.6±0.4^{c}	1.2±0.3^{ab}	1.10±0.8^{c}	1.3±0.9^{c}
	191	4.6±0.5^{f}	3.0±0.4^{ef}	4.0±0.6^{bc}	0.9±0.8^{j}	3.4±0.4^{a}	2.1±0.3^{f}	2.8±0.5^{b}	1.2±0.3^{ab}	1.30±0.7^{bc}	1.3±1.0^{bc}
	204	4.6±0.7^{f}	3.0±0.5^{ef}	4.2±0.7^{b}	0.9±0.8^{j}	3.4±0.3^{a}	2.1±0.3^{f}	2.9±0.7^{b}	1.2±0.4^{a}	1.45±1.0^{ab}	1.6±1.2^{b}

CHAPTER 3

Kinetics of Color Development of Peanuts during Dry Roasting using a Batch Roaster

Kinetics of Color Development of Peanuts during Dry Roasting using a Batch Roaster

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Abstract

The kinetics of color development during peanut roasting were investigated at roasting temperatures from 149 to 204 °C. These produced roasted peanuts with surface Hunter L color values of 25 to 65. Preliminary and equivalent roasting trials were conducted using a batch roaster simulating the parameters of an industrial continuous belt roaster. Hunter L values of peanuts were fitted well to either zero, first, or second order models (MEAN R^2>0.95), whereas the best fit for Hunter b values was first order model (R^2=0.93). The activation energies calculated from the first order model of the L and b values ranged from 1.0-1.1×10^8 J/kg mol. High temperature roasting decreased the uniformity of color development from seed to seed and throughout the kernel. A z_c value of 37.6 °C was calculated using the first order model of the L values. The cook values were 11.45-23.58, 24.51-31.63, and 41.45-57.52 minutes for light, medium, and dark roasting, respectively.

Practical Applications

Industrially, the validation of the kinetic model simplifies processing design and product quality control of food products. The kinetics of color development of roasted peanuts have not been reported in previous studies. The value of the model is to be able to predict the roast color of peanuts under known time-temperature combinations, as well as to calculate the roasting time required at a certain roasting temperature to achieve a desired color. The data derived from this pilot plant scale roasting study can be scaled up to industrial continuous roasting, as the parameters used in this study were well controlled and simulated the common settings of industrial roasting.

Introduction

A broad definition of food quality is meeting the expectation of the consumer (van Boekel, 2008). One challenge for food manufacturers and engineers is to provide a link between quality requirements and process design. Instead of fuzzy control of food processing with trial and error, a systematic model that simulates the industrial process that can be validated at the lab and/or pilot plant scale level will provide more precise processing. This will allow for better control of food quality attributes, such as color, flavor, textural changes, and microbial kill (Holdsworth and Simpson, 2007, van Boekel, 2008, van Boekel et al., 2010). Color is among the most important quality attributes of roasted peanuts. Industrially, peanuts are typically roasted to a specified color, as these measurements are rapid and color is well correlated with quality optimization, including flavor (Mason et al., 1966, Pattee et al., 1991). Equivalent colors of roasted peanuts have been achieved by different roast time-temperature schedules (McDaniel et al., 2012). Color of roasted peanuts can be measured with a colorimeter using Hunter Lab or CIELAB L* a* b* coordinates (Pattee et al., 1991). Of these, the L or L* value is the most commonly used coordinate to monitor the color change during roasting due to its high sensitivity to temperature and duration of heating (Demir et al., 2002). For roasted peanuts, with L* values in the range of 52-65, an empirical equation of L = L*-7 can be used to convert the values between the two color systems (Pattee et al., 1991). The ideal color for peanut paste prepared from roasted peanuts has a Hunter L value in the range of 51-52 (Pattee et al., 1991) and for blanched peanut kernels the range is 47.5-49.5 (McDaniel et al., 2012). Additionally, Hunter L values of 52-54 and 42-44 were considered light and dark roasts respectively for blanched roasted

peanut kernels (McDaniel et al., 2012). The pigments contributing to the characteristic golden brown color of roasted peanuts are mainly produced via non-enzymatic browning reactions, such as Maillard browning and caramelization (Corzo-Martínez et al., 2012). The calculation of the reaction kinetics of color change determines the processing time required to achieve desired colors at a given temperature, as well as predicts the color change at a designated time-temperature combination (Demir et al., 2002). The reaction kinetics of color change for peanuts during roasting at specific temperatures have not been reported, but those of tree nuts and coffee beans have been reported to be represented by either zero order or first order kinetics within a certain temperature range (Kaftan, 2012, Ozdemir and Devres, 2000, Wang and Lim, 2014). Whereas, a second order reaction was also found for color change and roasting time of roasted coffee beans (Somporn et al., 2011). For industrial applications, the validation of the model formula aids in process design and product quality control.

An important usage of kinetics is to optimize product and process design. Food safety and food quality are two aspects to be considered for thermal process design. As there is a difference in temperature sensitivity between food quality factors and microorganisms, the temperature dependency differs in chemical reactions and microbial inactivation (van Boekel, 2008). The process should be designed by selecting a combination of times and temperatures that could simultaneously achieve sufficient microbial kill and acceptable quality change (Goldblith, 1961, Singh and Heldman, 1984). For peanut roasting, *Salmonella* reduction and color development are the primary considerations for process design (Poirier et al., 2014). Previous work using the same roaster as the one used in this study proved that peanuts roasted to a color darker than the light roast (Hunter L=53)

achieved sufficient microbial kill of a *Salmonella* surrogate, *Enterococcus faecium*, which is slightly more heat tolerant than *Salmonella* (Poirier et al., 2014). Except for safety, color development is the most important factor of concern for peanut roasting protocol design. The kinetic parameter, cook value, is defined as the time of processing at a reference temperature that yields the same degree of quality change as in the process under study (Mansfield, 1962). This allows for comparison of the color development effects of different peanut roasting processes by relating each process to the reference process (Mansfield, 1962).

Although roast color of peanuts has been widely used as a rapid indicator of peanut quality in the food industry, the kinetics of color development of roasted peanuts has not been scientifically reported. In this study, the kinetics of color changes during peanut roasting were investigated for a temperature range of 149-204 °C producing Hunter L values of 25-65. The Arrhenius relationship was evaluated for the color coordinates in the Hunter Lab system to calculate the activation energy of the browning reaction. The validated model derived from this study can be used to design a process that achieves the desired color of roasted peanuts.

Materials and Methods

Materials

Jumbo grade size (>21/64 using a slotted screen) peanuts of the Georgia 06G cultivar, a large-seeded, runner-type variety, were obtained from the 2012 US harvest provided by National Peanut Research Lab (Dawson, Georgia) . The peanuts had been grown, harvested, cured, shelled, sized, and stored utilizing standard industry practices prior to delivery to the USDA ARS Market Quality & Handling Research Unit (Raleigh, NC). Shelled peanuts were stored in sealed containers under refrigeration until immediately prior to roasting, at which time samples were removed and tempered to ambient temperature. Studies were completed within 18 months of harvest. The average moisture content of the raw peanuts prior to roasting was 7.9% determined by loss on drying in a forced air oven at 130 °C (Young et al., 1982).

Peanut Roasting

Industrially, continuous dry roasters are used which consist of a perforated steel belt that conveys the peanuts through the roaster. The continuous roaster has one or more roasting units, with each unit consisting of up-flow and down-flow zones. This type of continuous dry roaster is divided into independent roasting units, and an up-flow cooling zone. The pilot plant scale batch roaster used in this study was identical to that described by Poirier and others (2014). The parameters used here (airflow rate, airflow direction, bed

depth, and air temperature) were specifically selected to simulate the industrial continuous dry roaster conditions as was previously described (Poirier et al., 2014). The air flow rate was set to 1.0 m/s and the bed depth was fixed at 76.0 ± 2.5 mm for all roasting treatments. The air flow direction was changed from up-flow to down-flow at the half-way point of the roasting time, which is the most common settings for each roasting unit of a continuous belt dry roaster (Poirier et al., 2014). The dimensions of the roasting tray and the locations of the thermocouples in the pilot plant dry roaster are shown in **Figure 3.1A**. Four thermocouples were configured in the roasting tray at the center of the top, middle, and bottom locations of the peanuts in the tray (indicated by T, M, and B, respectively), and inside of peanut seeds that were located at the center of the middle location (P). Unblanched peanuts were roasted in triplicate in the pilot plant scale roaster. Immediately following roasting, the roasting tray containing peanuts was placed onto a forced air blower (**Figure 3.1B**) and peanuts rapidly cooled to ambient temperature. The temperature history of equivalently roasted samples was recorded by a data logger and the temperature profiles were plotted as shown in **Figure 3.2**.

Preliminary roasting trials were conducted at 149, 163, 177, 191, and 204 ºC for various times to reach surface Hunter L values of 25-65. The time used for the preliminary roasting and the resulting L values are summarized in **Figure 3.3**. Equivalent roastings were conducted at the same 5 different temperatures to achieve Hunter L values of 53±1, 48.5±1, and 43±1, corresponding to light, medium, and dark roasts, respectively. Roasting time was determined by linear regression of the Hunter L value versus roast time curves derived from the preliminary roasting trials.

Color Measurement

The surface colors of the blanched peanuts and peanut pastes were measured using a Hunter Lab DP-9000 colorimeter (HunterLab, Reston, VA). Peanut paste was prepared by grinding the equivalently roasted, blanched peanuts using a Robot Coupe Blixer 3 food processor (Robot Coupe, Ridgeland, MS). To express the oils, peanuts were coarsely ground, wrapped with cheese cloth, and compressed using a Carver press (Carver, Wabash, IN) at 8000 kilograms for 15 minutes. Expressed oil color was measured using a Hunter Lab Ultrascan XE colorimeter (HunterLab, Reston, VA). Single seed color of 100 blanched kernels from equivalent roasts was measured using the Hunter Lab scale using a Data Processor DP-301 Chroma Meter (Minolta Camera Co., Ltd. Japan). The percentage of the single seeds with Hunter L values within each interval of L=2.5 was calculated by JMP Pro 10.0 (SAS, Cary, NC) and described using color distribution charts (**Figure 3.6**).

Model Fitting

The kinetics equations are simplified to **Equations 1-3** for the zero, first, or second order reactions, where c is the data of the attributes of interest, and k_n is the reaction rate, with n being the reaction order. To analyze the kinetics of color development, the equations were fitted to Hunter L, a, and b values of roasted peanuts prepared in the preliminary and equivalent roasting trails.

$$c = c_0 - k_0 t \quad (1)$$

$$c = c_0 e^{-k_1 t} \quad (2)$$

$$1/c_0 - 1/c = -k_2/t \quad (3)$$

Arrhenius Relationship

A mathematical formula was used to describe the temperature dependence of reaction rates as described in **Equation 4**, which can be linearized to **Equation 5**, where A is the pre-exponential factor (also called collision number or frequency number) in the unit of s^{-1}, E_a is the activation energy in units of J/kg mol, and R and T are the universal gas constant (R=8314 J/kg mol K) and absolute temperature in units of degrees of Kelvin. The activation energy (E_a) is the minimum energy which molecules must have for the reaction to occur. The exponential term of $\exp\left(-\frac{E_a}{RT}\right)$ is the fraction of molecules that collectively have the minimum energy (Goldblith, 1961, Singh and Heldman, 1984).

$$k = Ae^{-\frac{E_a}{RT}} \quad (4)$$

$$\ln k = \ln A - \frac{E_a}{RT} \quad (5)$$

Cook Value

The "lethality like" value for food quality is designated as cook value, abbreviated as C in **Equation 6**, where z_c describes the temperature change that would increase the reaction rate by one log within the temperature range of the conducted roasts (Mansfield, 1962). Cook

value is expressed in units of minutes. T is the air temperature (°C) at the middle location (M) as described in **Figure 3.1.** T_{ref} is the reference temperature, which was designated as 150 °C for this study. This reference temperature was selected to be within the range of 149-204 °C, and has been reported as the minimum temperature needed to produce roasted peanut flavors and begin the browning reactions (Davidson et al., 1999).

$$C = \int_0^t 10^{(T - T_{ref})/z_c} \, dt \quad (6)$$

Statistical Analysis

Results from triplicate experiments were analyzed using JMP PRO 10.0 (SAS, Cary, NC). One-way ANOVA was performed on the results of the color development. Normal distribution was fitted to single seed color of roasted peanuts, and the goodness of fit was tested using Shapiro-Wilk W test (Shapiro and Wilk, 1965). A significant standard α=0.05 was used.

Results and Discussion

Temperature History

Peanuts were equivalently roasted at five temperatures to achieve three equivalent blanched seed surface colors (light, medium, dark), resulting in 15 treatments. To achieve the equivalent color, either a longer time-lower temperature or a shorter time-higher

temperature protocol was used. The temperature history was monitored using thermocouples installed inside the roasting load (**Figure 3.1**), and the temperature profiles were plotted as shown in **Figure 3.2**. Long time-low temperature, like those roasts at 149 °C, can be considered more of an isothermal process as the majority of the roasting occurs at a constant temperature with a relatively short "come-up" phase; however, short time-high temperature roasting at 163, 177, 191, and 204 °C, featured a relatively long "come-up" phase throughout the roasting, and these were considered as non-isothermal processes (Demir et al., 2002). At the highest temperature of 204 ºC, the roast color developed very fast and the temperature history curve featured a very sharp increase throughout the entire heating process, indicating the majority of the roasting was not under the programmed temperature. The temperature history of the middle layer (M) was used to calculate the cook values listed in **Table 3.5**.

Kinetics of Color Development

Color development during peanut roasting was previously confirmed to be caused by non-enzymatic browning (Moss and Otten, 1989). In this study, one-way ANOVA statistics suggested both roasting time and temperature affected the color coordinates of Hunter L, a, and b values ($p<0.05$). Previous studies reported the color development of tree nuts and coffee beans could be represented by either zero order or first order reactions within a certain temperature range (Kaftan, 2012, Ozdemir and Devres, 2000, Wang and Lim, 2014), with certain exceptions represented by second order (Somporn et al., 2011). The color data of roasted peanuts prepared in both preliminary and equivalent roasting trials was fitted into zero (**Table 3.1**), first (**Table 3.2**), and second order (**Table 3.3**) models. In this study, a

correlation efficient (R^2) higher than 0.9 and a low mean square error (MSE) value was required for a good fit. For Hunter L values, the data fitted well with all three models with a MEAN R^2 higher than 0.95. For the roasts with final L values in the range of 25-65, as the roasting temperature increased, the time required to achieve the equivalent Hunter L value decreased, which was also demonstrated by the increased reaction rate calculated. Among the three models, zero order and first order models showed advantages over second order as they provided even higher R^2 (>0.98) and lower MSE values ($<7\times10^{-5}$). Also, for the second order model, the R^2 tended to decrease with the increased roasting temperature, indicating the L values deviated from this model as the temperature increased. For the color coordinate Hunter a values, the highest MEAN R^2 from all three models was 0.8, indicating none of the three models was a good fit for the Hunter a values; however, both zero and first order models tended to show increased R^2 with temperature increase, indicating the data fitted well into zero and first order at the higher temperatures (191 and 204 °C). For color coordinate b, the best fit was observed for the first order model with a MEAN R^2 of 0.93 and a very low MSE value of 6×10^{-3}; however, the data at 191 °C was an outlier with an R^2 of 0.78. The zero and second order models did not fit for Hunter b values with low MEAN R^2 (<0.46) and a relatively higher MSE than first order. Overall, the L values were the most successfully modeled over the temperature and color range of this study. As a coordinate for lightness of a product, L value is analogous to the color normally measured by food engineers in determining the degree of roasted products, thus it is preferred to Hunter a and b values for monitoring color development during peanut roasting (Moss and Otten, 1989).

Calculation of Activation Energy

Activation energies can be determined when the quality factor of interest fits the first order reaction model. As both Hunter L and b values were fitted well into the first order models, the Arrhenius equation (**Equation 4 and 5**) could be used for activation energy calculation. The Arrhenius temperature dependence of the reaction rate constants (k_1) of Hunter L and b values was plotted by ln (k_1) versus 1/T (**Figures 3.4** and **3.5**) according to **Equation 5**. The k_1 for both L and b values followed the Arrhenius relationship, giving R^2 values of 0.94 and 0.93, respectively. From the slope ($-\frac{E_a}{R}$) of the straight lines plotted, the activation energies to initiate the Hunter L and b value changes calculated from the first order model were 1.0×10^8 J/kg mol and 1.1×10^8 J/kg mol. The activation energies calculated from the L and b values were equivalent in magnitude, revealing the minimum energy required to initiate the browning reaction is $1.0\text{-}1.1\times10^8$ J/kg mol.

Single Seed Color Distribution

The single seed Hunter L values of roasted peanuts have been previously reported to present a perfect symmetrical distribution with the mean L value nearly close to the average seed surface color (Sanders and Bett, 1995). The probability distribution of single seed Hunter L values (n=100) for equivalently roasted peanuts was examined for normal distribution (**Figure 3.6**). Statistical analysis indicated all equivalent roasts were well fitted into the normal distribution, except the light roast at 204 °C ($p<0.001$). The light roast at

204 ℃ showed a left skewed distribution with several very dark seeds with relatively low L values. The mean L values (μ) of all equivalently roasted samples were comparable to the bulk seed surface L values. For each roast intensity of light, medium, and dark, there was no significant difference in color distribution; however, the standard deviation (σ) for roast intensity tended to be maximized at the high temperatures of 191 and 204 °C. High temperature (191 and 204 ℃) roasting seemed to present broader distributions of single seed color, indicating those high temperature roasts were less uniform in color development throughout the load. Previous work proved that as the roast time for high temperature roasting is much shorter while the temperature is constantly high, the peanut temperature at different locations will keep rising at different rates through the process and the temperature differences are not negligible at different locations in the load (Demir et al., 2002). The temperature differences within the roasting load will cause the non-uniformed color development throughout the load. In the protocol of short time-high temperature roasting, it was necessary to consider the resistance to heat flow in order to analyze heat transfer when air is the heating medium.

Surface Color, Paste Color, and Oil Color

In this study, equivalent roasts were achieved by roasting peanuts to specific average surface colors, but the color was not always uniformly developed throughout the kernels from interiors to exteriors. To understand the color uniformity throughout the kernels from outer surface to interior, the differences in the surface colors and paste colors were examined

(**Table 3.4**). The homogeneous nature of the paste ensured color was equilibrated throughout the roasted seed. If the color is uniform throughout the roasted kernels, the Hunter L values of surface and paste should be equivalent. It was expected that the interior color of roasted kernels would be lighter than the outer surface as the interior temperature is usually lower than the outer during roasting due to the heat resistance, but this is not always the case (Sanders and Bett, 1995). For some roasts, during the cooling process, if the exterior of the kernel is cooled very fast while the interior stays at a substantially high temperature, the interior could be darker than the outer surface. Statistical analyses suggested for the medium and dark roasts at 191ºC and 204 ºC, the paste color was significantly darker than the surface color, which indicated the roasted peanuts at such high temperatures had darker interiors than the outer surfaces. For the dark roast at 149 ºC, the paste color was darker than the surface, indicating the long time-low temperature roasting also resulted in a darker interior than the outer surface. The reason for the darker interior color was not clear but one hypothesis is, during cooling, the seed surface cooled much faster than the inside, allowing the roasting to continue for a longer time on the inside than on the surface. All roasts at 149, 163, and 177 ºC showed no significant differences between the surface color and the paste color, suggesting better uniformity of color development throughout the kernels.

The Hunter L values of the expressed oils were relatively high with values of 79-87 when compared to the surface colors of the roasted peanuts and the resulting paste colors due to the relatively high transparencies of the expressed oils as compared to the whole products. In general, the Hunter L values of the oils expressed from the roasted peanuts decreased as the roast intensity increased. This indicated the oil color darkened with increased roast

surface color. The increase in L value of the expressed oils can be attributed to the presence of Maillard browning products in the oil or due to polymerization of the oils as a result of the heat of roasting. As also reported in Table 3.4, the L values of the expressed oils decreased that is the oils darkened as the roast intensities of the peanuts increased. The oils from the dark roasted peanuts were darker than the oils from the medium roast, which were in turn darker than the light roasted ones. However, the Hunter L values of the expressed oils were not significantly different within the same roast color intensity, regardless of the time-temperature conditions required to achieve the intensities of light, medium, and dark roasts.

Cook Value

Cook value, which is defined as time of process at a reference temperature that yields the same amount of quality change as in the process under consideration, is calculated according to **Equation 6** when the reaction fits the first order model (Mansfield, 1962). Cook value is a relative value that should always be reported with the reference temperature, which must be in a specific temperature range (Holdsworth and Simpson, 2007). Using the Hunter L values determined for the roasted peanuts over the range of 149-204 °C, log k_1 was plotted over the roasting temperature. The z_c value derived from this study was consistent with a previous report that the z_c value of color degradation during food thermal processing was usually in the range of 17-57 °C (Holdsworth and Simpson, 2008). In this study, an arbitrary reference temperature of 150 °C (T_{ref}) was used as it was within the range of the applied roasting temperatures of 149-204 °C. This has been reported as the minimum temperature to produce roasted peanut flavors and browning colors (Davidson et al., 1999).

The cook values calculated are reported in **Table 3.5**. For each temperature, the cook value increased with increased roasting intensity. Theoretically, the cook value should be comparable for equivalent roasting. In this study, the cook values were 11.45-23.58, 24.51-31.63, and 41.45-57.52 minutes for light, medium, and dark roasting, respectively. One explanation for the deviation is the color was measured from the overall surface color of a bulk sampling of the roasted peanuts, while the temperature information used for the cook value calculation was derived from the air temperature at the center of the load. Another explanation is the color development in this study was not an ideal first order reaction. The ranges of the cook values determined here can assist manufacturers of peanut products to understand the extent of color development of roasted peanuts prepared from a process with known temperature profiles.

Conclusions

This study determined the kinetics of different color coordinates of the Hunter Lab system was best described by different models. Hunter L values of roasted peanuts fitted well with either zero, first, or second order models, while Hunter a and b values best fitted into zero order and first order, respectively. The activation energies calculated from the L and b values revealed the minimum energy required to initiate the browning reaction is 1.0-1.1×10^8 J/kg mol. The cook values were 11.45-23.58, 24.51-31.63, and 41.45-57.52 minutes for light, medium, and dark roasting, respectively. High temperature roasting reached the equivalent color using less time than the low temperatures, but it compromised the

uniformity of the resulting colors throughout the load and the kernels. The kinetics and color distribution information derived from this study can be used to design a peanut roasting process for the same peanut cultivar and same roasting settings as was used in this study, when the goal is to achieve similar colors and to meet the same quality requirement. The kinetics cannot be directly applied to peanuts of different cultivars as the color development is sensitive to other factors other than roasting time and temperature. Even slight differences in peanut chemical compositions, such as moisture content, or sugar content, may cause deviation from the desired color. For accurate process design, peanut variety, maturity, and post-harvest processing must also be carefully considered to achieve the desired roast peanut color.

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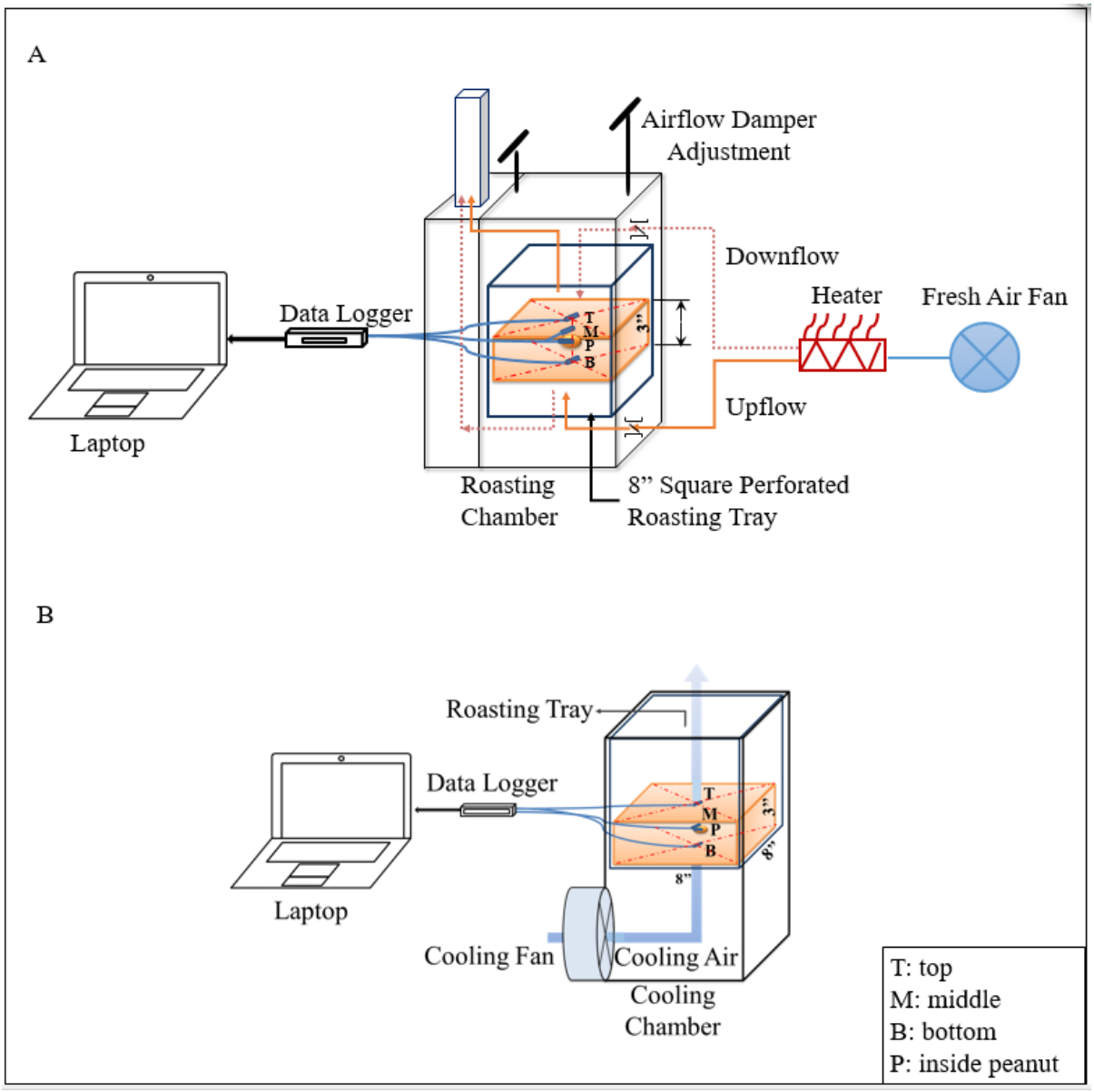

Figure 3.1. Schematic drawing of the roaster configuration. Figure 3.1A represents the roasting unit; Figure 3.1B represents the cooling unit.

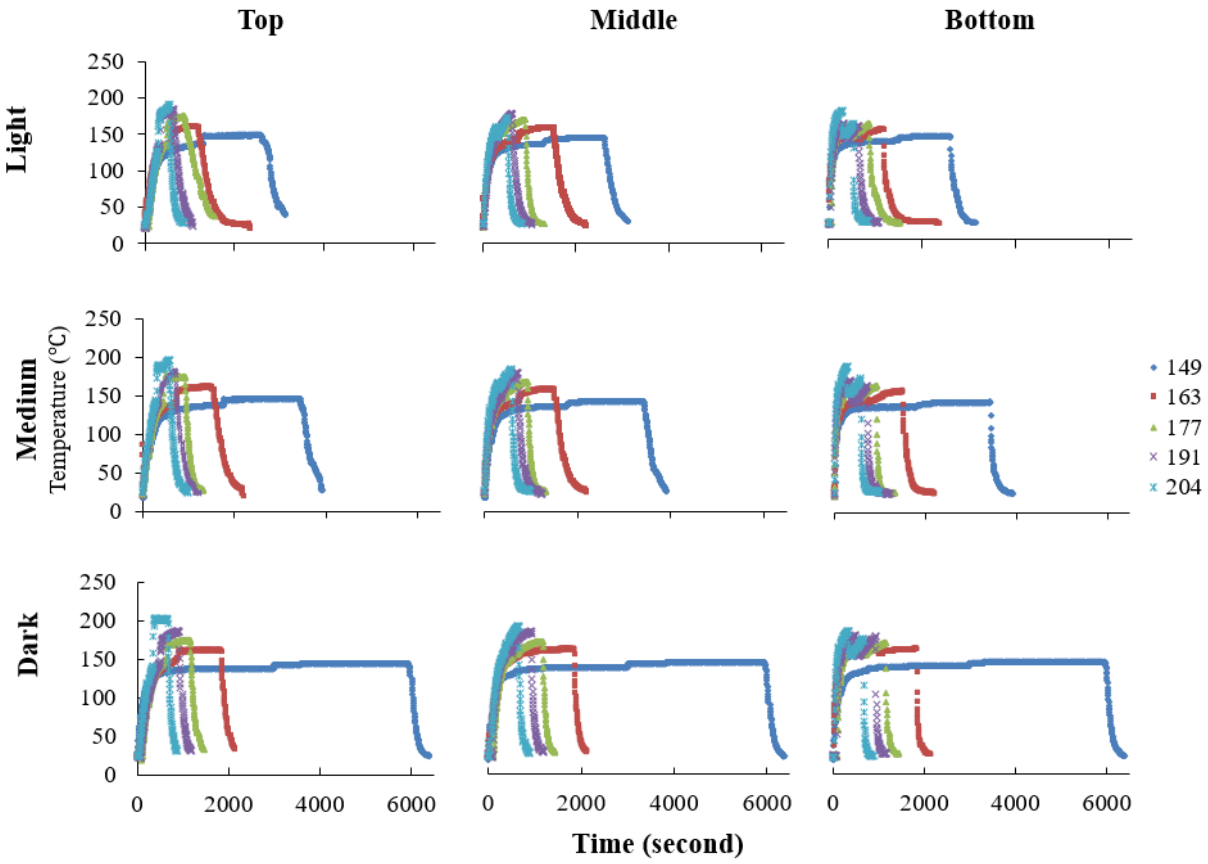

Figure 3.2. Temperature history of peanuts roasted to light, medium, and dark colors.

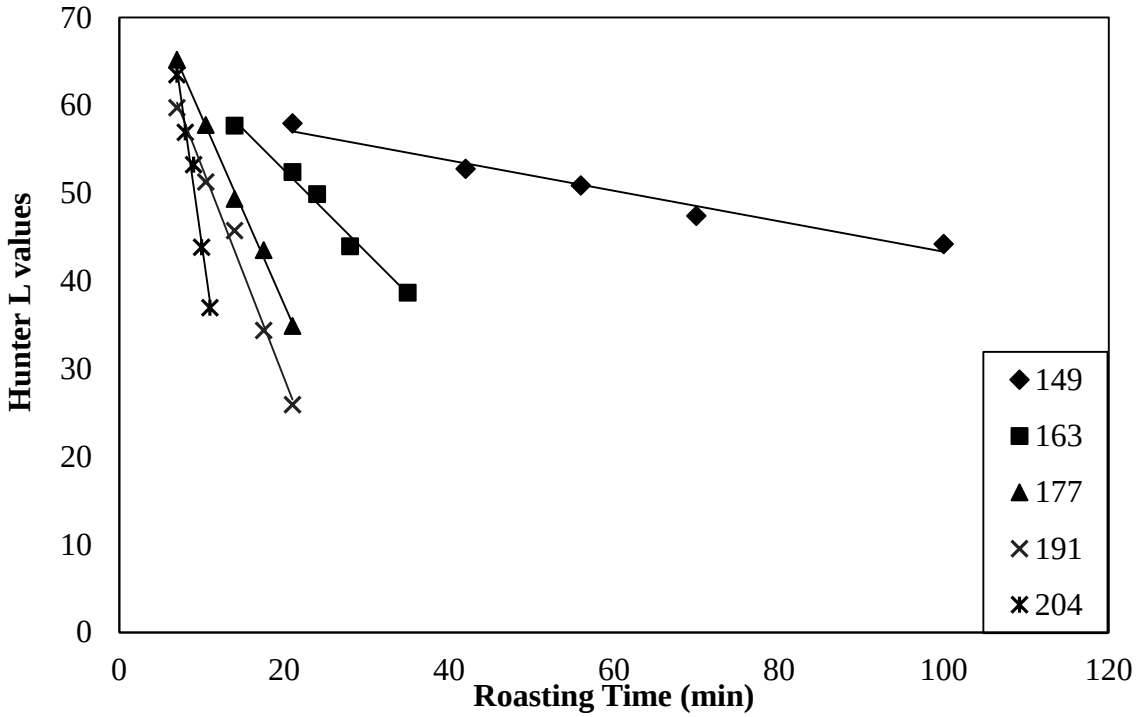

Figure 3.3. Hunter L value as a function of roasting time for each temperature achieved in preliminary roasts.

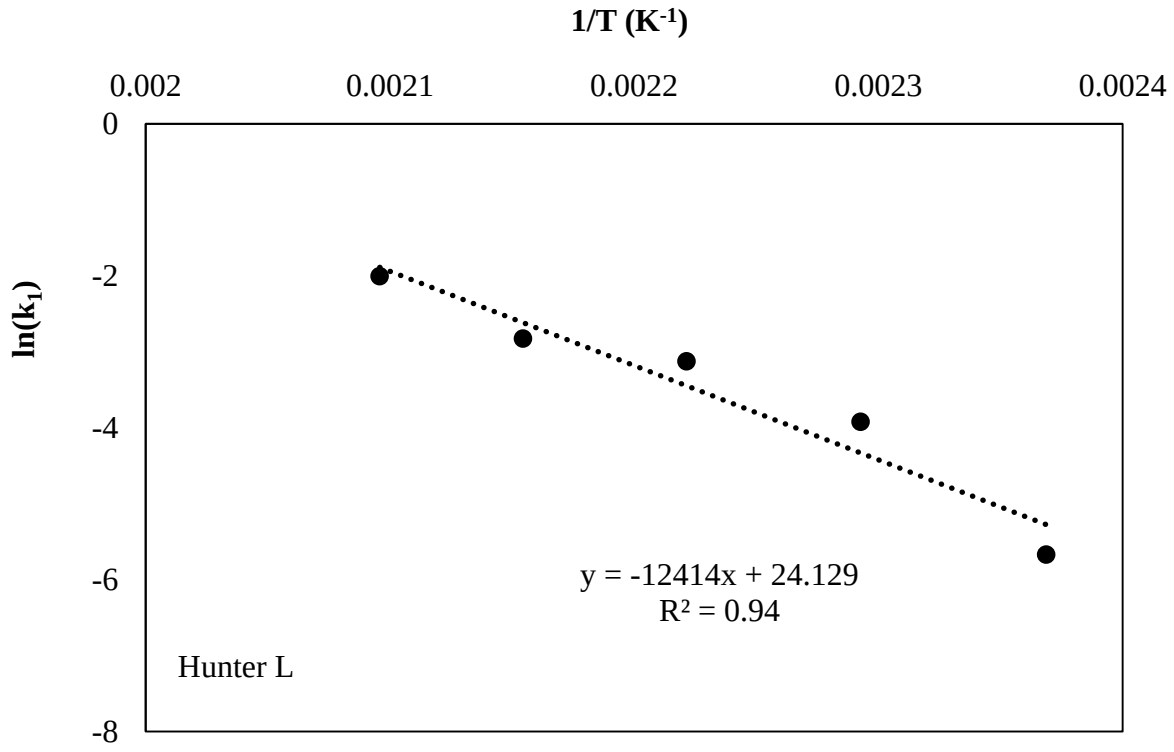

Figure 3.4. Arrhenius relationship of ln (k) versus 1/t based on first order models for Hunter L values.

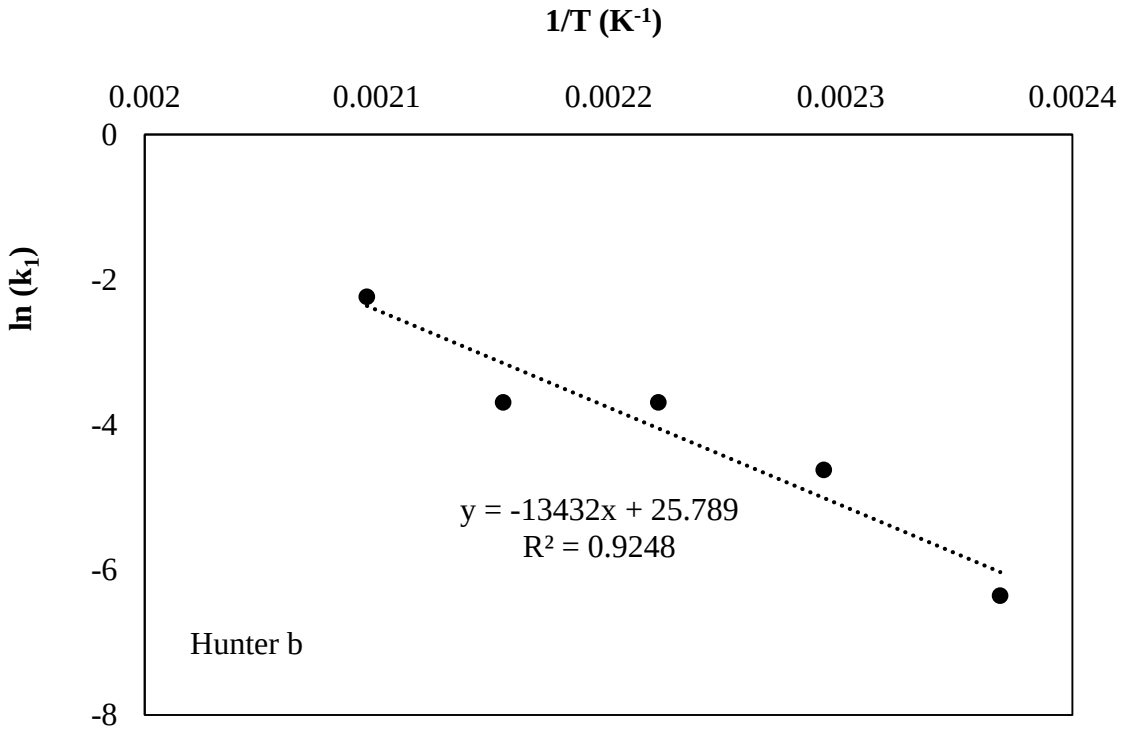

Figure 3.5. Arrhenius relationship of ln (k) versus 1/t based on first order models for Hunter b values.

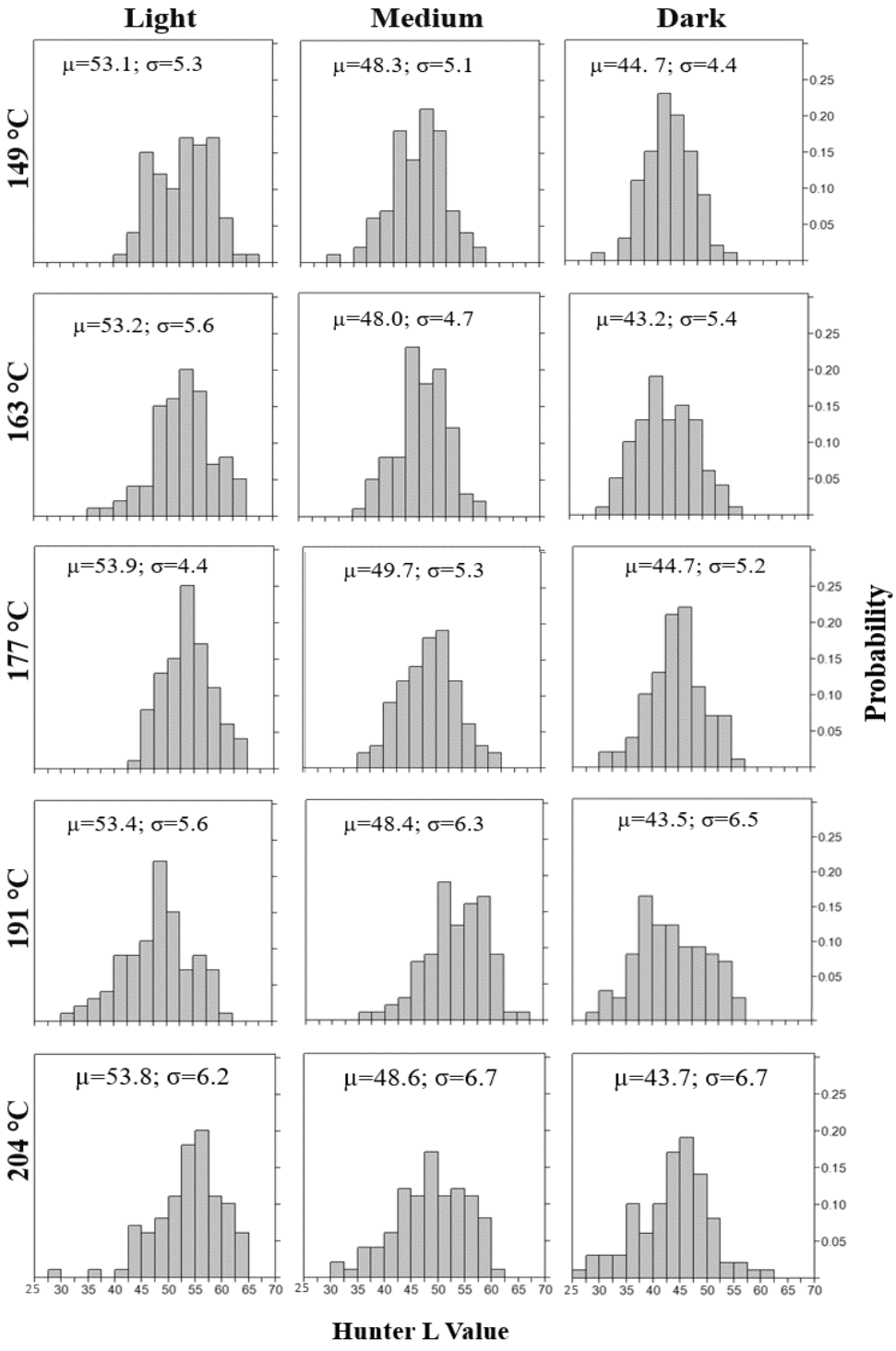

Figure 3.6. Single seed distribution of Hunter L values (n=100). The letter μ represents for the mean of Hunter L values, and σ is the standard deviation.

Table 3.1. Statistics of Hunter L values fitted into zero, first, and second order models.

Coordinate "L"	Zero-order		First-order		Second-order	
Temperature (°C)	**k**	**R^2**	**k**	**R^2**	**k**	**R^2**
149	-0.17	0.97	-3.4×10^{-3}	0.98	6.8×10^{-5}	0.99
163	-0.94	0.99	-2.0×10^{-2}	0.98	4.2×10^{-4}	0.96
177	-2.14	1.00	-4.4×10^{-2}	0.99	9.2×10^{-4}	0.96
191	-2.41	0.99	-5.9×10^{-2}	0.97	1.5×10^{-3}	0.92
204	-6.61	0.98	-0.13	0.97	2.8×10^{-3}	0.94
	Zero-order		**First-order**		**Second-order**	
MEAN R^2	0.99		0.98		0.95	
MSE	8.0×10^{-5}		7.0×10^{-5}		5.7×10^{-5}	

Table 3.2. Statistics of Hunter a values fitted into zero, first, and second order models.

Coordinate "a"	Zero-order		First-order		Second-order	
Temperature (°C)	**k**	**R^2**	**k**	**R^2**	**k**	**R^2**
149	0.03	0.54	4.8×10^{-3}	0.54	-7.3×10^{-4}	0.54
163	0.16	0.70	2.1×10^{-2}	0.70	-2.8×10^{-3}	0.69
177	0.55	0.81	0.18	0.62	-0.12	0.51
191	0.82	0.97	0.13	0.86	-2.5×10^{-2}	0.68
204	1.96	0.99	0.35	0.97	-7.4×10^{-2}	0.86
	Zero-order		**First-order**		**Second-order**	
MEAN R^2	0.80		0.74		0.66	
MSE	2.9×10^{-2}		2.4×10^{-2}		1.6×10^{-2}	

Table 3.3. Statistics of Hunter b values fitted into zero, first, and second order models.

Coordinate "b"	Zero-order		First-order		Second-order	
Temperature (°C)	**k**	**R^2**	**k**	**R^2**	**k**	**R^2**
149	-0.03	0.19	-1.7×10^{-3}	0.94	5.8×10^{-5}	0.16
163	-0.19	0.54	-9.8×10^{-3}	0.99	4.7×10^{-4}	0.47
177	-0.08	0.08	-2.5×10^{-2}	1.00	1.8×10^{-4}	0.08
191	-0.49	0.77	-2.5×10^{-2}	0.78	1.4×10^{-3}	0.75
204	-1.56	0.74	-0.11	0.91	4.5×10^{-3}	0.70
	Zero-order		**First-order**		**Second-order**	
MEAN R^2	0.46		0.93		0.43	
MSE	0.80		6.1×10^{-3}		7.4×10^{-2}	

Table 3.4. Surface color, paste color, and expressed oil color of equivalently roasted peanuts. Values followed by different letters within the same column are significantly different ($p<0.05$).

Roasting Intensity	Temperature (°C)	Surface L value	Paste L value	Oil L value
Light	149	52.91±0.70^{a}	52.30±0.67^{ab}	85.68±0.71
	163	52.49±0.60^{ab}	53.49±0.69^{a}	86.96±0.11
	177	52.36±0.19^{ab}	52.89±1.81^{a}	85.65±0.15
	191	53.20±0.68^{a}	53.20±0.66^{a}	86.27±0.63
	204	53.20±0.37^{a}	50.64±1.60^{bc}	85.80±0.64
Medium	149	48.50±0.55^{cde}	47.32±2.96^{efg}	82.11±1.14
	163	47.72±0.43^{def}	48.29±2.98^{de}	83.70±0.08
	177	48.83±0.36^{cde}	49.66±0.58^{cd}	83.23±0.44
	191	48.28±0.76^{de}	45.37±2.46^{ghi}	83.15±0.82
	204	48.84±0.45^{cde}	45.74±1.80^{fgh}	83.90±0.45
Dark	149	43.63±0.28^{hij}	40.83±1.70^{kl}	79.41±2.18
	163	42.75±0.63^{jk}	41.68±1.54^{jk}	81.17±1.12
	177	43.48±0.51^{ij}	43.90±1.88^{hij}	81.71±0.55
	191	43.16±0.67^{ij}	38.67±2.58^{l}	80.76±0.27
	204	43.34±0.52^{ij}	40.70±1.70^{kl}	81.25±0.59

Table 3.5. Cook value for each processing referring to reference temperature at 150 °C.

Roasting Intensity	Temperature (°C)	C-value (min)
Light	149	23.58
	163	16.94
	177	17.41
	191	20.41
	204	11.45
Medium	149	31.63
	163	26.55
	177	24.51
	191	28.48
	204	29.35
Dark	149	57.52
	163	41.45
	177	34.53
	191	46.20
	204	41.45

CHAPTER 4

Comparison of the Physical Properties, Microstructure, Sensory Properties, and Storability as Affected by Deep Frying, Blister Frying, and Dry Roasting

Comparison of the Physical Properties, Microstructure, Sensory Properties, and Storability as Affected by Deep Frying, Blister Frying, and Dry Roasting

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Short Title: Comparison of Peanut Properties as Affected by Different Roasting Methods.

Keywords: peanut, oil roasting, dry roasting, microstructure, shelf life

Highlights:

- Different roasting methods were able to achieve equivalent surface colors of peanuts at the same temperature using different roasting times.
- Peanut microstructure was most extensively damaged by blister frying, followed by deep frying, and then dry roasting.
- Blister fried peanuts were high in crispiness and crunchiness. For medium roasting, dry roast showed higher roasted peanutty than the other roasting methods.
- Deep fried peanuts had a faster and larger PV increase before the PV dropped, followed by the dry roasted, and then the blister fried.
- The shelf life ranking in storage was deep fry > blister fry > dry roast using loss of roast peanut flavor or “flavor fade” as the measure of roasted peanut quality.

Abstract

Jumbo-size runner peanuts were deep fried, blister fried, or dry roasted at 177 °C to average surface colors with Hunter L-values of 53±1, 48.5±1, and 43±1, corresponding to light, medium, and dark roasting, respectively. At a specified average surface color, single seed color revealed that one roasting method was not significantly different in color distribution from another, indicating there was no significant difference in the uniformity of roasting. In general, scanning electron microscopic images of rounded surfaces and outer regions of cross-sections showed the peanut microstructure was more extensively damaged by blister frying, followed by deep frying, and then dry roasting. For light roasting, blister fried peanuts had significantly higher moisture content than the deep fried and dry roasted, while for medium and dark roasting, blister fried had lower moisture than the other two. Blister fried peanuts achieved higher crispiness and crunchiness, followed by deep fried and then dry roasted. Flavor profiles were more closely correlated with the roast color than with the roasting method. For each roasting method, darker roasts had lower PV values than lighter roasted peanuts during storage. The deep fried had a faster and larger PV increase before the PV dropped, followed by the dry roasted, and then the blister fried. The shelf life ranking in storage was deep fried > blister fried > dry roasted when loss of roast peanut flavor or "flavor fade" as determined by descriptive sensory analysis was used as the measure of roasted peanut quality.

Introduction

In the U.S., the largest portion of the peanut crop is converted into value-added products, such as peanut butter, confections, and snack products. For these purposes, peanut kernels are processed using thermal techniques as the first step in the manufacture of the final products, to achieve specific flavor, color, and texture (Perren & Escher, 2013). Peanuts are typically processed by dry roasting or oil roasting, and to a lesser extent by boiling, microwave heating, or a combination of more than one processing method (Woodroof, 1983; Young, Schadel, & Heertje, 1993). Dry roasting is conducted by heating using hot air without the use of oil or water as a carrier, while oil roasting requires oil as the heat carrier. The most commonly used oil roasting methods are deep frying and blister frying. Blister frying has not been scientifically defined but according to accessible cooking instructions, this process involves the steps of boiling blanched peanuts, draining excessive water, deep frying the pre-soaked kernels, cooling, and then salting (BCP, 2015). The steps of blister frying are similar to the process used to produce a fried peanut product in Japan. For this product, the peanuts are soaked in water (95 °C, 5 min), air cooled, deep fried (150 °C, 12-13 min), and then seasoned (Miyagi, 2013). In the US, this process is known as blister frying or water blanching as it results in peanuts with blisters on the kernel surface and a characteristic texture with high levels of crispiness and crunchiness. Although there are several commercial peanut products prepared by dry roasting, deep frying, and blister frying, the scientific comparison of different roasting methods has not been reported.

A previous paper reported that temperatures above 150 °C were required for peanut roasting in order to produce the characteristic roasted peanut flavors and the brown color (Davidson, Brown, & Landman, 1999). For roasted products, color has been extensively used as a quick, non-destructive indicator of food quality for certain foods, such as roasted coffee beans, hazelnuts, almonds, and peanuts (Baggenstoss, Poisson, Kaegi, Perren, & Escher, 2008; Kaftan, 2012; Ozdemir et al., 2001; Pattee, Giesbrecht, & Young, 1991). Different temperatures and roasting time combinations were used to achieve the equivalent peanut surface colors (McDaniel, White, Dean, Sanders, & Davis, 2012; Smith, Perry, Marshall, Yousef, & Barringer, 2014). McDaniel et al. (2012) found that, for a given color, the moisture content of the roasted peanuts decreased with decreasing roast temperature due to the longer roast times required for the low temperature used to achieve the same color. It was also found that peanuts roasted at lower temperatures had higher tocopherol contents, indicating increased antioxidant capacity with the increase in roasted color (McDaniel et al., 2012). Another study investigating oven, microwave, and combination roasting suggested that significant differences were observed in flavor attributes for peanuts roasted to equivalent colors by different roasting methods; however, no significant differences were found in free fatty acid contents or peroxide values (Smith et al., 2014). Also, the different roasting methods, oil roasting and dry roasting, caused different types and/or extent of thermal modifications (e.g. cell wall rupture, protein body distension, and cytoplasmic network disruption) to the microstructure of peanut seeds (Young et al., 1993).

The method of roasting could potentially affect the physical, chemical, sensory, and storage properties of roasted peanuts. As oil roasting results in a shorter roasting time than

dry roasting, the ideal way to compare different roasting methods should be based on the concept of equivalent color roasting rather than the equivalent roasting time. The objective of this study was to systematically compare the effects of different roasting methods on peanut quality-related properties, including moisture content, microstructure, sensory properties, as well as storability, at equivalent surface colors. The data obtained could be used as guidance for the creation of high quality peanut products.

Materials and Methods

Materials

Jumbo grade peanuts of the Georgia 06G cultivar were obtained from the 2013 US harvest provided by National Peanut Research Lab (Dawson, Georgia). The peanuts had been cured, shelled, size screened (by 21/64 slotted screen), and stored using standard industry practices prior to their delivery to the USDA ARS Market Quality & Handling Research Unit at North Carolina State University (Raleigh, NC). Studies were completed within 12 months of harvest.

Roasting

Peanuts were dry roasted, deep fried, or blister fried at 177 ºC to the three equivalent surface colors (Light, Hunter L = 53±1, Medium, L = 48.5±1, and Dark, L = 43±1) as previously defined (McDaniel et al., 2012). Colors were determined by a Hunter Lab D25

colorimeter (Hunter Labs, Reston, VA). Processing time was determined using linear regression on the preliminary linear regression curves of Hunter L-value versus roasting time. The time used for each treatment is summarized in **Table 4.1**. For dry roasting, a pilot plant scale roaster (Bühler Aeroglide Corp, Cary, NC) was used to simulate an industrial continuous belt roaster (Poirier, Sanders, & Davis, 2014). The air flow rate was set at 1.0 m/s and the bed depth was 7.62 cm according to industrially used settings (Poirier et al., 2014). The batch size for dry roasting was 2000 ± 100 g to allow for a constant bed depth of 7.62 cm. The air flow direction was changed from up-flow to down-flow at the half point of the total roasting time. Following roasting, the roasting tray with peanuts inside was placed onto a forced air blower for cooling to ambient temperature. Dry roasted peanuts were manually blanched prior to storage. Deep fried and blister fried peanuts were blanched (skin removed) by a whole nut blancher (Ashton Food Machinery Co. Inc., Newark, NJ) prior to processing. For blister fried peanuts, samples were prepared by immersing the kernels in boiling water (kernel/water ratio (w/v) = 1:2.5) for 10 minutes prior to oil frying. A pilot plant scale fryer (Vulcan-Hart, Baltimore, MD) filled with 8 gallons of peanut oil (Ventura, Brea, CA) was used for both the deep frying and blister frying. The batch size for deep frying and blister frying was 2000 g peanuts per batch. Followed frying, the peanuts were spread onto a wire mesh screen with a cooling fan installed above for cooling to ambient temperature prior to storage. Roasted samples were placed into glass jars and sealed. Samples for storage tests were stored at 21 °C. Prior to testing, samples for other tests were stored in cold storage (-26 ºC) until further analysis.

Color Distribution

Single seed color of 100 blanched kernels for each treatment was measured using a Data Processor DP-301 Chroma Meter (Minolta Camera Co., Ltd. Japan). The percentage of the single seed Hunter L value within each unit interval of L=2.5 was calculated by JMP Pro 10.0 (SAS, Cary, NC) and described by color distribution charts.

Protein Content of Rinse Water

A CE Instruments NA 2100 Protein Analyzer from Thermo Finnigan (Milan, Italy) was used to determine the total nitrogen content using combustion technology. The thermal conductivity detector temperature was set at 60 °C and the pressure was set to 1200 Pa. Phenylalanine was used as the internal standard. The total nitrogen values were converted to total protein using a factor of 5.46.

Sugar Content of Rinse Water

The water used to soak the peanuts before blister frying was analyzed for sugar content using the method of Pattee and others (2000). In brief, analytically weighed defatted peanut meal (100 mg) was dissolved into 15 ml of extraction solvent (60/25/15 (v/v/v) methanol/chloroform/deionized water), then sonicated for 20 min. After centrifugation, the supernatant was decanted and evaporated at room temperature. Internal standards of lactose and cellobiose in water were then added to dissolve the dried residue. The resulting solutions

were diluted with water and filtered through a Dionex OnGuard ® II H Filter (Dionex, Sunnyvale, CA). An external standard solution was prepared containing myo-inositol, glucose, fructose, sucrose, raffinose, stachyose and the internal standards. Samples and the standard were analyzed using a Dionex BioLC HPLC system consisting of a gradient pump, an auto-sampler, and a Pulsed Amperometric Detector (PAD). The column used was a Dionex PA-1, 250 mm length and 4 mm diameter, fitted with a Dionex PA-1 Guard column. The mobile phase was 200mM NaOH in water at a flow rate of 1.0 mL/min. Sugars were identified through comparisons of retention time of unknown samples to known standards. Sugar concentrations were calculated from peak heights of the individual sugars relative to the internal standards compared to the response factors calculated from the external standard.

Microstructure

Peanut kernels were cut with a clean razor blade to create either a 1-1.5mm thick cross-section profile of 1/4 of the seed or trimmed to provide a 2-3mm^2 surface profile. Approximately 8 pieces per sample were placed into a solution of cold 3% glutaraldehyde in 0.05M KPO4 buffer (pH 7.0) and stored for approximately 5 days at 4 °C. Samples were rinsed in three 1-hour changes of 0.05M KPO_4 buffer pH 7.0 followed by 24-hour changes of 30%, 50%, 70%, 95% and 100% ethanol, all on ice. The samples were then warmed to room temperature, and dehydration was completed using two additional 24-hour room temperature changes of 100% ethanol. All samples were critical point dried for 15 minutes in liquid CO_2 (Tousimis Samdri-795, Tousimis Research Corporation, Rockville, MD). Samples were mounted on stubs with double-stick tape and silver paint, sputter coated with approximately

50Å gold-palladium (Hummer 6.2 sputtering system, Anatech U.S.A., Union City CA) and stored in a vacuum desiccator. Samples were viewed at 15kV using a JEOL JSM-5900LV scanning electron microscope (JEOL U.S.A., Peabody, MA).

Moisture Content (MC)

Whole peanut seeds from each treatment were analyzed in triplicate using a forced air oven at 130 ºC for 6 hours (Young et al., 1982). The weight losses were compared to dry mass for moisture content (% dry weight) calculation.

Tocopherol Analyses

Peanut samples were coarsely ground, and the oil was expressed using a Carver press (Carver, Wabash, IN) at 8000 kilograms for 15 minutes. Tocopherols were analyzed in the expressed oil using the high performance liquid chromatography (HPLC) method initially as described by Hashim and others (1993), with later modifications (Dean, Hendrix, Holbrook, & Sanders, 2009). In brief, 200 mg oil was analytically weighed and diluted with 0.8 mL of 1% (v/v) isopropanol in hexane solvent. Twenty µL of the diluted sample was injected onto the HPLC system configured with a Luna silica column (5µ, 250 mm length, 4.60 mm I.D.) (Phenomenex, Torrance, CA) and a Waters 2487 Dual Wavelength Absorbance Detector (Waters, Milford, MA) set to 294 nm. A mobile phase of 1% (v/v) isopropanol in hexane was used at a flow rate of 1.2 mL/min. Peak areas of prepared samples were compared to authentic standards (Sigma, St. Louis, MO) diluted in mobile phase.

Peroxide Value

Peroxide values were measured after roasting and then every 4 weeks until 16 weeks after roasting. Peroxide values (PVs) were determined as described in AOAC method 965.33. Briefly, peanuts were coarsely ground and the oil expressed using a Carver press (Carver, Wabash, IN) at 8000 kilograms for 15 minutes for oil extraction. Oil smaples of 5.00±0.05 g were weighed into 250 ml flasks, dissolved using 30 ml acetic acid-chloroform solvent (3:2 v/v). Subsequentially, 0.5 ml saturated aqueous KI was added to each flask. After shaking for 1 minute, 30 ml H_2O was added, followed by the addition of 0.5 ml 1% starch solution as an indicator. The solution was titrated using 0.01 or 0.001N $Na_2S_2O_3$ until the blue color just disappeared. The PVs were calculated by the equation of $PV=S\times N\times 1000/W$, where S is the volume of $Na_2S_2O_3$ used for titration, N is the normality of $Na_2S_2O_3$, W is the weight of oil.

Descriptive Sensory Analysis

Descriptive sensory panels were conducted at the USDA Market Quality and Handling Research Unit (Raleigh, NC). Sensory analysis was conducted immediately after roasting for the initial panel and then every 4 weeks until 16 weeks after roasting. Duplicates of the roasted samples were evaluated by trained panelists ($n>6$) in randomized order. A peanut lexicon based on Johnsen et al. (1988) with modifications by Sanders, Vercellotti, Crippen, & Civill (1989) and Schirack, Drake, Sanders, & Sandeep (2006) was used. The texture lexicon, containing terms of crispy, crunchy, hardness, and breakdown) was built by

the descriptive panel referring to the terms commonly used to describe the texture of oilseed and nuts (Tunick et al., 2013; Varela, Salvador, & Fiszman, 2008; Vickers, Peck, Labuza, & Huang, 2014; Wanlapa & Jindal, 2006). The Spectrum^{TM} analysis (Sensory Spectrum, Inc., Chartham, NJ, USA) method was used for the training and evaluation sessions.

Statistical Analysis

The data analyzed using JMP PRO 10.0 (SAS, Cary, NC). Factorial analysis of variance (ANOVA) and least-squares means (LSMEANs) Student's t test was conducted on the color distribution, moisture content, tocopherols, sugars, and yield stress. Normal distribution was fitted to single seed color of roasted peanuts, and goodness of fit was tested using Shapiro-Wilk W test. One-way ANOVA was performed on the results of sensory analysis. A significant standard α=0.05 was used.

Result and Discussion

Color Distribution

The single seed color of roasted peanuts has been reported to produce a perfect symmetrical distribution with the mean L value nearly close to the average seed surface color (Sanders & Bett, 1995). The probability distribution of single seed color (n=100) for each sample was fitted into a normal distribution (**Figure 4.1)**. As oil roasting was conducted by heating the peanut seeds in direct contact with the heating medium, it was expected that deep

frying and blister frying would result in a higher uniformity of color distribution. It was found that for each roast color, there was no evidence that one roasting method was significantly different from another in color distribution, indicating there was no difference in the uniformity of roasting. Statistical analysis also indicated that there was no significant evidence of an interaction between the roasting method and the surface color. Under current experimental conditions, the single seed color distribution was highly correlated with degree of roast ($p < 0.001$) but not roasting method.

Microstructure

The scanning electron microscopic (SEM) image of the raw peanut outer rounded surface was composed of well aligned rectangular epidermal cells (**Figure 4.2.A**). This image was compared with those previously published (Young & Schadel, 1990). The outer region of the cross section of raw peanut kernel was composed of a single layer of epidermal cells [E] and parenchyma cells [P] (**Figure 4.2.B**). Previous studies reported the larger granules (4-15 μg in diameter) were protein bodies and starch grains, while the smaller ones (1-2 μg) were fat bodies (Yatsu, 1981; Young & Schadel, 1990). In our study, as most oil was removed during the fixation step, most granules in view were starch and protein bodies, although they were not distinguishable by SEM (Young & Schadel, 1991). The membrane of the granules formed a continuous dense net, which was the cytoplasmic network (Young & Schadel, 1991).

The SEM images of the outer surface of the roasted peanut seeds are compared in **Figure 4.3**. For the deep fried, some damage to the outer surface of the seed was observed. The SEM views were focused on the damaged regions, where the damaged epidermal cells exposed the inner parenchyma cells underneath. With the increase in the roast color intensity, more cytoplasmic substances [cp] were lost from the cell structures, leaving more empty cells [em]. For blister fried peanuts, there were more damaged regions seen on the seed surface than the deep fried. In those damaged regions, almost all cp were lost, leaving the hive-like cell wall structures [W]. The protein and sugar contents of the peanut rinse water were 2.52 ±0.03 mg/ml and 3.98 ±0.26 mg/ml respectively, responding to approximate substance losses of 2.5% in protein and 4.0% in sugars during the water boiling step prior to oil frying. As the amounts of these substances lost during the boiling step was considered low, it was assumed that most substance losses occurred during the deep frying operation of blister frying. For the dry roasted peanuts, no obvious epidermal damage was observed but with the increase of the in the roast color intensity, there was a higher degree of deformation of the epidermal cells from the well-aligned rectangle to an irregular shape. Overall, more outer surface damage was seen for blister fried peanuts, followed by the deep fried, with the least seen in the dry roasted.

The outer, middle, and inner regions of the cross sections of the roasted peanut seeds were examined using SEM. As there was no obvious damage to the middle and inner regions, the SEM images of the middle and inner regions are not shown. As for the outer region of the cross section of peanut seeds (**Figure 4.4**), there was no obvious difference among the different roast colors for each roasting method, although the darker dry roasted

peanuts showed higher degrees of cell wall rupture. When compared across the different roasting methods, the deep fried and dry roasted seeds showed similar changes in the cell structure, that is mainly cp and network disruption. Comparable changes in peanut microstructure during oil and dry roasting were also reported by previous studies (Young & Schadel, 1990; Young et al., 1993). Extensively damaged cell structure was observed for blister frying, resulting in a number of em depleted of cell substances. Blister fried peanuts also had a high degree of cell wall rupture and disruption of the cytoplasmic network at the outer region of the cross sections. Those depleted cells and severely damaged cells were confined to the outer region of seeds, forming a distinguishable crust at the outer most 3 to 4 layers of the kernel. Air cavities [C] under the protruding area together with the raised cells were collectively referred to as blisters. The formation of distinguishable crust and blisters was attributed to water absorption during boiling and quick water release from the cell structure to the bulk oil during frying. The formation of blisters caused severe structural damage to the peanuts, and the cell damage was exacerbated with the loss of cp. The extensive damage to the blister fried peanuts is discussed below as related to the moisture change and storability.

Moisture Content

The moisture contents of the raw and roasted peanuts are summarized in **Figure 4.5**. The moisture decreased from an initial level of 5.66% based on dry weight to final values of 0.85 to 1.64%. The moisture contents decreased with increased surface color, as there was more moisture loss with the longer heat processing time (McDaniel et al., 2012). The initial

moisture content of peanuts prepared for blister frying was relatively high at 18.78% due to the peanuts being immersed in boiling water prior to frying. This resulted in the light roasted blister fried peanuts having higher moistures than the deep fried and the dry roasted at the same roast color intensity. Due to the extended had processing time of blister frying, the medium and dark roasted color blister fried peanuts significantly lower moisture contents than the deep fried and the dry roasted, which was attributed to the increased moisture loss from the extensive structure damage to the cells .

Descriptive Sensory Analysis

Radar plots (**Figure 4.6**) were used to describe the sensory properties of roasted peanuts immediately after roasting. Flavor profiles included the attributes of roasted peanutty, sweet aromatic, dark, beany, woody, sweet, bitter, and astringency. In general, the overall flavor profiles of roasted peanuts were highly correlated with the roast color, rather than the roasting method. Panelists were unable to distinguish differences in the astringency of the samples. When peanuts were light roasted, there was no significant difference in the samples for the roasted peanutty, sweet aromatic, beany, and sweet attributes. For light roasting, deep fried and blister fried peanuts showed significantly higher bitterness than the dry roasted, but there was no significant difference in bitterness between the deep fried and the blister fried. For medium roasting, no significant difference was observed in sweet aromatic, dark, and woody attributes. Dry roasting showed a higher roasted peanut intensity than the other processes, but there was no significant difference between the blister fried and the deep fried peanuts. As for the bitter attributes, dry roasting was significantly higher than

with the other two roasting methods. When the peanuts were dark roasted, the deep fried and the dry roasted showed higher roasted peanut intensity than the blister fried, with no significant difference between the first two. The sweet aromatic followed the trend of deep > blister > dry. There was no significant difference between the dry roasted and the blister fried in bitterness, but the bitterness of these two was higher than the deep fried. Across three roasting colors, roasted peanutty tended to increase with the increase in roasting intensity from light to dark, which is consistent with a previous study (McDaniel, 2011). With the increase in roast color, more volatile flavor compounds were expected to be formed via Maillard browning thus enhancing the roasted peanutty. The other positive attribute of sweet aromatic, however, had no significant increase with increased roasting color, indicating increase in the formation of volatile compounds responsible for the aromatic caramel-like flavor.

Texture profiles were composed of the attributes of crispy, crunchy, hard, and breakdown (**Figure 4.7**). The texture profile patterns were very similar across the three roasting colors of light, medium, and dark. In general, blister fried peanuts always showed the highest crispiness, crunchiness, and hardness, and the lowest breakdown. Deep fried peanuts were found to have higher crispiness and hardness than the dry roasted. The highest breakdown was observed in the dry roasted peanuts at the light roast color intensity, but there was no difference in breakdown between the deep fried and the dry roasted peanuts with medium and dark roasting. The moisture loss, crust formation, and changes in the levels of storage proteins, were considered to be the main factors in texture development of roasted peanuts, resulting in increased crispiness, crunchiness, and hardness (Metwalli, Zoueil,

Mohamed, & El-Zalaki, 1975; Smyth et al., 1998). In this study, the loss of moisture did not explain the higher crispiness/crunchiness of the blister fried peanuts as the light blister fried peanuts had a higher moisture content than the deep fried and dry roasted. The apparent greater oil observation of oil absorption of deep fried peanuts than the blister fried peanuts can explain the softer texture of deep fried peanuts. Combined with the information from the SEM images (**Figures 4.3** and **4.4**), the crust formed by the disrupted epidermal cells and substance losses from parenchyma cells of the outer region of the cotyledons was considered the major factor responsible for the higher crispiness/crunchiness of the blister fried peanuts.

Tocopherols

Tocopherol contents were measured after blister frying, deep frying and dry roasting (**Figure 4.8**). For the raw and roasted samples, α- and γ- tocopherols comprised 84-95% of the total tocopherols, whereas β- and δ- tocopherols made up the rest. The retention of tocopherols during roasting was never less than 75%, which was consistent with a previous study that found tocopherols were resistant to roasting and manufacturing (Chun, Ye, Lee, & Eitenmiller, 2003). In general, the highest tocopherol retention was observed from dry roasted peanuts, especially the medium and dark dry roasted, as comparable amounts of tocopherols were observed from these two samples when compared to the raw peanuts. Deep fried peanuts had relatively higher tocopherol retention than the blister fried. This was attributed to washing out of the tocopherols by the cooking oil during frying. For the oils from the dry roasted peanuts, the tocopherol loss was less for darker roasted peanuts, while there was no significant difference in total tocopherols among the different roast colors for

the blister fried and the deep fried peanuts. Previous studies attributed the reduced tocopherol degradation of the darker dry roasted peanuts to the protection from enhanced antioxidant capacity via the formation of Maillard compounds and/or the release of previously bound polyphenolic compounds (Oliviero, Capuano, Cammerer, & Fogliano, 2009; Talcott, Passeretti, Duncan, & Gorbet, 2005). For blister and deep fried peanuts, there may be no more formation of antioxidant compounds despite the increase in the color.

Peroxide Value

Peroxide value (PV) is a measure of the concentration of peroxides and hydroperoxides formed in the initial stages of lipid oxidation (Chakrabarty, 2003). Shelf life was estimated as the earliest time needed to reach an arbitrary peroxide value of 10 milliequivalents/kg oil, which is considered to be the upper limit for commercially fresh oil (Gordon, 1990). The PVs of the roasted peanuts as a function of storage time are summarized in **Figure 4.9**. As the standard deviation was too small to be shown in the figure, the error bars were not included. Raw peanuts stored under the same conditions had relatively low PVs throughout 16 weeks due to the presence of small amounts of other materials, such as water and cell tissue, protecting the oil masses in the tissue from oxygen (Miyagi, 2013). For each roasting method, there was a trend that the lighter roasted peanuts had higher PVs than the darker, especially during the first 12 weeks, indicating the darker roasted peanuts were less prone to lipid oxidation. This trend had also been reported in another study investigating the effects of roasting on peanuts (Davis, Dean, Price, & Sanders, 2010). This was explained by a hypothesis that there may be more antioxidants formed

during thermal processing for darker samples that protected the samples from oxidation (Davis et al., 2010). The PV of the deep fried peanuts increased at a faster rate and produced a larger increase before dropping. The PV drop was less in the dry roasted peanuts, and even smaller in the blister fried peanuts. The faster and larger increase in PV values for the deep fried peanuts compared to the dry roasted before the drop is attributed to the higher tocopherol levels of the dry roasted peanuts providing better protection against lipid oxidation. Also, as oil was absorbed into the surface of the peanut kernels during deep frying, deep fried peanuts were more prone than the dry roasted to lipid oxidation, which may be responsible for the further increase in the rate of PV development for the deep fried peanuts. The relatively low PVs of the blister fried peanuts throughout the entire storage time was associated with the loss of the lipid bodies and other substances from the damaged cell structures during frying.

In the deep fried peanuts, the PVs increased at the highest rate for the first eight weeks, but the rate decreased dramatically from week 8 to week 12, and then had a minor increase from week 12 to week 16. As PV measures only the primary products formed in the initial stages of lipid oxidation, the decreases after 8 weeks are expected to be due to the decay of the primary products in the latter stages of lipid oxidation (Sheabar & Neeman, 1988). As the first measurement during storage testing was at week 4 and by this time point the PV was already much higher than 10 milliequivalents/kg oil, the shelf life for the deep fried peanuts was shorter than 4 weeks. For all the different color intensities of the blister fried peanuts, the PVs increased for the first 4 weeks, but decreased to lower levels afterwards. A previous study also reported the same trend of PV changes with storage time

in water blanched, oil fried peanuts (Miyagi, 2013). In that study, the peanuts were prepared by soaking in hot water at 95 °C for 5 minutes, followed by deep frying at 150 °C for 12-13 min. It was observed that the PV increased for the first 10 days after the water blanching-oil frying, but declined quickly afterwards (Miyagi, 2013). For dry roasted peanuts, the PV increased progressively for the first 12 weeks, but decreased slightly for medium and dark roasted samples. Similar to the deep fried and the blister fried peanuts, the decrease was due to the decay of primary products during the latter stages of lipid oxidation (Sheabar & Neeman, 1988). The decrease of the PVs of the dry roasted peanuts observed in this study was different from previous studies (Riveros et al., 2010; Silva, Martinez, Casini, & Grosso, 2010). In the first study, it was observed that PVs of dry roasted peanut pastes prepared at 140 °C/30min (Hunter L=50±1) increased progressively throughout 25 weeks from 0 to 9, 11, and 15 milliequivalent/kg oil, when stored at 4, 23, and 40 °C, respectively (Riveros et al., 2010). The second study found that the PVs of dry roasted peanuts prepared at 170 C/25min (Hunter L=50±1) increased from 0 to 56 milliequivalents/kg oil after 12 weeks at storage temperature of 40 °C (Silva et al., 2010). The inconsistency of the PV trend of dry roasted peanuts between these two studies can be associated with the different roasting temperatures and times, as well as differences in peanut varieties and storage times and temperatures.

Flavor Stability

Flavor fade in the roasted peanuts is the loss of positive attributes associated with fresh roasted peanuts such as roasted peanutty and sweet aromatic. The accompanied development of off flavors has been observed during storage (Abegaz, Kerr, & Koehler, 2004). In this work, the off flavor development exclusively referred to cardboardy, painty, and other oxidized flavors. Previous studies found that roasted peanut flavors decreased during storage, but cardboardy, painty, and oxidized flavors increased with storage time (Silva et al., 2010; Williams, Duncan, Williams, Mallikarjunan, & O'Keefe, 2006). The changes in the sensory intensities of the flavor attributes associated with flavor fade are summarized in **Figure 4.10**. For the roasted peanutty, all samples showed progressive 10-30% decreases in intensity throughout the 16 weeks, regardless of roasting methods and roast color intensities. The decrease of roasted peanutty was considered to be the result of interactions between the roasted flavor compounds and off flavor compounds, as well as the masking effects from the off flavor compounds, such as volatile aldehydes (Warner, Dimick, Ziegler, Mumma, & Hollender, 1996; Williams et al., 2006). Also, the volatile and semi-volatile roasted flavor compounds may naturally dissipate over time. The PV of blister fried peanuts remained at low levels, the roasted peanutty decreased dramatically for light and medium blister fried peanuts, indicating the sensitivities of PV and roasted peanutty to lipid oxidation were different. In particular, for the light roasted peanuts, the percentage of the decrease in roasted peanutty throughout 16 weeks followed the order of blister > dry > deep, while for medium and dark roast colors the percentage decrease in roasted peanutty was

ranked as dry > blister > deep. Unlike roasted peanutty, another positive attribute of sweet aromatic remained relatively stable throughout the 16 weeks.

The sensory intensities of off flavors that developed are summarized in **Figure 4.11**. For the negative flavor attributes of cardboardy and painty, similar patterns were observed from the curves of cardboardy and painty as a function of storage time. As the painty intensity was always lower than 1.2 up to 16 weeks, cardboardy was the major off flavor observed during the test period. The general intensity ranking of cardboardy was dry roast > blister fry > deep fry. It was not until the 12 week sampling that a significant increase in the intensity of cardboardy was detected. In general, the flavor fade data revealed the order of the length of shelf life for roasted peanuts was deep fry > blister fry > dry roast.

The cardboardy flavor intensity and the PV data were not correlated with each other in this study as was seen previously (Riveros et al., 2010). This inconsistency indicated that the oxidative stability might not be well described by just one method. The reasoning could be either the cardboardy development is more than just aldehyde production and the oxidation of fatty acids, or the panelists were not able to adequately determine the low levels of the off flavors. A comprehensive evaluation including both chemical measurements and sensory analysis is required to better understand the oxidative stability of roasted peanuts. In this study, PV was determined to be the more sensitive measure of oxidative stability of the deep fried and the dry roasted peanuts, as the increase in PV emerged earlier than the development of off flavors. This was considered reasonable as PV measures only the primary products formed in the initial stage of lipid oxidation, while off flavor development

is due to the formation of volatile aldehydes, such as nonanal, octanal, decanal, and hexanal, during the later stages of lipid oxidation (Warner et al., 1996). The sensitivity and convenience of PV analysis have allowed universal use as a laboratory and industrial tool for peanut shelf life measurement. The major quality concern for peanut, however, is sensory analysis as it is reasonable to judge peanut shelf life based on flavor fade or loss of roast peanut flavor and off flavor development.

Conclusion

Both the roasting methods and the roasted color affected the physical, sensory, and storability of roasted peanuts. There was more extensive damage to the blister fried peanuts than the deep fried and dry roasted due to the fast moisture migration during boiling and frying. The flavor profiles were highly correlated with the roasted color, while the microstructure, moisture content, texture, and shelf life stability were significantly affected by roasting methods. Different sensitivities of the chemical analyses and the descriptive sensory panel were observed in the assessment of the shelf life of roasted peanuts. The deep fried had a faster and larger PV increase before dropping due to more oil pick up at the surface that promoted lipid oxidation. The lowest PV increase of the blister fried is attributed to loss of components such as sugars and the formation of a protective crust. The inconsistency of the PV and the cardboard flavor development data is thought to be due to the formation of cardboard flavor not being a direct result of oil oxidation, or possibly the insensitivity of the descriptive panel to off flavors. To better understand the storage life of

roasted peanuts, a combination of chemical and sensory analyses should be considered for a more precise estimation.

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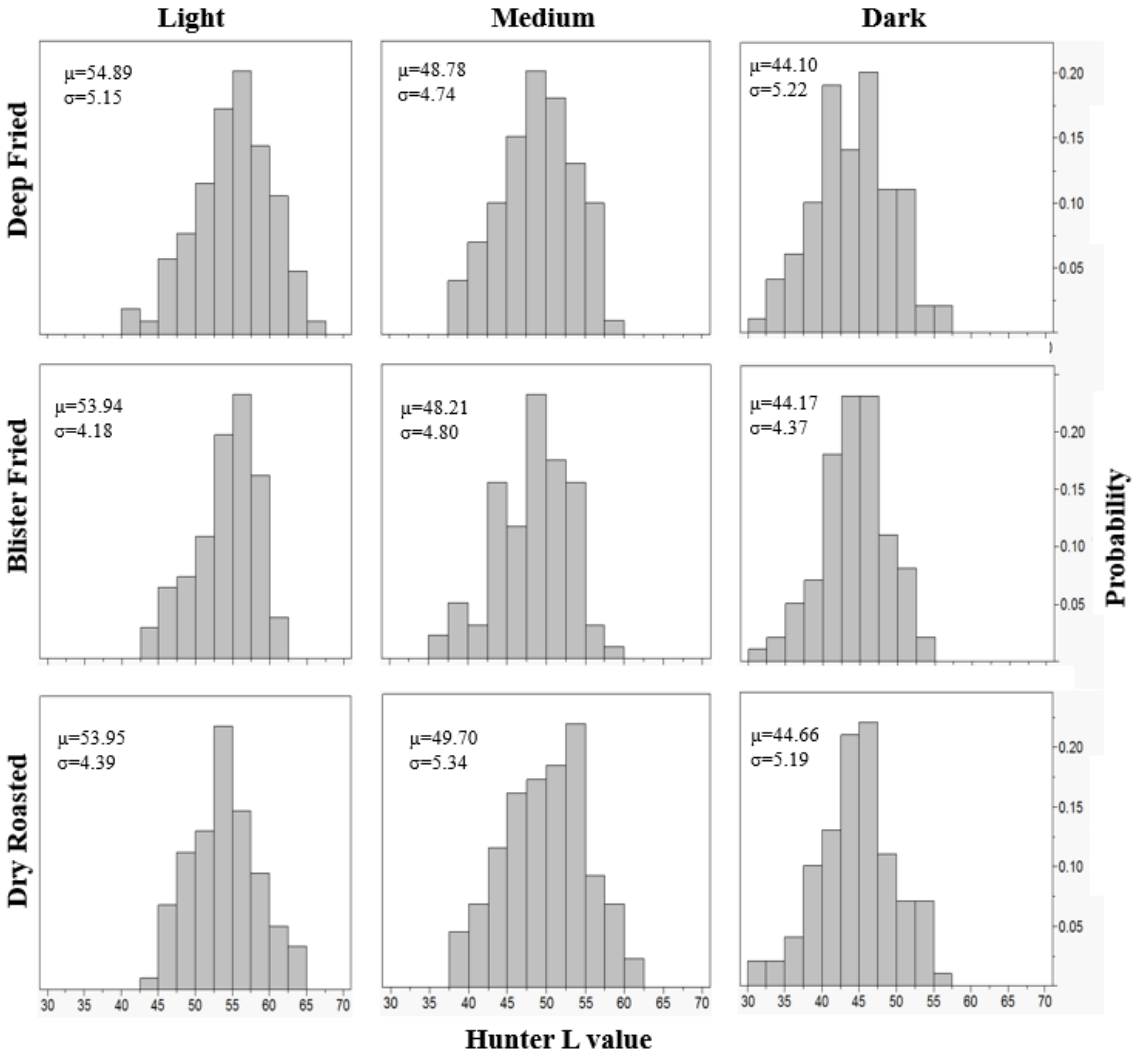


Figure 4.1. Single seed color distribution of deep fried, blister fried, and dry roasted peanuts at equivalent light, medium, and dark surface colors.

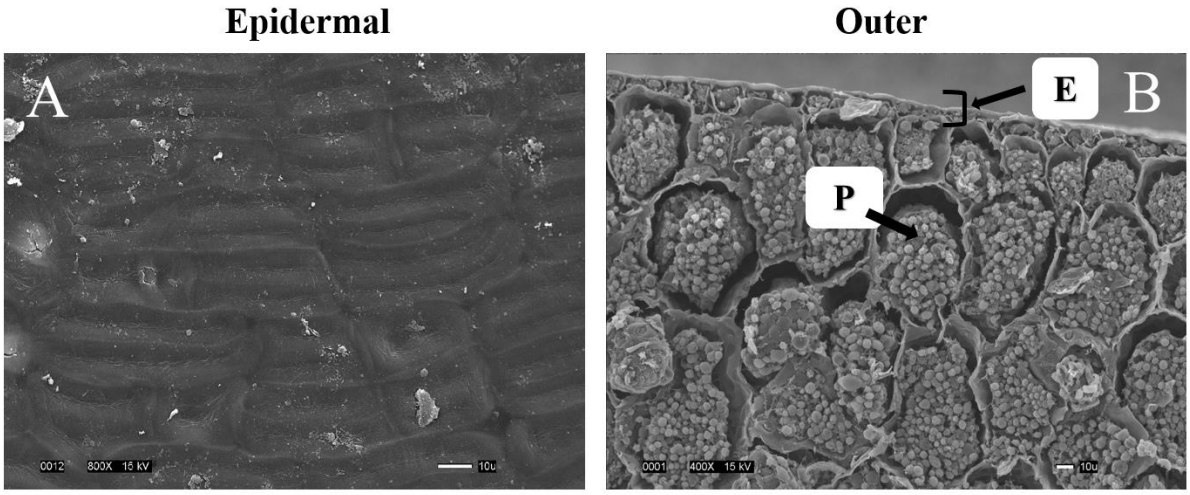


Figure 4.2. Scanning electron micrograph of an unroasted peanut. [E] indicates the epidermal cells, [P] indicates the parenchyma cells.

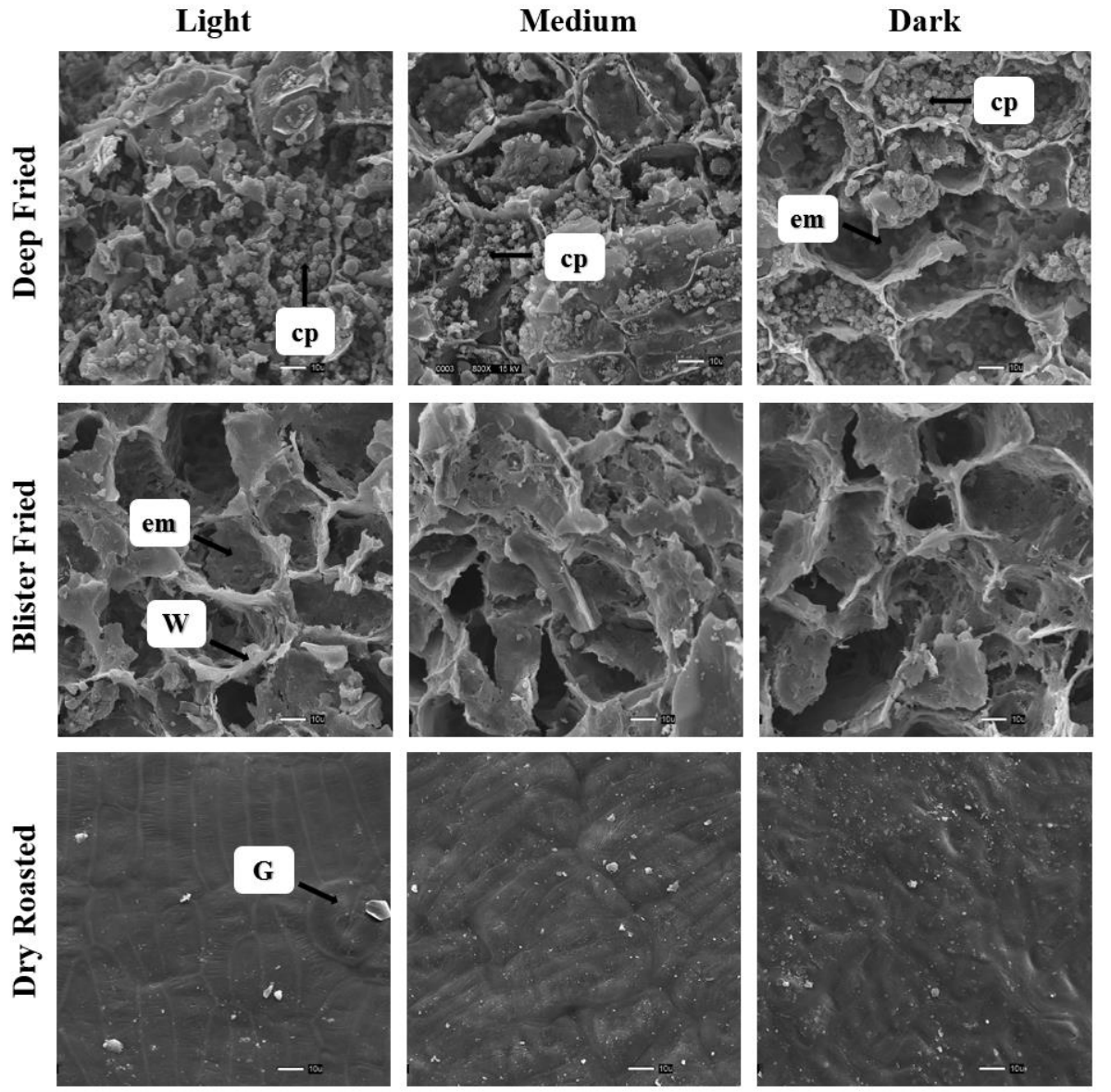


Figure 4.3. Scanning electron micrograph of the deep fried, blister fried, and dry roasted cotyledons of light, medium, and dark surface colors on the outer rounded surface. Images were taken at locations with damaged epidermal cells for deep fried and blister fried peanuts. [cp] is the cytoplasm, [em] is empty cell, [W] is cell wall, and [G] is guard cell.

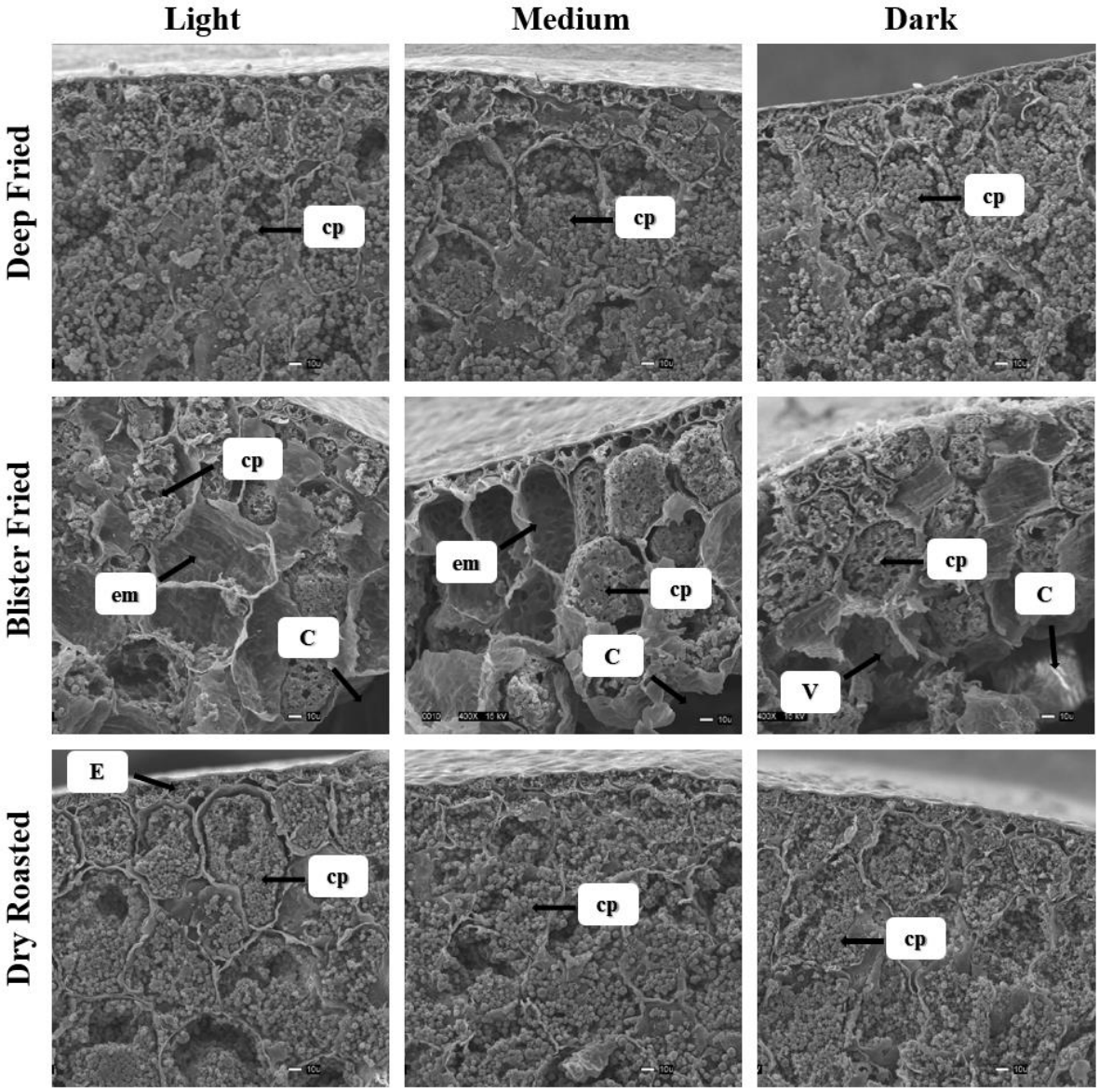


Figure 4.4. Scanning electron micrograph of deep fried, blister fried, and dry roasted cotyledons of light, medium, and dark surface colors at the cross section. [cp] is the cytoplasm, [em] is empty cell, [C] is air cavities, [E] is epidermal cell.

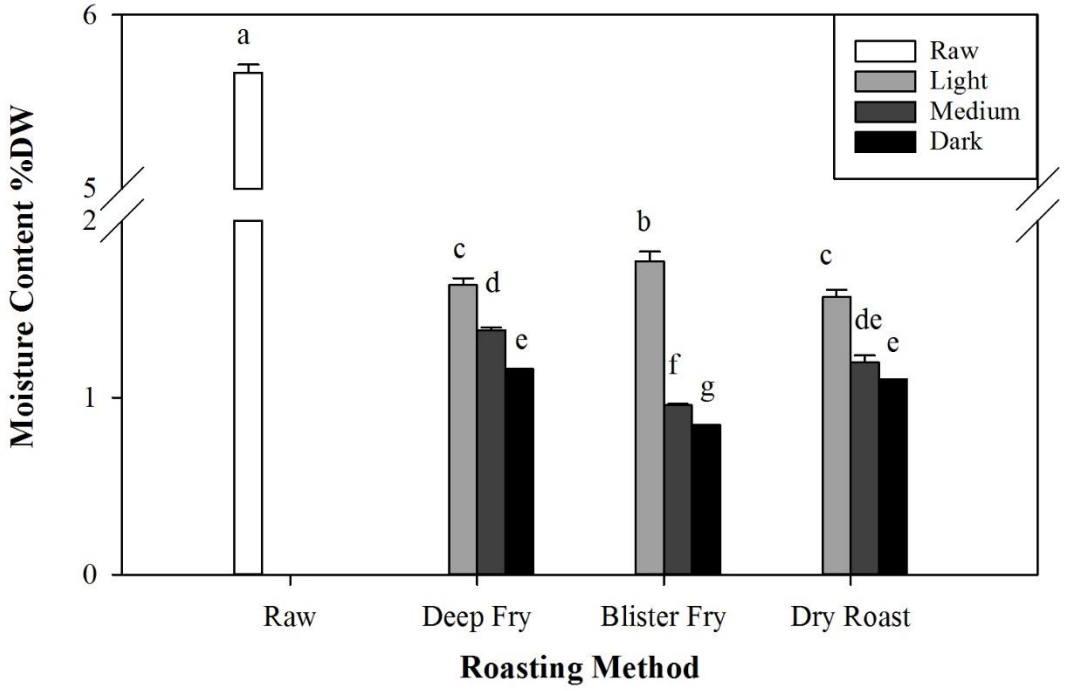


Figure 4.5. Moisture content of blanched raw and roasted peanuts as a function of roasting method.

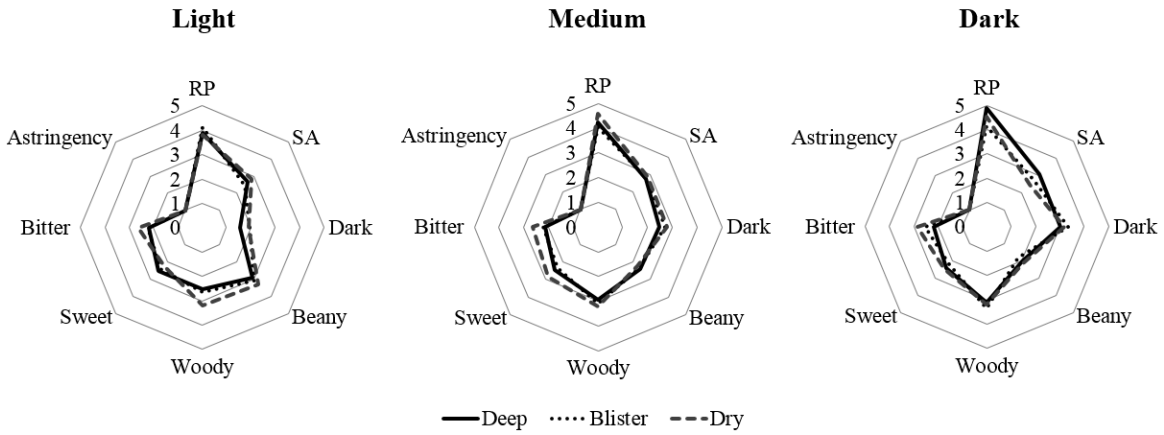


Figure 4.6. Flavor profile analysis of light roasted peanuts prepared by deep frying, blister frying, and dry roasting.

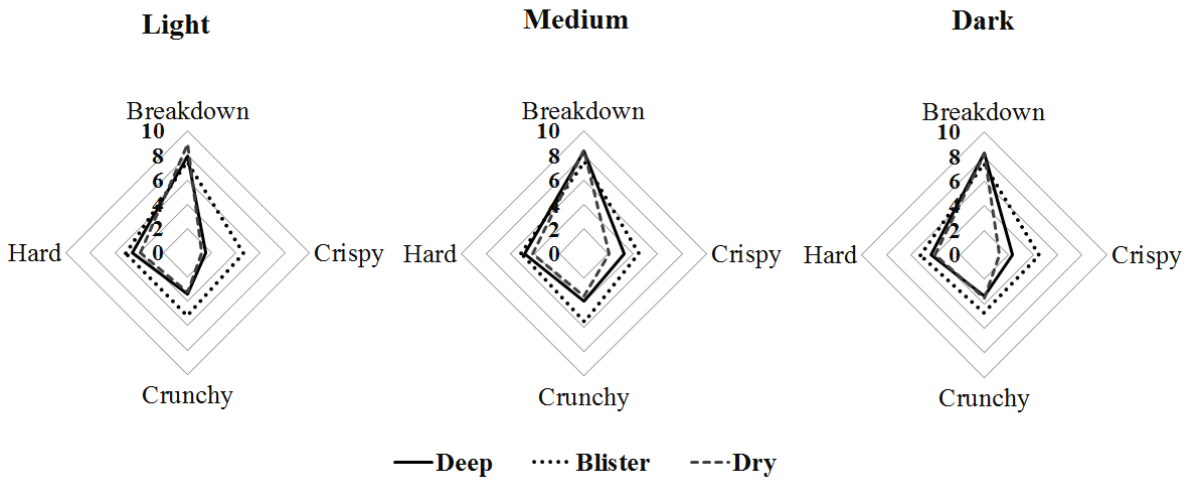


Figure 4.7. Texture profile analysis of dark roasted peanuts prepared by deep frying, blister frying, and dry roasting.

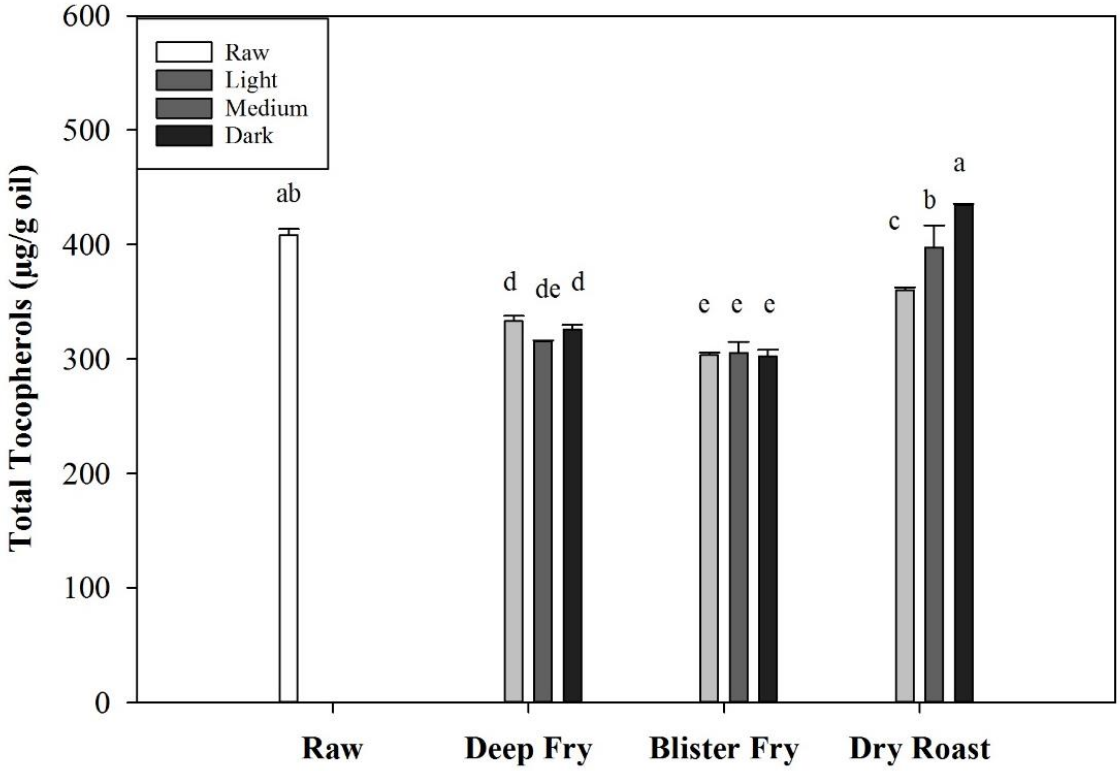


Figure 4.7. Total tocopherols of oils expressed from raw and roasted peanuts oil as a function of roasting methods. Bars labelled with different letters are significantly different ($p<0.05$).

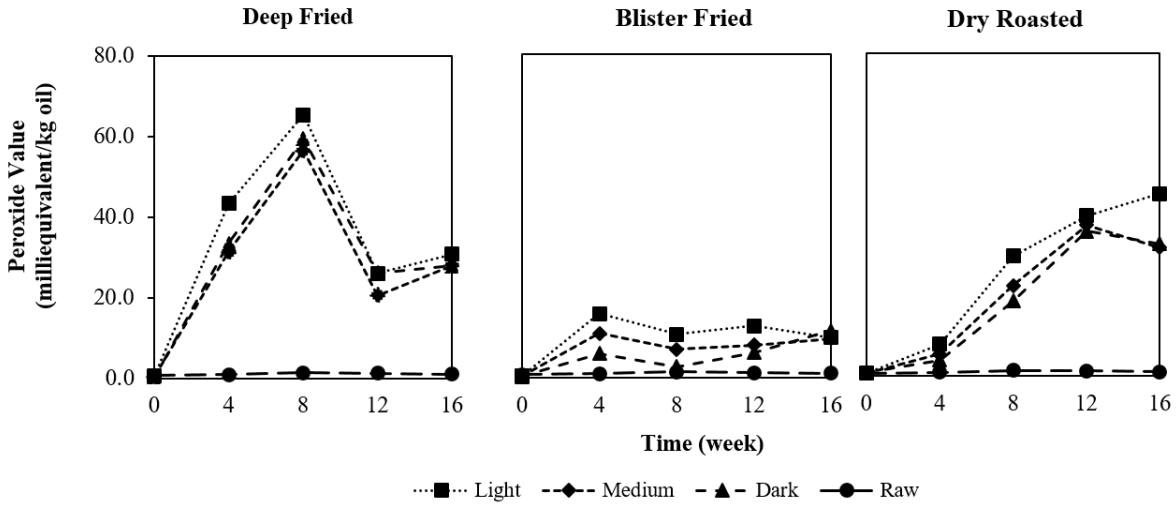


Figure 4.8. Peroxide values of deep fried, blister fried, and dry roasted peanuts at light, medium, and dark surface colors during storage at ambient room temperature.

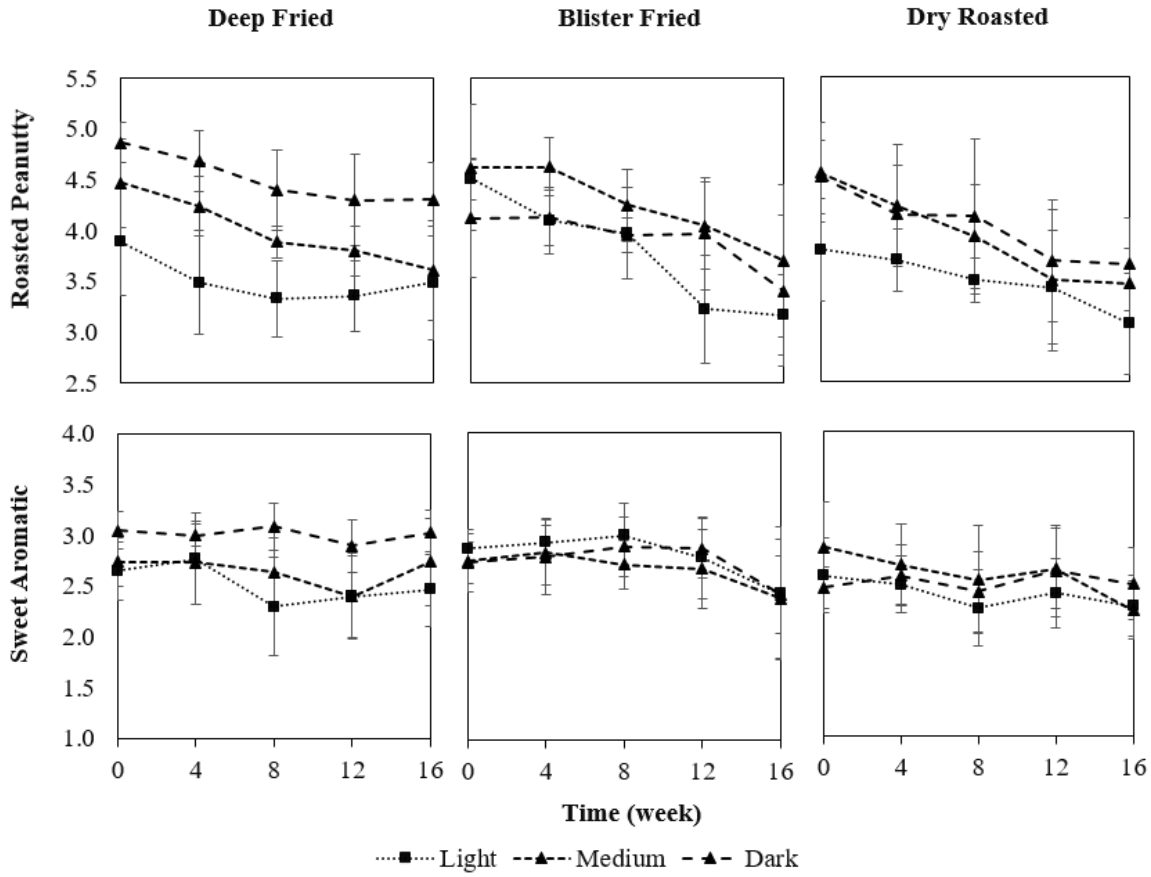


Figure 4.9. Flavor fade of roasted peanutty and sweet aromatic as a function of storage time for deep fried, blister fried, and dry roasted peanuts.

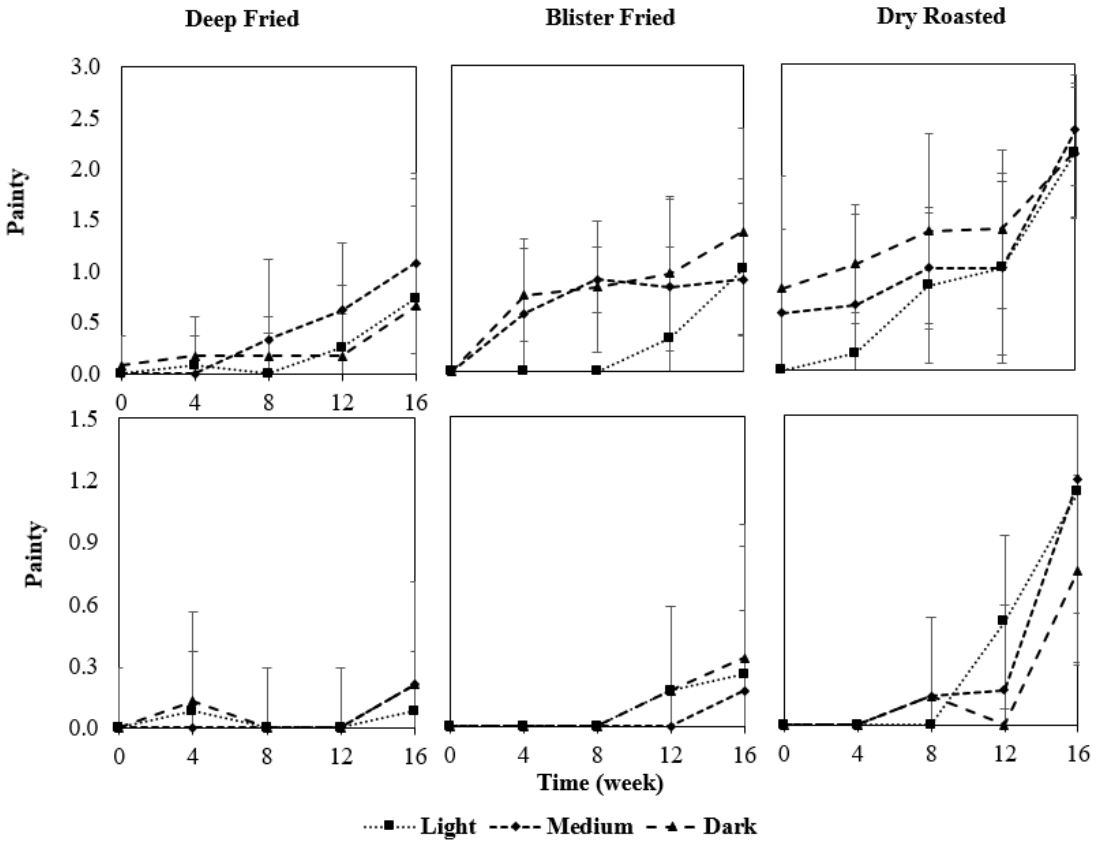


Figure 4.10. Off flavor development of cardboardy and painty as a function of storage time for deep fried, blister fried, and dry roasted peanuts.

Table 4.1. Roasting time (minutes) used for each treatment to achieve equivalent color roasting of light, medium, and dark at average surface Hunter L values of 53±1, 48.5±1, and 43±1, respectively.

	Deep Fry	**Blister Fry**	**Dry Roast**
Light	1.3	3.0	11.9
Medium	1.6	3.5	14.0
Dark	2.0	4.3	17.0

CHAPTER 5

Concluding Summary and Suggestion for Future Work

Concluding Summary and Suggestion for Future Work

In this study, peanuts roasted to equivalent surface colors under different roasting conditions, i.e. temperature/time combinations and roasting methods, were investigated for variations in chemical, physical, sensory, and storable properties. For dry roasting, the flavor of roasted peanuts was found to be optimal at medium roasting. The color coordinates of dry roasted peanuts were found to fit well into several kinetics models. The first order model for Hunter L and b values was used to estimate the activation energy to initiate color development to be $1.0\text{-}1.2\times10^{8}$ J/kg mol. For peanuts prepared by different roasting methods, peanut microstructure was most extensively damaged by blister frying, followed by deep frying, and then dry roasting. In storage tests of up to 16 weeks, descriptive sensory analysis indicated the shelf life ranking was deep fry > blister fry > dry roast. The information obtained in this study could be used for designing a process for optimal quality peanuts.

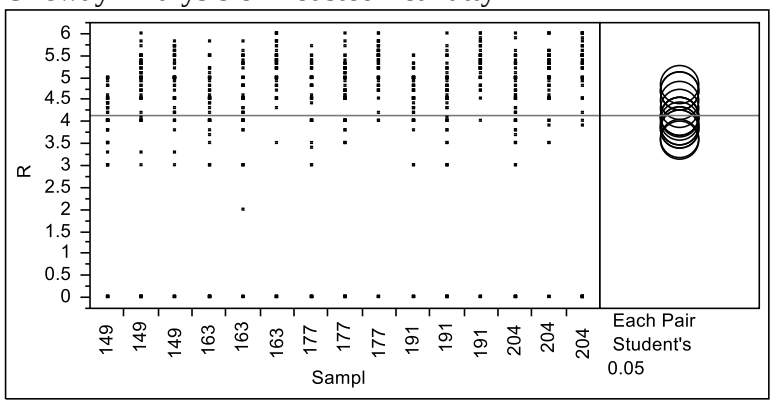
Two directions could be considered for future work. One is to scale up the batch roasting study to industrial roasting. The kinetics built in this study would be useful for predicting the temperature/time required to reach a certain surface color during industrial roasting. As the batch roaster used in this study simulated the settings of an industrial continuous belt roaster, and the batch oil roaster imitated the industrial oil roaster, the scaled up processes should be able to produce peanut products with comparable physical, sensory, and storage properties. Another direction for future work could be in expanding the kinetics to a wider color range. In this study, all preliminary and equivalent roasts resulted in average

surface Hunter L values of 25 to 65. To investigate the kinetics within wider mean color range, very light and very dark roasting will be required to push the kinetics to extremes. Different phases of color development with time are expected to be observed at a wider roast color range. At present, the kinetics cannot be directly applied to peanuts of different cultivars as the color development is sensitive to other factors other than roasting temperature and time. Most importantly, even slight changes or differences in peanut chemical compositions, such as moisture content, or sugar content, may cause deviation from the desired color. For accurate process design, peanut variety, peanut size, maturity, as well as post-harvest processing must also be carefully considered along with roasting temperature and time to achieve desired color.

APPENDICES

Appendix A. Statistics of flavor attributes of dry roasted peanuts prepared by different combinations of temperature and time

Oneway Analysis of Roasted Peanutty



Missing Rows
658

Means Comparisons

Comparisons for each pair using Student's t

Confidence Quantile

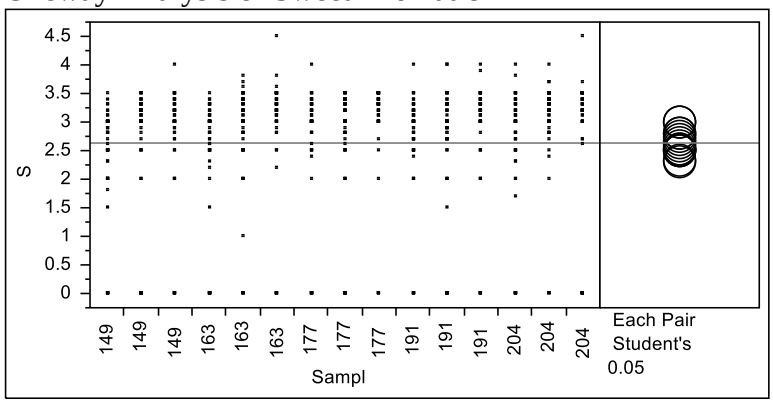
t	Alpha
1.96248	0.05

Connecting Letters Report

Level						Mean
177M	A					4.8515625
204L	A	B				4.7125000
191M	A	B				4.6984375
163M	A	B	C			4.4796875
149M	A	B	C	D		4.3046875
204M		B	C	D	E	4.1296875
163L		B	C	D	E	4.1125000
191D		B	C	D	E	4.1015625
149L			C	D	E	3.9953125
177L			C	D	E	3.9187500
204D			C	D	E	3.9015625
191L				D	E	3.8390625
177D				D	E	3.8171875
163D					E	3.6093750
149D					E	3.5750000

Levels not connected by same letter are significantly different.

Oneway Analysis of Sweet Aromatic



Missing Rows
320

Means Comparisons

Comparisons for each pair using Student's t

Confidence Quantile

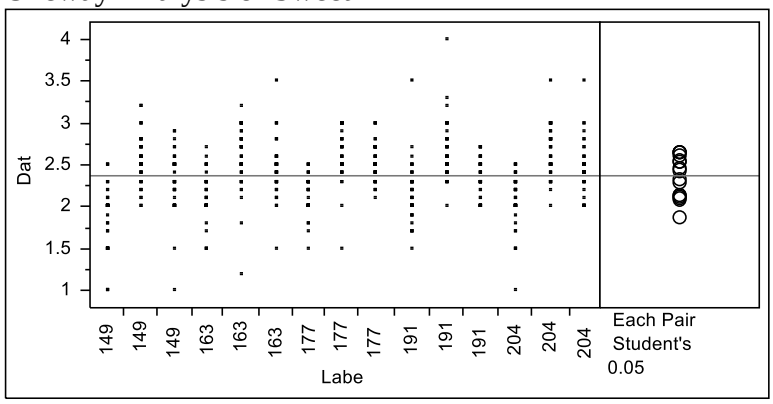
t	Alpha
1.96248	0.05

Connecting Letters Report

Level					Mean
204L	A				3.0062500
177M	A				2.9984375
191M	A	B			2.8187500
163M	A	B			2.7937500
163L	A	B			2.7484375
149M	A	B	C		2.7046875
191D	A	B	C	D	2.6406250
204M		B	C	D	2.5859375
204D		B	C	D	2.5375000
177L		B	C	D	2.5140625
191L		B	C	D	2.5031250
177D		B	C	D	2.5000000
149L		B	C	D	2.4984375
149D			C	D	2.3468750
163D				D	2.3015625

Levels not connected by same letter are significantly different.

Oneway Analysis of Sweet



Missing Rows
139

Means Comparisons

Comparisons for each pair using Student's t

Confidence Quantile

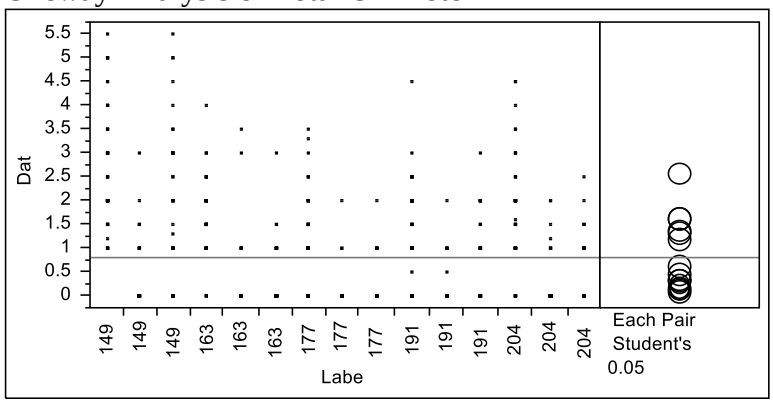
t	Alpha
1.96291	0.05

Connecting Letters Report

Level								Mean
177L	A							2.6490566
204L	A							2.6483333
191L	A	B						2.6452830
163L	A	B						2.6155172
149L	A	B	C					2.5461538
177M		B	C					2.5389831
163M			C					2.4545455
204M			C	D				2.4360000
191M				D	E			2.3368421
149M					E			2.2928571
191D						F		2.1438596
177D						F		2.1294118
163D						F		2.1137255
204D						F		2.0944444
149D							G	1.8727273

Levels not connected by same letter are significantly different.

Oneway Analysis of Total Off Note



Missing Rows
143

Means Comparisons

Comparisons for each pair using Student's t

Confidence Quantile

t	Alpha
1.96293	0.05

Connecting Letters Report

Level							Mean
149D	A						2.5685185
163D		B					1.6274510
204D		B					1.6150943
149M		B	C				1.3535714
191D		B	C				1.3157895
177D			C				1.1884615
191M				D			0.6160714
204M				D	E		0.4600000
163M				D	E	F	0.3333333
149L				D	E	F	0.3173077
163L					E	F	0.2500000
204L					E	F	0.1783333
191L					E	F	0.1415094
177M						F	0.1355932
177L						F	0.0769231

Levels not connected by same letter are significantly different.

Appendix B. Statistics of surface, paste, and oil Hunter L values of dry roasted peanuts prepared by different combinations of temperature and time

Oneway Analysis of L value

Means Comparisons
Comparisons for each pair using Student's t
Confidence Quantile

t	Alpha
1.98667	0.05

Connecting Letters Report

Level																						Mean
163LO	A																					86.960000
191LO	A																					86.266667
204LO	A	B																				85.796667
149LO	A	B	C																			85.680000
177LO	A	B	C																			85.643333
204MO		B	C	D																		83.896667
163MO			C	D	E																	83.706667
177MO				D	E	F																83.233333
191MO				D	E	F																83.150000
149MO				D	E	F	G															82.113333
163DO					E	F	G															81.776667
177DO						F	G															81.710000
204DO						F	G	H														81.253333
191DO							G	H														80.760000
149DO								H														79.413333
163LP									I													53.490000
191LP									I													53.203333
204LS									I													53.203333
191LS									I													53.196667
149L_S									I													52.910000
177LP									I													52.890000
163LS									I	J												52.483333
177LS									I	J												52.363333
149LP									I	J												52.296667
204LP										J	K											50.643333
177MP											K	L										49.660000
204MS											K	L	M									48.840000
177MS											K	L	M									48.826667
149M_S												L	M									48.503333
163MP												L	M									48.293333
191MS												L	M									48.280000
163MS												L	M	N								47.720000
149MP													M	N	O							47.316667
204MP														N	O	P						45.740000
191MP															O	P	Q					45.373333
177DP																P	Q	R				43.900000
149D_S																	Q	R	S			43.630000
177DS																	Q	R	S			43.480000
204DS																		R	S			43.340000
191DS																		R	S			43.163333
163DS																		R	S	T		42.750000
163DP																			S	T	U	41.680000
149DP																				T	U	40.830000
204DP																					U	40.700000
191DP																						V 38.670000

Levels not connected by same letter are significantly different.

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
4.08570	0.05

Connecting Letters Report

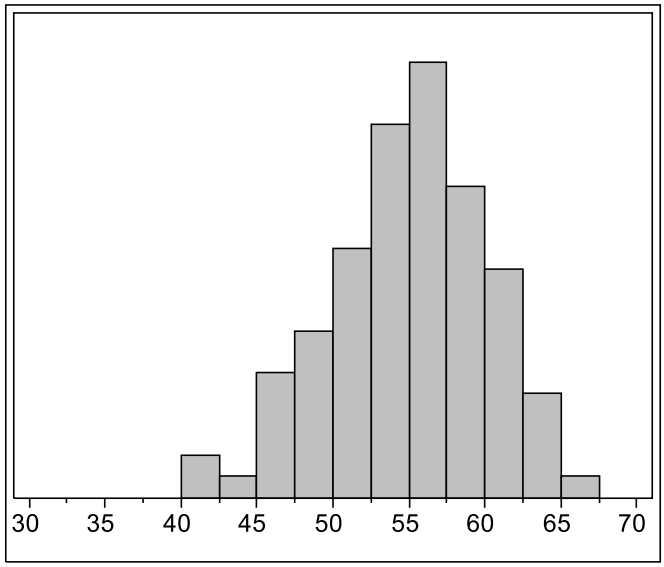
Level																				Mean
163LO	A																			86.960000
191LO	A																			86.266667
204LO	A	B																		85.796667
149LO	A	B	C																	85.680000
177LO	A	B	C																	85.643333
204MO	A	B	C	D																83.896667
163MO	A	B	C	D																83.706667
177MO	A	B	C	D	E															83.233333
191MO	A	B	C	D	E															83.150000
149MO		B	C	D	E															82.113333
163DO		B	C	D	E															81.776667
177DO			C	D	E															81.710000
204DO				D	E															81.253333
191DO				D	E															80.760000
149DO					E															79.413333
163LP						F														53.490000
191LP						F														53.203333
204LS						F														53.203333
191LS						F														53.196667
149L_S						F	G													52.910000
177LP						F	G	H												52.890000
163LS						F	G	H	I											52.483333
177LS						F	G	H	I	J										52.363333
149LP						F	G	H	I	J	K									52.296667
204LP						F	G	H	I	J	K	L								50.643333
177MP						F	G	H	I	J	K	L	M							49.660000
204MS							G	H	I	J	K	L	M	N						48.840000
177MS								H	I	J	K	L	M	N						48.826667
149M_S									I	J	K	L	M	N						48.503333
163MP										J	K	L	M	N						48.293333
191MS											K	L	M	N						48.280000
163MS												L	M	N	O					47.720000
149MP												L	M	N	O	P				47.316667
204MP													M	N	O	P	Q			45.740000
191MP														N	O	P	Q			45.373333
177DP															O	P	Q	R		43.900000
149D_S																P	Q	R		43.630000
177DS																P	Q	R		43.480000
204DS																P	Q	R		43.340000
191DS																	Q	R		43.163333
163DS																	Q	R		42.750000
163DP																	Q	R	S	41.680000
149DP																		R	S	40.830000
204DP																		R	S	40.700000
191DP																			S	38.670000

Levels not connected by same letter are significantly different.

Appendix C. Statistics of single seed Hunter L values of deep fried, blistered fried, and dry roasted peanuts roasted to equivalent surface colors.

Distributions

Deep_L



Quantiles

100.0%	maximum	65.77
99.5%		65.77
97.5%		64.0915
90.0%		61.107
75.0%	quartile	58.6225
50.0%	median	55.375
25.0%	quartile	51.6525
10.0%		47.687
2.5%		42.3953
0.5%		41.16
0.0%	minimum	41.16

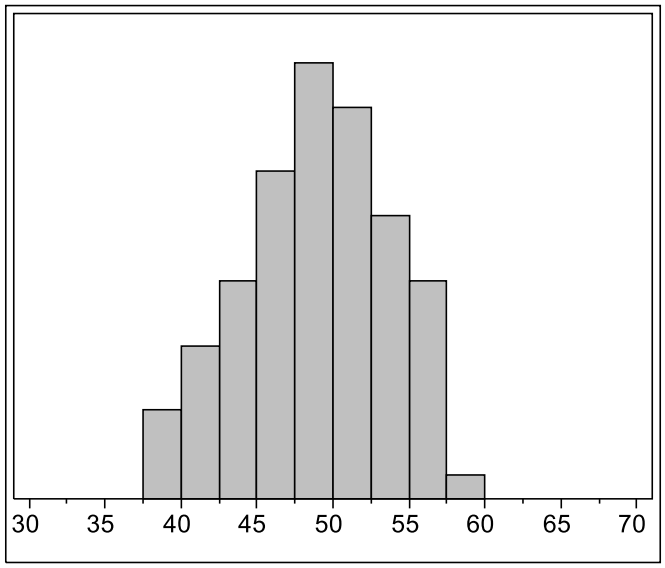
Summary Statistics

Mean	54.8922
Std Dev	5.1511959
Std Err Mean	0.5151196
Upper 95% Mean	55.914309
Lower 95% Mean	53.870091
N	100

All Modes

Modes	Count
53.62	2
47.36	
59.23	

Deep_M



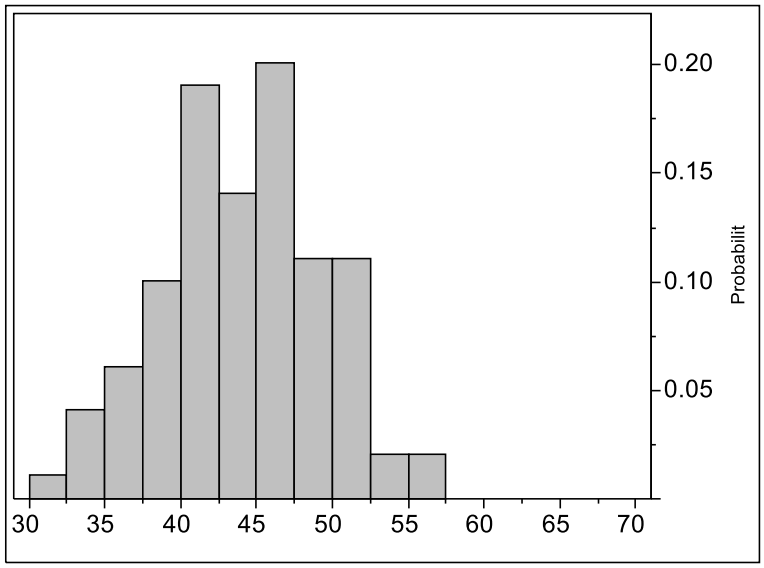
Quantiles

100.0%	maximum	59.46
99.5%		59.46
97.5%		56.8645
90.0%		55.188
75.0%	quartile	52.3225
50.0%	median	48.97
25.0%	quartile	45.315
10.0%		42.113
2.5%		38.8163
0.5%		38.27
0.0%	minimum	38.27

Summary Statistics

Mean	48.77898
Std Dev	4.7388629
Std Err Mean	0.4786974
Upper 95% Mean	49.729062
Lower 95% Mean	47.828898
N	98

Deep_D



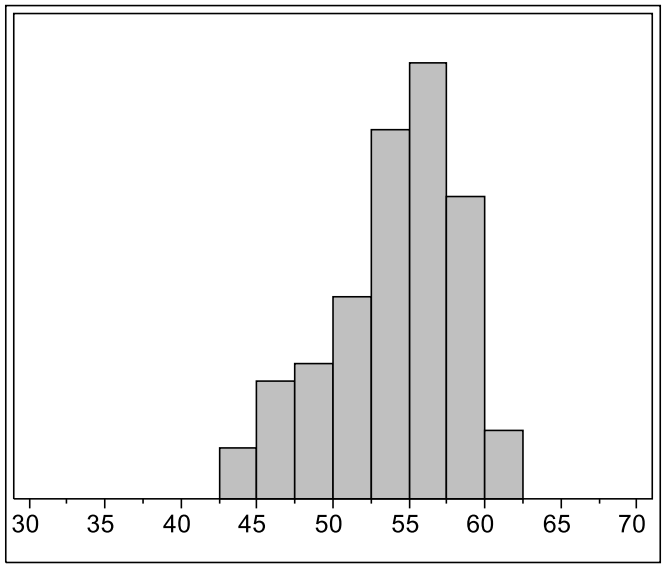
Quantiles

100%	maximum	55.74
50%	median	44.41
0%	minimum	31.48

Summary Statistics

Mean	44.1081
Std Dev	5.217372
Std Err Mean	0.5217372
Upper 95% Mean	45.14334
Lower 95% Mean	43.07286
N	100

Blister_L



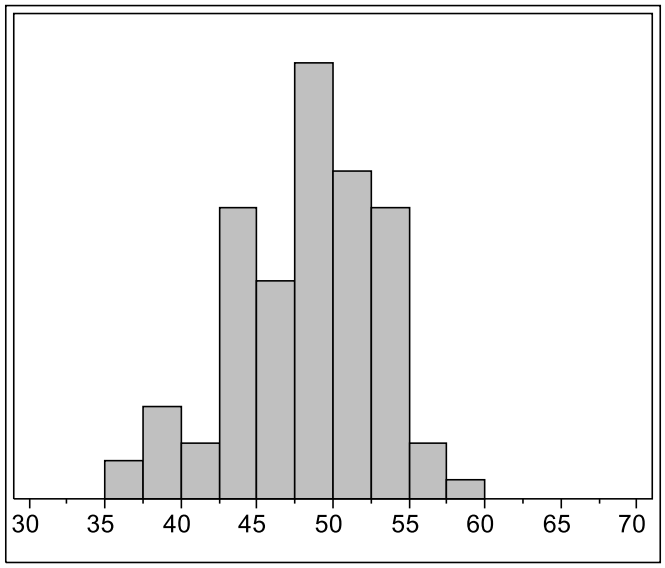
Quantiles

100.0%	maximum	61.36
99.5%		61.36
97.5%		60.707
90.0%		58.494
75.0%	quartile	57.3175
50.0%	median	54.845
25.0%	quartile	51.215
10.0%		47.272
2.5%		43.3888
0.5%		42.74
0.0%	minimum	42.74

Summary Statistics

Mean	53.9358
Std Dev	4.1779965
Std Err Mean	0.4177997
Upper 95% Mean	54.764805
Lower 95% Mean	53.106795
N	100

Blister_M



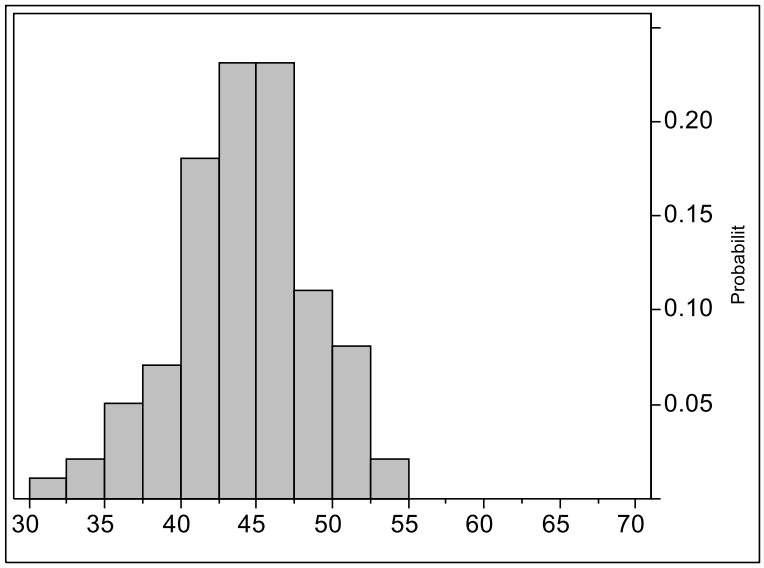
Quantiles

100.0%	maximum	58.85
99.5%		58.85
97.5%		56.6188
90.0%		54.307
75.0%	quartile	51.9475
50.0%	median	48.525
25.0%	quartile	44.885
10.0%		41.917
2.5%		37.4505
0.5%		37.12
0.0%	minimum	37.12

Summary Statistics

Mean	48.2132
Std Dev	4.7966488
Std Err Mean	0.4796649
Upper 95% Mean	49.164959
Lower 95% Mean	47.261441
N	100

Blister_D



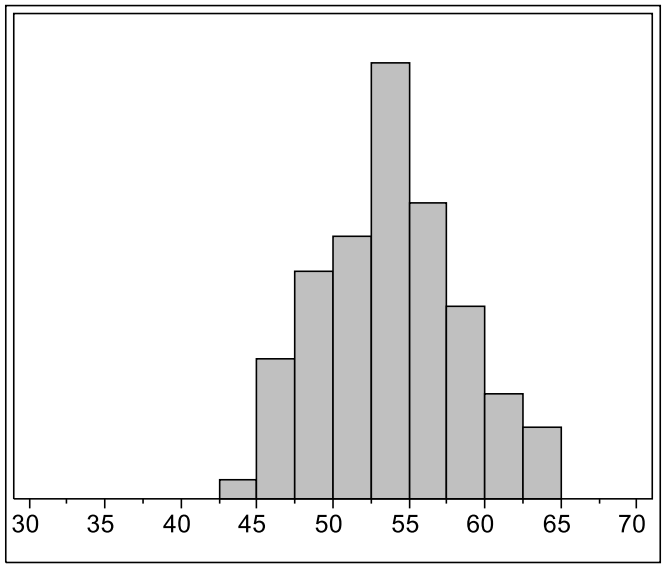
Quantiles

100.0%	maximum	53.47
99.5%		53.47
97.5%		52.4818
90.0%		50.012
75.0%	quartile	46.9325
50.0%	median	44.585
25.0%	quartile	41.7975
10.0%		38.001
2.5%		34.4583
0.5%		32.05
0.0%	minimum	32.05

Summary Statistics

Mean	44.1742
Std Dev	4.3657786
Std Err Mean	0.4365779
Upper 95% Mean	45.040465
Lower 95% Mean	43.307935
N	100

Dry_L



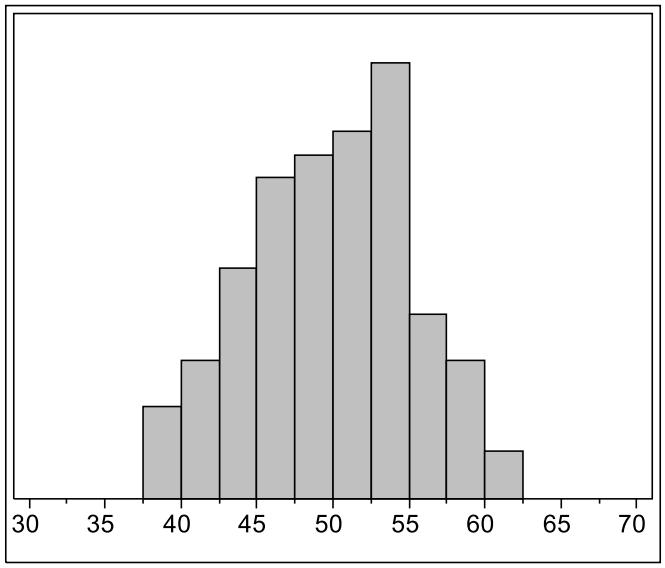
Quantiles

100.0%	maximum	63.26
99.5%		63.26
97.5%		63.005
90.0%		60.173
75.0%	quartile	56.9475
50.0%	median	53.82
25.0%	quartile	50.725
10.0%		47.582
2.5%		45.5873
0.5%		44.8
0.0%	minimum	44.8

Summary Statistics

Mean	53.9507
Std Dev	4.3940095
Std Err Mean	0.439401
Upper 95% Mean	54.822567
Lower 95% Mean	53.078833
N	100

Dry_M



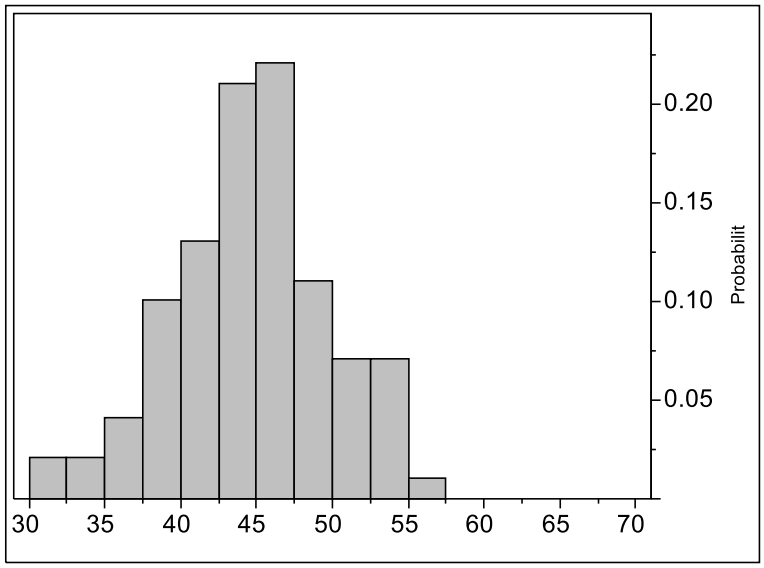
Quantiles

100.0%	maximum	62.12
99.5%		62.12
97.5%		60.4343
90.0%		56.32
75.0%	quartile	53.255
50.0%	median	50.045
25.0%	quartile	45.7425
10.0%		42.482
2.5%		38.4275
0.5%		37.62
0.0%	minimum	37.62

Summary Statistics

Mean	49.7001
Std Dev	5.3374735
Std Err Mean	0.5337473
Upper 95% Mean	50.759171
Lower 95% Mean	48.641029
N	100

Dry_D



Quantiles

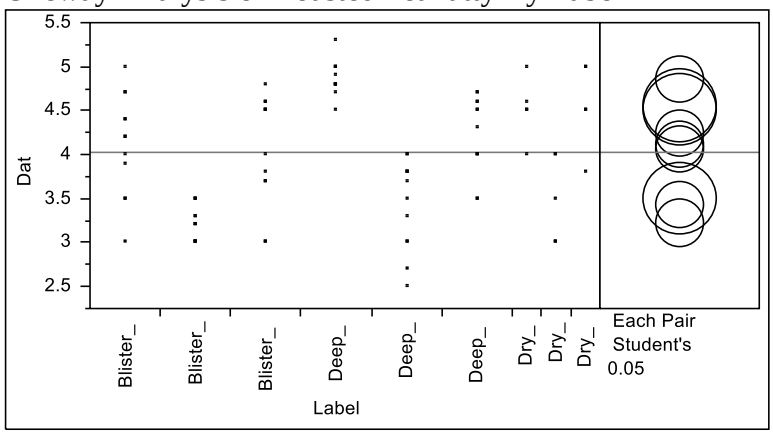
100.0%	maximum	57.24
99.5%		57.24
97.5%		54.439
90.0%		51.975
75.0%	quartile	47.6025
50.0%	median	44.76
25.0%	quartile	41.5225
10.0%		37.983
2.5%		33.049
0.5%		30.77
0.0%	minimum	30.77

Summary Statistics

Mean	44.6605
Std Dev	5.1948711
Std Err Mean	0.5194871
Upper 95% Mean	45.691275
Lower 95% Mean	43.629725
N	100

Appendix D. Statistics of flavor attributes of deep fried, blistered fried, and dry roasted peanuts roasted to equivalent surface colors of light (L), medium (M), and dark (D).

Oneway Analysis of Roasted Peanutty By Label



Missing Rows
21

Means Comparisons

Comparisons for each pair using Student's t

Confidence Quantile

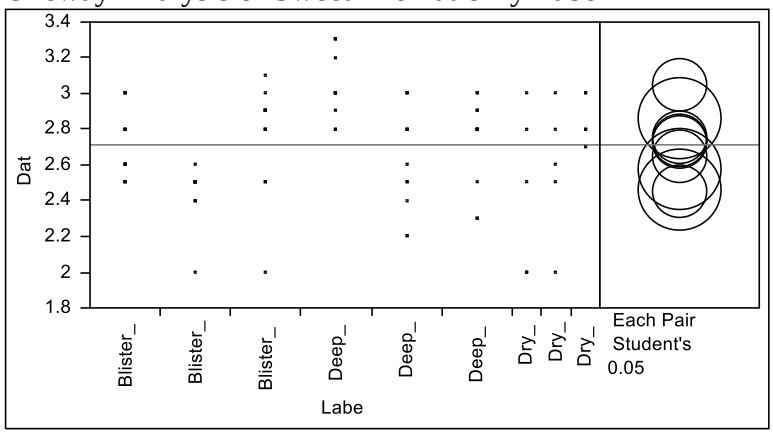
t	Alpha
1.99085	0.05

Connecting Letters Report

Level					Mean
Deep_D	A				4.8666667
Dry_M	A	B			4.5600000
Dry_D	A	B	C		4.5200000
Deep_M		B	C		4.2416667
Blister_D		B	C		4.1250000
Blister_M			C		4.0583333
Dry_L				D	3.5000000
Deep_L				D	3.4250000
Blister_L				D	3.2250000

Levels not connected by same letter are significantly different.

Oneway Analysis of Sweet Aromatic By Label



Missing Rows
21

Means Comparisons

Comparisons for each pair using Student's t

Confidence Quantile

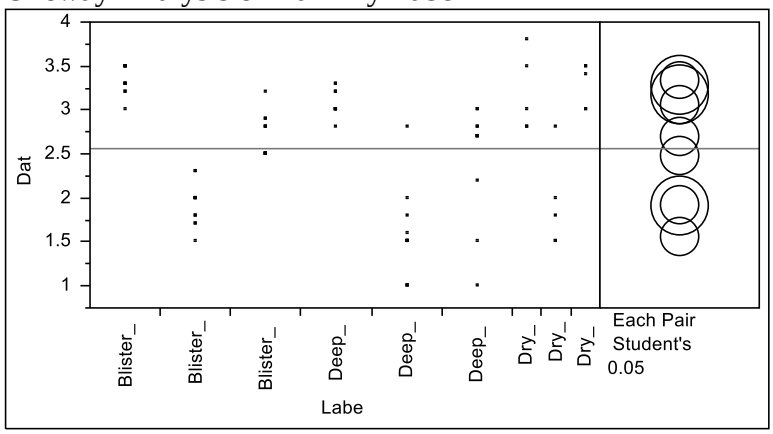
t	Alpha
1.99085	0.05

Connecting Letters Report

Level					Mean
Deep_D	A				3.0500000
Dry_M	A	B			2.8600000
Blister_M		B			2.7583333
Deep_M		B			2.7416667
Blister_D		B	C		2.7250000
Deep_L		B	C	D	2.6500000
Dry_L		B	C	D	2.5800000
Dry_D			C	D	2.4600000
Blister_L				D	2.4500000

Levels not connected by same letter are significantly different.

Oneway Analysis of Dark By Label



Missing Rows
21

Means Comparisons

Comparisons for each pair using Student's t

Confidence Quantile

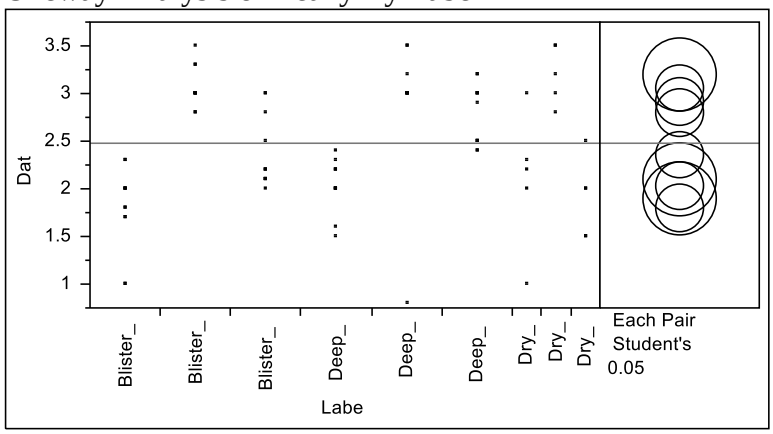
t	Alpha
1.99085	0.05

Connecting Letters Report

Level					Mean
Blister_D	A				3.3416667
Dry_M	A				3.2800000
Dry_D	A				3.1800000
Deep_D	A				3.0666667
Blister_M		B			2.7000000
Deep_M		B			2.4833333
Blister_L			C		1.9250000
Dry_L			C	D	1.9200000
Deep_L				D	1.5583333

Levels not connected by same letter are significantly different.

Oneway Analysis of Beany By Label



Missing Rows
21

Means Comparisons

Comparisons for each pair using Student's t

Confidence Quantile

t	Alpha
1.99085	0.05

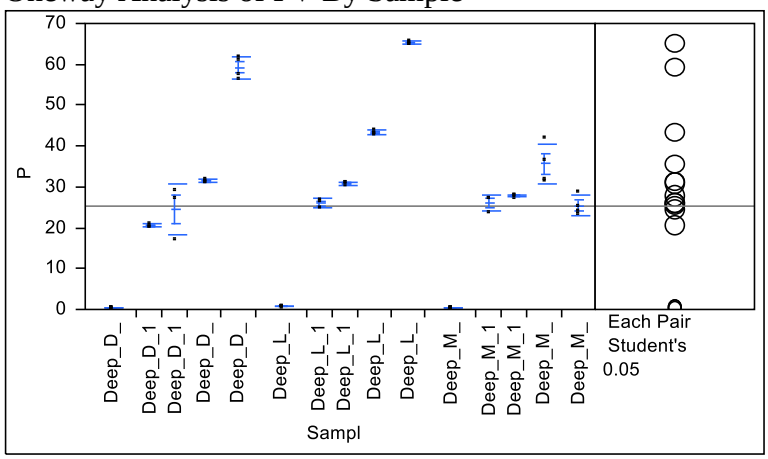
Connecting Letters Report

Level				Mean
Dry_L	A			3.2000000
Blister_L	A			3.0583333
Deep_L	A			2.9166667
Deep_M	A			2.8000000
Blister_M		B		2.3583333
Dry_D		B	C	2.1000000
Deep_D		B	C	2.0333333
Dry_M			C	1.9000000
Blister_D			C	1.8000000

Levels not connected by same letter are significantly different.

Appendix E. Statistics of peroxide values of deep fried, blistered fried, and dry roasted peanuts roasted to equivalent surface colors of light (L), medium (M), and dark (D) and stored for 0-16 weeks.

Oneway Analysis of PV By Sample



Missing Rows
1

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Deep_D_0	6	0.4367	0.06282	0.0256	0.371	0.503
Deep_D_12	3	20.5867	0.35852	0.2070	19.696	21.477
Deep_D_16	3	24.5000	6.33375	3.6568	8.766	40.234
Deep_D_4	4	31.4175	0.42524	0.2126	30.741	32.094
Deep_D_8	4	59.2100	2.65118	1.3256	54.991	63.429
Deep_L_0	6	0.6717	0.07627	0.0311	0.592	0.752
Deep_L_12	3	26.0033	1.09418	0.6317	23.285	28.721
Deep_L_16	3	30.8333	0.39107	0.2258	29.862	31.805
Deep_L_4	4	43.3225	0.48321	0.2416	42.554	44.091
Deep_L_8	4	65.2600	0.32527	0.1626	64.742	65.778
Deep_M_0	6	0.3767	0.01366	0.0056	0.362	0.391
Deep_M_12	3	26.0767	1.94731	1.1243	21.239	30.914
Deep_M_16	3	27.8200	0.37027	0.2138	26.900	28.740
Deep_M_4	4	35.5925	4.89082	2.4454	27.810	43.375
Deep_M_8	4	25.4675	2.44986	1.2249	21.569	29.366

Means Comparisons
Comparisons for each pair using Student's t
Confidence Quantile

t	Alpha
2.01410	0.05

Connecting Letters Report

Level									Mean
Deep_L_8	A								65.260000
Deep_D_8		B							59.210000
Deep_L_4			C						43.322500
Deep_M_4				D					35.592500
Deep_D_4					E				31.417500
Deep_L_16					E	F			30.833333
Deep_M_16						F	G		27.820000
Deep_M_12							G		26.076667
Deep_L_12							G		26.003333
Deep_M_8							G		25.467500
Deep_D_16							G		24.500000
Deep_D_12								H	20.586667
Deep_L_0								I	0.671667
Deep_D_0								I	0.436667
Deep_M_0								I	0.376667

Levels not connected by same letter are significantly different.