ABSTRACT

DEBRUCE, MINIAYAH TYASIA. Influence of Moisture Content on Quality and Shelf-life of Oil Roasted Virginia-type Peanuts. (Under the direction of Dr. Timothy H. Sanders and Dr. Lisa Dean).

Consumer studies have shown that oil roasted peanuts are preferred by many consumers; however, oil roasting of food products often increases oil content. Numerous factors can affect roasting oil uptake including moisture content. Moisture content is measured and monitored throughout processing in the peanut industry. The moisture content of shelled peanuts used for processing, may range from 5.5% – 8.5%. The purpose of this study was to determine if pre-roast moisture content has an effect on the amount of oil uptake or exchange that occurs during oil roasting of virginia market type peanuts and also to determine the effect of pre-roast moisture content on the physical characteristics, sensory attributes and storage quality of oil roasted peanuts.

Peanuts with wet weight moistures of 4.2%, 4.5%, 5.8% and 6.6% were roasted in peanut oil and placed in storage for 48 weeks. Higher pre-roast moisture content samples had significantly higher free fatty acids and lower oxidative stability index values; however, peroxide values were not different among pre-roast MC. Storage caused roast peanutty values to drop slowly in all pre-roast MC and lower moisture content had higher roast peanutty flavor throughout storage. Some off-flavors, such as painty, were higher in higher pre-
roast MC samples. Lower MC peanuts exhibited increased seepage of oil.

Uptake was studied further by roasting the same peanuts used in the storage study in a peanut oil/coconut oil mixture in which the lauric acid (C12) from the coconut oil served as a marker compound. The presence of the C12 fatty acids present only in coconut-peanut fryer oil in the roasted peanuts indicated uptake did take place. Oil uptake was slightly higher at lower pre-roast MC. The lower MC also had much greater amounts of surface oil than the higher MC. Surface oil fatty acid profiles were similar to fryer oil profiles. The surface oil from higher MC was most like the fryer oils. With decreasing MC, the surface oil had a corresponding decrease in C12:0 content which was interpreted as dilution from endogenous oil present in the peanuts prior to roasting. In raw samples, true density, bulk density did not vary much with pre-roast MC. Increasing pre-roast MC was associated with slightly lower true density and lower bulk density in roast samples. Porosity data was difficult to interpret due to noise in the data but there was an increase in porosity in roasted samples with higher pre-roast MC. Scanning electron microscopy images revealed that more structural damage was prevalent after roasting on peanuts with high moisture content than those with low moisture content.
Influence of Moisture Content on Quality and Shelf-life of Oil Roasted Virginia-type Peanuts

by
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DEDICATION

Dedicated to my brothers Takeem Champion, Khalil Macklin and Ranier Champion,
my nieces Arielle Champion and Camryn Champion and in loving memory of my
mother, Paula DeBruce Champion
Miniayah Tyasia DeBruce was born on August 14, 1985 in Queens, New York. She graduated from Bowie High School in Bowie, Maryland May 2003. Immediately following high school Miniayah received her first experience in food science. She attended a summer apprenticeship program at Alabama Agricultural and Mechanical University. This experience led to her to complete her undergraduate degree at Alabama A&M University. While attending A&M Miniayah was very active working as an undergraduate research assistant her entire tenure; as well as an active member of the food science club. Miniayah graduated May 2007 Magna Cum Laude with a B. S. degree in Food science and Technology and a minor in Chemistry. Miniayah continued her education and by attending North Carolina State University to obtain a Master’s in Food Science with a minor in nutrition.
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To my parents; Robert Champion and Paula DeBruce Champion thank you for planting the seed of education and determination. To my second mom Evelyn
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Approximately 60% of the peanuts produced in the United States are processed into foods such as peanut butter, salted peanuts, confections and roasted peanuts (Moss and Rao, 1995). Roasted salted peanuts are one of the most commonly consumed products around the world (Nepote et al., 2009). The quality of roasted peanuts is thus vital to the peanut industry.

One important quality factor to the peanut industry is moisture content (Kandala et al., 2008). Chemical reaction rates can be increased by increased moisture content (Chiou and Tsai, 1989). Moisture content is important both before and after processing. Moisture content affects the stability, quality, and texture of roasted peanut products (Lee and Resurreccion, 2006).

Oil roasting provides unique properties for finished products and is used widely to roast peanuts; however, industry and consumer concerns exist regarding the potential for increased oil content after roasting (Pinthus et al., 1995). Frying involves several individual complex processes such as moisture loss, protein denaturation, crust formation, starch gelatinization, oil/fat uptake and microstructural changes in the food (Blumethnal, 1991). Roasting can result in damage to surface cells and roasting oil can penetrate the food at these locations; however, most of the oil uptake occurs after the food is removed from the fryer (Moreira et al., 1997). During roasting water becomes steam and escapes from the
food product. The pores created by the escaping steam become points of entry by
the oil when the food leaves the fryer (Moreira et al., 1999). Oil uptake during
roasting can be affected by oil temperature, duration of roasting, type and quality of
the oil, moisture content, and size and shape of the product (Pokorny, 1999).

After roast processing, lipid oxidation is a major concern in preservation of
high quality. Oxidation of the oil may occur during storage and is often the cause of
the perception of the common term, rancidity, and other off flavors in peanuts
(Nepote et al., 2006). Peanuts contain approximately 50% oil and this oil contains
high levels of mono and polyunsaturated fatty acids. The fatty acids are the major
reactants resulting in lipid oxidation (Nepote et al., 2008). The relationship of
moisture content and the rate of lipid oxidation are important to understanding
shelf-life and overall maintenance of quality of food products (Nelson and Labuza,
1992). Studies have demonstrated that maximum stability of food products occurs at
lower moisture contents and stability decreases with increasing moisture content.

In consideration of these facts, the primary objective of this study was to
determine the effect of pre-roast moisture content on roasting oil uptake/exchange
during and/or after oil roasting of virginia-type peanuts. In this study, peanuts were
air dried to sequential preselected moisture contents, shelled, and sized to obtain a
single grade size before they were oil roasted. The roasting oil contained a marker
compound, lauric acid (C12:0), from the addition of coconut oil, which was used to
determine uptake and/or exchange of roasting oil in the peanuts. The second
objective of the research was to determine the effect of pre-roast moisture content on
the physical, chemical and sensory characteristics of oil roasted virginia-type
peanuts. Peanuts of various moisture contents were oil roasted before storage under
nitrogen. The chemical and sensory properties of the oil were determined as
measures of quality over 48 weeks of controlled storage.
REFERENCES


CHAPTER 2: LITERATURE REVIEW
Peanuts

History and Origin

Majority of nuts are consumed as snacks in which peanuts (*Arachis hypogaea* L.) are one of the most commonly consumed (King et al., 2008). Peanuts are one of few plants that form underground fruits (Moss and Rao, 1995). The leading producers of peanuts are India, China and the United States (Sanders et al., 1993). This legume is a cultivated species grown widely throughout the tropics and subtropics areas. The early Spanish and Portuguese explorers found the indigenous people cultivating the peanut in the West Indies, Brazil, Mexico and in the Rio de la Plata Basin of South America including Argentina, Peru, Paraguay, and Bolivia. This important commodity was then spread from these regions to Europe, Africa, Asia, the Pacific Islands and the United States (Hammons, 1973).

The foundation of the multibillion dollar U.S. peanut industry is the unique flavor of roasted peanuts (Sanders et al., 1989). In the United States, most of the peanuts produced are used in the manufacture of peanut butter; however, in other countries the majority of peanuts are used for oil. Peanuts are considered one of the five most important oilseeds worldwide (Carley and Fletcher, 1995).
Market Types

Peanuts are generally classified into the four market types, runner, spanish, valencia and virginia, each having specific compositional and seed size attributes (Ahmed and Young, 1982; Adsule et al., 1989). Runner-type peanuts have been popular because of the desirable pod and seed size and account for about 75% of the total production in the United States. The runner type is mostly grown in Georgia, Alabama, Florida, Texas and Oklahoma (Sholar et al., 1995). The pods and seeds of the virginia-type are the largest size and account for most of the roasted in shell peanuts. A total of about 18% of the U.S. peanut production is the virginia-type which is produced mainly in Texas and the Virginia- Carolina area. Spanish market type peanuts account for approximately 6% of the total U.S. production and are primarily used for salted nuts, and peanut candy. Spanish peanuts have small seeds, reddish brown testa, and are grown in Oklahoma, Texas and New Mexico (Sholar et al., 1995). The last market type is characterized by having three or more seeds per pod. Valencia market type peanuts are mostly found commercially as roasted and in shell or as boiled peanuts; and only account for approximately 1% of the total U.S. production.
Peanut Growth, Handling and Composition

Peanut Growth

Peanuts have an indeterminate flowering pattern, that is the flowering and initiation of peanut development transpires over an extended period of time (Sanders et al., 1995). Peanut planting in the U.S. generally occurs from March to May depending on geographical location (Sholar et al., 1995). The flowers of the peanut begin to form approximately 25-30 days after planting (Ketring, 1982). After fertilization, the fertilized ovary begins to elongate into a peg, which grows into the soil due to a positive geotropic response. After penetration of the soil to about an inch the peg stops elongating and fruit development occurs (Moss and Roa, 1995).

Harvesting

Peanuts are usually harvested when about 70 percent of the peanuts have reached maturity. At an optimum harvesting time more mature pods are obtained which generally corresponds with the highest yield (Sanders and Bett, 1995). Harvesting in the United States is highly mechanized and includes all operations involving the removal of peanuts from the soil and separating them from the vines. Digging and combining are the two main steps of harvesting. Digging is generally accomplished with a digger-shaker-inverter. The digger cuts the tap root then lifts
and shakes the plant before depositing the peanut plant inverted into a windrow, in which the peanut pods on top are exposed to the air (Young et al., 1982).

The curing process is also mechanized and refers to the drying of the peanut to a moisture content that is considered safe for maintenance of quality during storage (Young et al., 1982). Curing begins with windrow drying of peanuts in which peanuts are exposed to ambient air and sunlight in order to reduce moisture content to 18-25%. After windrow drying, peanuts are combined and placed in wagons for further drying with heated air. During wagon drying, ambient air is forced upward through the perforated floor of the wagon and through the peanuts. Initially a drying zone is created at the bottom and moves upward through the peanuts until the drying process is complete (Young et al., 1982).

Peanuts are dried to an average moisture content of 10% (Sanders et al., 1987). Moisture content can be expressed in either wet-basis (w.b.), which is used in the marketing system, or dry basis (d.w.) which is a more convenient method for determining the amount of moisture to be removed during drying (Young et al., 1982).
Maturity

Maturity is a factor that must be considered in all aspects of curing and storage (Sanders et al., 1987). Maturity or maturation can be defined as the extent of the interactions of genetic potential, physiological and biochemical processes that produce the chemical composition of the peanut seed (Sanders et al., 1995). Maturity is significantly related to many quality characteristics and the maturity distribution within a grade size will significantly influence flavor, roast color, storage and other quality characteristics (Sanders, 1989). Immature peanuts have less potential for full roast flavor and higher potential for off-flavor in peanuts of the same grade size (Sanders et al., 1989).

Maturity determination is often used to indicate optimum harvest time. The Hull Scrape method or the Pod Maturity Profile is a nondestructive method that involves scraping a portion of the pod exocarp, to reveal various colors and structural characteristics that allow for visual maturity determination. These colors which range from white to black (Figure 1) are present in the mesocarp, which is the middle layer of the hull consisting of sclerenchyma tissue that forms the mechanical or supportive structure of the hull (Williams et al., 1987). Classes one and two are white in mesocarp color, three is light yellow, four deep yellow, five orange to brown, six is brown and seven is black (Figure 1) (Williams and Drexler, 1981).
Storage Stability

Seed composition is associated with the storage stability of peanut based foods. One of the contributing factors to the instability during storage is the high fat content of peanuts (Shewfelt and Young, 1977). Peanuts are a semiperishable crop; however, when exposed to suitable storage environments they can be stored for years (Woodroof, 1983). The recommended conditions for dry bulk storage of farmer’s stock (unshelled) peanuts are about 7.5% seed moisture content (w.b.) at 10°C. If these conditions are met, peanuts can be maintained with little loss in quality (Davidson et al., 1982). Peanuts are usually stored in shell in farmer’s stock storage.
warehouses including tanks, bins, concrete silos and flat-type storages. Peanuts in the United States are generally stored in flat-type storages, which are popular because of low initial cost and ease of loading and unloading. Individual peanut pods normally range between 5-15% moisture due to maturity and drying conditions when placed in storage (Davidson et al., 1982).

Storage stability of shelled peanuts is affected by the degree of unsaturation of the oil, moisture content, and storage time (Shewfelt and Young, 1977). Shelf-life stability of raw and roasted peanuts is affected by whether the peanuts are stored with or without skins (Woodroof, 1973). The storage life of shelled, roasted, salted peanuts is approximately three weeks at room temperature (Shewfelt and Young, 1977). Roasted peanuts are placed in packaging to extend shelf-life including vacuum-packed cans/glass jars, cellophane/glassine bags or nitrogen flushed laminated foil packs. The use of nitrogen flushed packaging can give a 1-2 year shelf-life (Heinis and Young, 1987).

**Moisture Content and Water Activity**

In roasted peanuts, water activity and moisture content affect stability, quality, and texture of the final products (Lee and Resurrecion, 2006). Determining moisture of raw peanuts is usually a prerequisite step in establishing the roasting
process. An increase in moisture content can cause an increase in chemical reaction rates; nevertheless, excessive moistures will decrease chemical reactivity (Chiou and Tsai, 1989). During storage, moisture contents of 9% resulted in significant deterioration of quality when compared to moisture contents of 6% (Pattee and Young, 1982).

Water activity, or the amount of water available for chemical reaction, can affect deterioration of foods. Both sensory and chemical properties may be affected by water activity of storage (Baker et al., 2002). In many foods, lipid oxidation and water activity correlate (Leung, 1987). Water activity can have a major effect on oxidation rates; thus, affecting off flavor compound formation (Reed et al., 2002).

**Sugar Content**

Sugars are the simplest carbohydrate molecule. Carbohydrates contribute to various properties of foods such as flavor, texture and aroma (Horton, 2006). Peanut seeds have an approximate carbohydrate content of 10% in which sucrose and starch are the major constituents (Salunkhe et al., 1992). The total available carbohydrate fraction of peanuts consists of water soluble carbohydrates (monosaccharides, disaccharides) and oligosaccharides (including starch, stachyose and raffinose) (Savage and Keemam, 1994). There are six sugars commonly found in peanuts
including glucose, fructose, myo-inositol, raffinose, stachyose, and sucrose (Oupadissakoon et al., 1980).

Photosynthesis in plants produces sugars in the leaves which are translocated into the seed of the plant. The peanut plant converts those sugars into starches during development and as a starch; they are converted into oil during maturation. The sugar concentration in peanuts decreases as the peanut matures (Pattee et al., 1974).

**Peanut Oil**

Peanuts are a major oil seed crop. In countries such as India, most peanuts are used for extraction of edible oils; whereas, most of the production in the U.S. goes to peanut products such as peanut butter and salted peanuts (Damamae et al., 1990). Peanuts have high oil content, and the composition of the oil defines peanut quality. Peanuts contain approximately 50% oil, of which the fatty acids palmitic (16:0); oleic (18:1) and linoleic (18:2) together constitute 90% of the fatty acid (Grosso and Guzman, 1995). Shelf life of peanut products is highly dependent on oil stability (Mugendi et al., 1998). A high level of unsaturated fatty acids increases the potential for off flavor development in foods (Mugendi et al., 1998). High linoleic acid content is undesirable because it decreases the shelf-life of peanuts. Conversely, nutritionally
linoleic acid is more desirable because of its hypocholesterolemic effect (Sekhon et al., 1972). Thus, from a quality aspect, a higher ratio of oleic acid to linoleic acid is more desirable and indicates a more stable oil (Young and Waller, 1972; Taira, 1985).

**Flavor Development**

**Malliard Reaction**

Flavor plays a major role in the success of the peanut industry in America. The main factor that affects flavor development in peanuts is maturity because maturity determines protein, oil, moisture content, and carbohydrate composition (Sanders, 1989). Second to the formulation of peanut butter, most peanuts are consumed as roasted peanuts. Roasting is a cooking process applied to peanuts for the development of a unique and desirable flavor (Oupadissakoon and Young, 1984). The most significant attribute in the flavor of roasted peanuts is described as roasted peanutty flavor, which may be related to pyrazines developed through the Maillard reaction. The Maillard reaction, also known as a browning reaction, is a sugar-amine nonenzymatic reaction. This chemical reaction results in a mixture of flavor, antioxidant, and color compounds, both desired and undesired, during frying, roasting, or baking (Bailey, 1992).
Sensory Analysis: Descriptive Analysis

Descriptive sensory is a useful tool that can track product changes over time aiding in gathering a clear understanding of shelf life (Murray et al. 2001). With the use of a trained panel descriptive sensory involves discrimination and description of both the qualitative and quantitative sensory components of a consumer product (Meilgaard et al., 1991). Descriptive analysis has been used to describe attributes of various peanut products, such as peanut paste (Muego-Gnanasekharan and Resurreccion, 1993) by detecting and describing sensory aspects of a product both qualitative and quantitative. The use of trained individual panelist was developed in the 1970’s with the Quantitative Descriptive Analysis (QDA) and the Spectrum™ method of descriptive sensory. These methods generate a panel average based on the scores given by the trained panel (Piggott et al., 1998). The use of flavor lexicons, a simple set of words to describe the flavor of a product or commodity, is common. Lexicons are applied using descriptive sensory analysis techniques and offer a source list to describe a product (Drake and Civille, 2003).

In 1975, at North Carolina State University, the first trained descriptive panel for roasted peanut flavor was established in which the descriptive terminology included three categories and 14 sensory character notes (Oupadissakoon and
The peanut flavor lexicon used at North Carolina State University was expanded upon in 1986 (Johnsen et al., 1988) followed by the addition of the “fruity fermented” term by Sanders et al in 1989. The current peanut flavor lexicon includes the terms, roasted peanutty, raw bean/peanutty, dark roasted peanut, sweet aromatic, woody/hulls/skins, cardboard, painty, burnt, green, earthy, grainy, fishy, chemical/plastic, skunky/mercaptan, sweet, sour, salty, bitter and the chemical feeling factors astringent and metallic (Johnsen et al., 1988). The flavor lexicon is generally descriptive and discriminating and used to document and describe sensory perception of selected foods (Drake and Civille, 2003). Intensity of off flavors through descriptive panels could be useful variables for predicting consumer response to stored peanut products (Nepote et al., 2009).
Table 1: Selected Attributes of the Peanut Flavor Lexicon

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roasted peanutty</td>
<td>Aromatic associated with medium-roast peanuts (about 3-4 on USDA color chips) and having fragrant character such as methylpyrazine</td>
</tr>
<tr>
<td>Raw bean/peanutty</td>
<td>Aromatic associate with light-roast peanuts (about 1-2 on USDA color chips) and having legume like character (specify beans or pea if possible)</td>
</tr>
<tr>
<td>Dark Roast peanut</td>
<td>The aromatic associated with dark-roasted peanuts (4+ on USDA color chips) and having very browned or toasted character</td>
</tr>
<tr>
<td>Sweet aromatic</td>
<td>Aromatics associated with sweet material such as caramel, vanilla, molasses, fruit (specify type)</td>
</tr>
<tr>
<td>Off-flavors</td>
<td></td>
</tr>
<tr>
<td>Cardboard</td>
<td>Aromatic associate with somewhat oxidized fats and oils and reminiscent of cardboard</td>
</tr>
<tr>
<td>Painty</td>
<td>Aromatic associated with linseed oil, oil-based paint</td>
</tr>
</tbody>
</table>

Adapted from Johnsen et al. 1988

Lipid Oxidation

The fatty acid composition of peanuts makes peanuts susceptible to lipid oxidation (Braddock et al., 1995; St. Angelo, 1996; Frankel, 2005). Lipid oxidation is the main source of flavor deterioration and off flavor development (Reed et al., 2002). Lipid oxidation is associated with the formation of volatile components such as ethanol, pentane, pentanal and hexanal which are indicators of poor peanut oil quality (Brown et al., 1977; Crippen et al., 1992). Factors such as moisture, light, oxygen or exposure to high temperatures may accelerate the lipid oxidation process.
The level of oxidation may be affected by other factors such as maturity, seed size, and processing methods; however, the most predominate factor is the fatty acid composition of the peanut (Braddock et al., 1995). As the level of polyunsaturated fatty acids increases in peanuts, so does potential for oxidation (O’Keefe et al., 1993). During processing such as roasting, the oil moves to the surface of the kernels, which causes concern for lipid oxidation that could occur during storage (Albu et al., 2004).

**Lipid Oxidation Determination**

Vercellotti et al. (1992) stated that the degree of lipid oxidation can be determined by methods such as peroxide value (PV), instrumental techniques such as gas chromatography (GC) and by sensory analysis. The measurement of lipid oxidation is essential to the determination of its effect on food and food oil quality (Perkins, 1992). Peroxide value (PV) is the measure of the state of oxidation of an oil or fat which is affected by the type and length of storage as well as the fatty acid composition of the fat or oil (Baur, 1995). The free fatty acid (FFA) content is considered an indicator of oil quality or the freshness of the oil. Oxidative stability index (OSI) measures the point of maximum change of the rate of oxidation (Baur, 1995). Descriptive sensory remains a method of determining consumers’ perception
of flavor and can be used to monitor the rate of deterioration or oxidation (Bett and Boylston, 1992). Oxidation processes increase the chemical and sensory indicators of lipid oxidation (Nepote et al., 2006).

**Effects of Lipid Oxidation on Flavor**

Oxidation during storage is a contributing factor to the development of undesirable flavors in peanuts. Lipid oxidation can cause flavor loss and an increase of off flavors. The reactions involved in lipid oxidation form compounds such as aliphatic aldehydes, ketones, and alcohols with “cardboardy” or “painty” flavor characteristics (Litman and Numrych, 1978; Forss, 1972). The sensory quality of peanut products decreases as a result of rancid flavors and oxidation products (Gills and Resurrecion, 2000; Grosso and Resurrecion, 2002). Increased storage time results in a significant reduction in roasted peanutty flavor (Bett and Boylston, 1992). Lipid oxidation causes the increase of various compounds such as hexanal, heptanal, octanal, 2-octenal, 2-decenal, 2-hexanal-1-ol, and 2-heptanone (St. Angelo, 1996). Hexanal specifically has been identified as a product of linoleic acid oxidation (Bett and Boylston, 1992). This chemical reaction causes food products to be unacceptable to the consumer (St. Angelo, 1996). The following report is based on either the Johnsen et al lexicon work or on my work on maturity. Studies by Johnsen et al
(1988) indicated when comparing flavors of fresh and oxidized peanut paste from the same peanut source, there is a decrease in the “fresh/on” peanut characteristics like roasted peanutty, sweet aromatic, sweet and an increase in the cardboardy and painty flavors (Table 2), indicating a direct effect of oxidation on flavor.

**Table 2. Example Comparison of Fresh Peanut Paste and Oxidized Peanut Paste**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Fresh</th>
<th>Oxidized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roasted Peanutty</td>
<td>6.1</td>
<td>2.7</td>
</tr>
<tr>
<td>Raw Bean/peanut</td>
<td>1.7</td>
<td>1.4</td>
</tr>
<tr>
<td>Dark roasted peanut</td>
<td>2.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Sweet aromatic</td>
<td>3.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Woody/hull/skins</td>
<td>1.2</td>
<td>2.1</td>
</tr>
<tr>
<td>Cardboardy</td>
<td>0</td>
<td>3.4</td>
</tr>
<tr>
<td>Painty</td>
<td>0</td>
<td>4.7</td>
</tr>
<tr>
<td>Sweet</td>
<td>2.9</td>
<td>1.4</td>
</tr>
<tr>
<td>Bitter</td>
<td>1.2</td>
<td>2</td>
</tr>
<tr>
<td>Astringency</td>
<td>1.6</td>
<td>2</td>
</tr>
</tbody>
</table>

Adapted from Johnsen et al, 1988

**Static Headspace Analysis**

Static headspace analysis has been a method used by researchers investigating oil flavor quality (Raghavan et al., 1994). Headspace analysis is the analysis of the gas (vapor) phase of a binary heterogeneous system in equilibrium.
The other phase in this system is either a liquid or solid (condensed phase). The analysis is commonly executed through gas chromatography measurements (Kolb and Ettre, 1997). In this technique, gas comes in contact with a liquid or solid sample and is analyzed, giving the nature and/or composition of the original sample. There are two steps to headspace-gas chromatography (HS-GC). In the first, the sample is placed in a vessel having a gas volume above it and the vessel or vial is then closed. The vial is heated to a constant temperature until equilibrium is reached between the vapor and condensed phases (Kolb and Ettre 1997). An aliquot of the headspace from the vial is introduced into the carrier gas stream of the GC, which carries it into the column where it is then analyzed. The heating process can consist of a heated metal block, an air thermostat or an oil bath. This step is very important for precise temperature control (Kolb and Ettre, 1997).

In headspace analysis, the GC peak area obtained for a given analyte is proportional to the concentration of the analyte in the analyzed sample. The conclusion that can be drawn is that if an aliquot of the headspace at equilibrium is analyzed by GC, the obtained peak area of the analyte will be directly proportional to its concentration in the original sample (Kolb and Ettre, 1997).
Oil Roasting

Oil Roasting (Frying)

One of the most widely consumed foods in the world is oil roasted peanuts (Lee and Resurrecion, 2006) which has a higher consumer acceptance than the commonly consumed dry roasted peanut (Grosso and Resurrecion, 2002). The optimization of roasting is a minimizing of both underoast and overoast characteristics to form a maximum roasted peanut flavor intensity (Pattee et al., 1991). Peanuts are either oil-roasted or dry roasted in which, oil roasting is applied to surrounding of the food with hot oil (Salunkhe et al., 1992). In oil roasting, peanuts are immersed into heated coconut, peanut or cottonseed oil for approximately 3- 5 minutes (Heinis and Young, 1987).

Oil roasting, which is the term used when referring to nuts specifically, and frying, can be considered the same. Frying is a common method of food production with unique sensory characteristics (Saguy and Dana, 2003). Oil roasting (frying) is a complex process that involves several developmental changes occurring in the food matrix such as starch gelatinization, protein denaturation, water vaporization and textural changes. During this complex process oil is absorbed by the food while water is volatilized (Ortheofer and Cooper, 1996; Perkins and Erickson, 1996). Oil roasting (frying) is a composite of particular elements including the production of
the food, the processing equipment and the processing environment itself (Steir and Blumethal, 1990). With the oil roasting operation there are several basic constant factors that must be taken into consideration: the mass of oil in the fryer, operating temperature, the make up of the food going into the fryer and the type of oil used. Oil roasting is considered a dehydration process in which the water inside of the foods is driven out into the surrounding oil, and the heat is transferred from the non aqueous medium into the aqueous medium, the food (Steir and Blumethal, 1990). The moisture in the interior of the food migrates to the surface to replace water lost on the surface. The food materials, the breakdown of the oil, and the oxygen absorption at the oil air interface all contribute to changes in the oil. The breakdown of the oil can cause changes in heat transfer and oil cooking functionality (Steir and Blumethal, 1990). Surfactants affect the heat transfer at the oil food interface, hence, reducing the initial high surface tension between the two immiscible materials. More surfactants are developed as the oil degrades and the contact between the food and oil increases (Steir and Blumethal, 1990). Consequently, excessive oil uptake by the food and increased rate of heat transfer to the surface of the food occurs. Eventually, excessive drying and darkening of the surface occurs, while the consistency in the conduction of the heat to the interior occurs (Steir and Blumethal, 1990).
Parameters of Oil Roasting

There are several contributing factors involved in frying some of which include heat transfer, mass transfer and water loss. Heat transfer is the movement of energy from one point to another or from the heat source to the oil and finally to the food being fried. The rate of heat transfer is determined by the difference in temperature. Conduction, radiation and convection are the three mechanisms of heat transfer. Conduction is when positive heat flow occurs in the direction of decreasing temperature; whereas, convection occurs when molecules move from one point to another and exchange energy (Orthoefer et al., 1996). Convection is defined as the rate of heat exchange at the interface between a fluid and a solid. Both conduction and convection are involved in frying, convection occurs from the fluid oil and conduction occurs through the food. With oil roasting water and oil are the two major factors in heat transfer. Oil provides heat transfer toward the food; whereas, water provides heat transfer within the food being fried (Orthoefer et al., 1996).

Other parameters involved in frying include mass transfer, which includes dehydration, distillation, liquid extraction and leaching. With the continuous evolution of steam, dehydration and distillation occurs giving the fried food a distinctive odor. Both extraction and leaching of particular components occur from
the food to the frying oil. During mass transfer, frying oil is absorbed into the food being fried (Orthoefer et al., 1996).

Water loss is a process that occurs to help prevent the charring of food from the hot oil. The water present at the surface evaporates in a continuous process resulting in the outward migration of water. This flow of water outward during frying is called pumping (Lydersen, 1985). While this occurs, steam is constantly being emitted indicating that the pressure in the food is greater than that of the fryer or the frying oil and this action limits the penetration of frying oil.

When food is taken out of the fryer, viscosity and product surface characteristics are increased. The decreased drainage of oil from the product, leads to higher oil uptake by the product. Oil viscosity increases considerably with extended oil roasting time (Benedito et al., 2002).

**Oil Uptake**

The initial oil used in the process of oil roasting is considered the “break in” oil which is said to have little or no surfactants. Therefore, the heat is not being transferred to the food. During this “break in” time the oil and food are in contact for only about 10% of the actual immersion time (Blumethal, 1991). At different points of oil roasting, the oil and food contact percentage changes. These points of
roasting are fresh oil, optimum oil breakdown, and runaway oil, which are at the percent contact of 20%, 80% and 90%, respectively (Steir and Blumethal, 1990). Water being forced from the food efficiently pushes the oil away from the surface of the food and without oil and food contact, heat transfer through conduction is not possible. The surface of the food remains white and uncooked resulting in the inside starches not being properly gelled. In addition, there is very little oil pick up (Steir and Blumethal, 1990). As the process the next two zones are fresh and optimum. The food produced in these zones will be fully cooked and will have an acceptable amount of oil absorbed. The increase in contact time between the surface of the food and the oil allows the oil to penetrate the surface allowing conduction heat transfer to occur (Steir and Blumethal, 1990). Furthermore, browning occurs and water is driven from the surface. The last two zones the oil goes through are the breakdown and runaway zones. The oil at this point is of low quality and has a decreased shelf-life.

With cooking methods such as oil roasting, the oil used often determines the acceptability of the food prepared in it (Perkins and Erickson, 1996). Oil is a significant portion of the resulting food product. After oil roasting this portion can be up to approximately 45% (Saguy and Pinthus, 1995). As a result of oil roasting, the oil goes through various physical and chemical changes (Fritsch, 1981). The
types of degradation occurring in oils are thermal, oxidative and hydrolytic, which produce a variety of changes in the oil (Perkins and Erickson, 1996). These changes cause an increase in viscosity, volatile materials, polarity, free fatty acid content, color development, and increase in oil foaming tendency. Additionally there are decreases in the following, iodine value, refractive index and surface tension (Perkins and Erickson, 1996). The means of oil migration is not fully understood. The internal moisture is transformed to steam which generates a pressure gradient as the surface dries out which affects the product by the oil adhering to the surface of the product and entering the product at damaged areas of the surface (Gamble and Rice, 1987). This is followed by water vapor in the pores condensing resulting in a vacuum that pulls in the oil once the product is removed from the fryer (Gamble and Rice, 1987). There is an array of factors affecting oil absorption in fried foods including oil quality and composition, roasting temperature and time, moisture content, porosity, surface treatments, and initial interfacial tension (Gamble and Rice, 1987; Pinthus et al., 1995; Blumethal, 1991). Many studies claim that higher initial moisture content increases oil uptake (Moreira et al., 1997). As initial moisture content decreases, final oil content increases according to the Rock-Dudley’s study on tortilla chips (Gamble and Rice, 1987). Besides the previous factors mentioned, other researchers state that there are other factors affecting oil uptake in oil roasting.
(frying) which include the product and its shape, oil temperature, prefrying treatments (drying, blanching), coating, surface roughness and others (Pinthus et al., 1993).

Dina and Saguy report that there are three mechanisms, which are water replacement, cooling-phase effect and surface-active agents, that have been proposed to explain the process of oil uptake during oil roasting (frying) (2006). With water replacement, the oil replaces the evaporated water when exposed to the high temperatures of oil roasting (frying) (Dina and Saguy, 2006). When this water evaporates the outer surface of the food becomes dry and a crust forms. The moisture inside of the food becomes steam and escapes through cracks or open capillaries. The oil adheres to the food and enters into these voids that were produced from the water evaporation and the structure change from drying (Dina and Saguy, 2006). Rice and Gamble stated that the mechanism of no inner resistance due to the positive water vapor pressure can explain the direct correlation between water loss and oil uptake (1989). Without the mechanisms of cooling-phase effect and surface-active agents, oil uptake can not be fully understood. When the food leaves the oil roasting (frying) medium, it starts cooling which leads to water vapor condensation and a succeeding decrease in internal pressure (Dina and Saguy, 2006). Oil that was present on the surface is now drawn in due to the vacuum effect (Dina
Oil uptake is a surface phenomenon involving equilibrium between adhesion and drainage of oil as the food is removed from the oil bath (Ufheil and Escher 1996). The third mechanism involved in oil uptake is surface-active agents. As oil roasting (frying) progresses, the cooking medium, oil, degrades causing multiple compounds to form in the oil. This changes the oil from a mixture of triglycerides to a mixture of hundreds of compounds (Dina and Saguy, 2006). These compounds include diglycerides and monoglycerides (surface-active agents), free fatty acids and glycerols forming from the high oil temperatures. Some of the compounds formed due to degradation play a role in interfacial tension reduction between oil and the food product (Dina and Saguy, 2006). While enhancing the contact between the food and the oil, surfactants affect heat transfer and the oil-food interface, which reduces the surface tension between the two as well as results in excessive absorption. Higher water migration and surface dehydration occurs as the contact time between the food and the oil increases because more heat is transferred from the oil (Dina and Saguy, 2006).

Studies have not yet been done on oil uptake in peanuts; nonetheless, they have been done for other food items. In the Moreira et al. (1997) study, including fried tortilla chips, it was observed that 20% of the total oil content was absorbed by the product and about 80% of the total oil content remained on the surface. This
changed once the chip began to cool, which during this time 64% of the total oil content was absorbed by the chips leaving only 36% on surface (1997). The explanation for this phenomenon is that starch gelatinizes and moisture evaporates within the first 10-15 seconds of oil roasting (frying). This causes an expansion of the capillary pores. It is at this point that the oil flows into the food product’s damaged areas after adhering to the surface (Moreira et al., 1997). The temperature of the product does not increase until all the water evaporates; while the temperature increases the oil absorption rate decreases due to a decrease in interfacial tension and capillary pressure (Moreira et al., 1997). However, after removing the product from the fryer the temperature drops and the pressure within the pore space decreases. The interfacial tension between the oil and air increases and the oil on the surface begins to flow in rapidly raising the internal oil content (Figure 2) (Moreira et al., 1997).
Figure 2: Oil distribution during oil roasting (frying) and cooling of a tortilla chip which shows oil uptake in a food commodity (Moreira et al., 1997).

Bolton and Sanders (2002) reported that total oil increased by 2.1-3% in peanuts during roasting. It has been seen that during roasting, oil degrades and more surfactants are formed, causing an increase in contact between oil and the food product. This increases the rate of heat transfer to the surface of the food and increases oil uptake by the food (Blumenthal, 1991).

Porosity

Porosity is a factor that affects oil uptake. Porosity is one of several physical properties of biological materials that is moisture dependent (Aydin, 2007). In fact,
research indicates that there is a linear relationship between porosity and moisture content (Marousis and Saravacos, 1990). Research studies demonstrate that there is also a linear relationship between initial porosity (prior to frying) and oil uptake and that initial porosity determines the final oil uptake in fried products. Research studies further indicate that both porosity and oil uptake increases during frying and are a function of each other (Pinthus et al., 1995). Porosity is the volume fraction of the air or the void fraction in the sample which is calculated using the following equation:

\[ P = 1 - \frac{D_b}{D_p} = \frac{V_{air}}{V_{sample}} \]  

[1]

Where: \( D_b \) = Bulk density; \( D_p \) = Particle density (Pinthus et al., 1995)

Porosity is computed from the values of true density and bulk density using the following relationship, true density minus bulk density divided by true density times 100 would be better as an equation (Mohsenin, 1970). True density (particle density) of a peanut is the ratio of the mass of a sample of a food to the solid volume occupied by the sample (Deshpande et al., 1993). A linear relationship was found between product porosity prior to oil roasting (frying) and oil absorption (Pinthus et al., 1995). Pinthus et al. (1995) also found that both porosity and oil uptake increased
during the oil roasting (frying) process in a dependent manner Other researchers such as Visvanathan et al. (1996) and Deshpande et al. (1993) found in their research of the neem nut and the soybean that a linear relationship in porosity and moisture content existed which showed as moisture content increased porosity decreased. Whereas researcher, Aydin (2002, 2003, 2007) found in studies of moisture dependent physical properties that porosity in peanuts, hazel nuts and almonds increased as moisture content increased. In the peanut study the relationship between moisture content and porosity can be represented with a $R^2$ of .98 in both the kernel and peanut (Aydin, 2007).

**Project Objectives**

The objectives of this research were to determine the effects of initial moisture content on the amount of oil uptake/exchange that occurs as a result of oil roasting. Additionally, we wanted to determine the effects of moisture content on the physical characteristics, sensory attributes and storage quality of oil roasted virginia market-type peanuts.
REFERENCES


CHAPTER 3:

THE RELATIONSHIP OF INITIAL MOISTURE CONTENT AND OIL UPTAKE AND EXCHANGE DURING OIL ROASTING OF VIRGINIA-TYPE PEANUTS

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Keywords: moisture content, oil uptake, oil roasting

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ABSTRACT

Uptake of oil from frying media is of concern in many types of foods. Uptake may influence flavor, shelf-life and other properties related to consumer acceptance. Oil uptake may occur during roasting or during the succeeding cooling phase and can be significantly affected by factors such as moisture content and porosity. During oil roasting of peanuts, oil uptake is the net result of several processes including movement of fryer oil to the interior of the peanut, accumulation of fryer oil at the surface, loss of seed oil into the fryer and accumulation of internal seed oil at the surface of the peanut. Net movement of oil to and from the frying medium is termed exchange. The objective of this research was to determine the relationship between pre-roast moisture content (MC) of peanuts and oil uptake and exchange. Peanuts dried to 4.2%, 4.5%, 5.8% and 6.6% MC (wet weight basis or wwb) were roasted in peanut oil containing 10% coconut oil. Lauric acid (C12:0) from the coconut oil was used as a marker to follow oil movement. The mean oil content (dry weight basis or dwb) of roasted peanuts was higher than in non-roasted peanuts. Oil uptake (dwb) was slightly higher at lower initial MC. Fatty acid analysis indicated the presence of lauric acid (C12:0) at the surface of the peanuts as well as within the peanut. Surface oil was similar to fryer oil which averaged 5.6% C12:0 while internal seed oil contained 0.31% C12:0, twenty times less than the surface oil. The
C12:0 in total kernel oil (surface + internal oil) did not vary with MC. Oils from hexane-dipped kernels did vary with MC with lower pre-roast MC having slightly higher C12:0 contents. The amount of surface oils varied strongly with MC. The 4.2 and 4.5% samples had almost 3 times the amount of surface oil as higher MC. Surface oil and MC were strongly negatively correlated (r=0.95). Bulk density of raw samples did not vary with MC; however, in roasted samples, bulk density fell from 1.03 to 1.01 as pre-roast MC rose. True density followed a similar pattern except that the raw samples rose very slightly with increasing pre-roast MC. Porosity of raw samples was fairly similar across MC. Porosity of roasted samples increased slightly with increasing MC with means ranging from 3.06 to 3.88. The range of MC employed in the study was limited and the parameters measured may have varied more if a wider range of MC were used. Scanning electron microscopy indicated greater physical damage on the surfaces of the higher MC samples which may be attributable to the release of greater amounts of steam from the high MC samples during roasting.
INTRODUCTION

Roasted peanut flavor is the principal characteristic of peanuts accounting for high consumer appeal and wide consumption. Peanuts can be roasted with dry heat or in oil. Among the changes that occur during oil roasting of all foods is oil uptake and/or migration into or out of the food (Pokorny, 1999). Research has shown that most of the oil uptake occurs during the cooling phase. During roasting, water exits the food with a degree of force. After removal from the fryer, steam present in the pores of the product condenses and creates a negative pressure. This negative pressure creates a driving force for oil uptake (Gamble, Rice and Selman, 1987). Fryer oil that remains associated with the food may be found in the interior of the food and on the surface. For example, in a study of tortilla chips, after cooling about 64% of the oil on the surface was absorbed and 36% remained on the surface (Moriera et. al., 1997). Studies using an oil-soluble dye indicated that frying resulted in an oil layer approximately 1 mm in depth (Krokida et al., 2000).

In foods other than peanuts, some factors that have been reported to affect oil uptake include food moisture content, shape, porosity, pre-frying treatments and product composition (Moreira et al., 1997). Water loss and oil uptake have a direct relationship in that oil replaces water that has been evaporated during the frying process (Dana and Saquy, 2006). Most of the models developed to explain uptake
have concentrated on particulate mixtures such as flour in tortilla chips. The fine structure of the peanut may provide different pore structures and smaller pores than some of the foods used previously in various studies. It remains to be seen if the same phenomena driving oil uptake into tortilla chips and doughnuts operate in foods such as peanuts and other nuts that may remain intact before oil roasting begins.

The physical properties of foods are important in processing (Kashaninejad et al., 2006). Bulk density is the ratio of peanut mass to the total volume (solids and voids). True density is the ratio of the mass of the peanuts solids to the volume of only the solids (Aydin, 2007). Porosity is the ratio of the volume of internal pores and bulk volume of a food and is calculated using a relationship between bulk density and true density of the food. No studies relating peanut porosity and oil uptake were found in the literature, however, research on other foods suggests that higher initial porosity should correlate with increased oil uptake. Studies have indicated that porosity and oil uptake have a linear relationship (Pinthus et al. 1993; Gamble et al. 1987) and that changes in oil and water content with frying time were related to the structure (pore size and distribution) of the samples (Krokida et al., 2000).
Porosity and bulk density are considered to be moisture-dependent physical properties (Kashaninejad et al., 2006). Water loss tends to increase true density while oil gain tends to decrease it. Density decreases during frying as a result of pore development, water vaporization and oil uptake (Krokida et al., 2000). In food systems with much higher moistures than peanuts, true density will be affected by the mass transfer operations of water loss and oil uptake (Krokida, et al., 2000). Such a system would show measureable shrinkage. With peanuts, the change in moisture will be significantly smaller, so that any change in density would be more difficult to measure, but none the less, may give some indication of the nature of oil movement between the peanuts and the roasting oil during the roasting process.

The objective of this research was to determine the effects of the initial moisture content of virginia-type extra large kernel (ELK) grade size peanuts on the amount of oil uptake or exchange that occurs during oil roasting. Measurement of oil uptake and oil exchange of peanuts with initial moisture contents of 4.2%, 4.5%, 5.8% and 6.6% were determined after roasting by analysis of their oil and water contents combined with determination of C12:0 fatty acid from coconut oil used as the marker substrate in the fryer oils.
MATERIALS AND METHODS

Sample Handling

Virginia 98R peanuts were supplied by the North Carolina Research Station; Rocky Mount, NC and were harvested and dried using accepted practices to a moisture content of approximately 12%. Peanuts were delivered to North Carolina State University in Raleigh, NC and further dried using forced ambient air. For each target MC, samples were taken when moisture content of the seed was about 1-1.5% higher than the target moisture content. Moisture content was determined on shelled peanuts using a Grain Analysis Computer (GAC) 2000 (Dickey- John Corporation, Auburn, IL).

Samples with the selected moisture contents were held in cold storage until they were shelled and sized to obtain only ELK grade size peanuts. Peanuts were sized using standard slotted grade screens and peanuts greater than 7.9mm width were used. Blanching (seed coat removal) began by placing peanuts in a forced air oven at 88°C for 45 min to loosen seed coats which were subsequently removed by hand. Peanuts that did not blanch were excluded from the study. The final moisture contents of the four moisture samples were 4.2%, 4.5%, 5.8% and 6.6% (wet weight basis). These values were lower than intended because blanching removed more
moisture than anticipated. Peanuts were placed in doubled plastic bags and held at 4°C until use. Peanuts were tempered to room temperature before roasting.

**Oil Roasting**

Before roasting of any MC samples, each batch of oil was pretreated by roasting two 350g samples of runner peanuts which were then discarded. Peanut oil provided by Golden Peanut Company (Alpharetta, GA) was heated to 177°C in a P-H-T Fryer model 500 (Henny Penny Corporation, Eaton Ohio) for 2-3.5 min. Coconut oil (Tropical Traditions, Springville, CA) was added to the peanut oil until 10% coconut oil was achieved by weight. Samples (350 g) of each moisture content were randomly roasted on one day followed by a second rep on the next day. Samples were roasted to obtain a Hunter L color value of 48+/- 1. Color was measured with a HunterLab D25L DP 9000 colorimeter (Hunter Associates Lab Incorporated, Reston, VA). Roasted peanuts were removed from the fryer and placed on perforated metal racks to facilitate excess oil drainage and cooling to room temperature.
Dipping

After roasted samples were cooled, 30 grams of peanuts from each roasted sample were placed in a wire mesh cylinder. The cylinder containing the peanuts was dipped in 600 ml of hexane for 2 seconds to remove oil on the exterior of the peanut. Dipped peanuts were removed from the cylinder and placed in pint glass jars until analyzed. The hexane was decanted into a round bottom flask and evaporated using a Thermo Neslab RTE 17 Evaporator (Thermo Corporation, Waltham, MA) equipped with a Buchi R-124 Rotavapor and a Buchi B-481 waterbath (Buchi Corporation, New Castle, DE). The oil residue weight was determined gravimetrically. Oil residue and oil expressed from the peanuts were used for fatty acid analysis.

Water Activity and Moisture Content

Water activity was determined using a 3TE Aqua Lab water activity meter (Decagon Device Incorporated, Pullman, WA). Moisture content was determined gravimetrically on peanuts that were dried at 130ºC for 6 hours in a LXD Series Despatch forced air oven (Despatch industries, Minneapolis, MN).
Total Oil Content

Each sample was ground and 4 grams placed in a 25 X 30 mm cellulose extraction thimble (Whatman, New Jersey). Total oil was determined using a semi-continuous solvent extraction method in which oil was extracted using hexane continuously for 6 hours (Neilson, 2003).

Fatty Acid Analysis

Fatty acid analyses were conducted on the hexane extracted oil, roasting oil and oil expressed from the roasted ground peanuts as well as from the raw peanuts. Oil was expressed from the roasted and raw peanuts using a Laboratory Press (Fred S. Carver, Inc., Wabash, IN) for 10 min at 20,000 lbs. The lipids were hydrolyzed to fatty acids, converted to their methyl esters according to AOCS Ce 2-66 (AOCS, 2004) and analyzed using gas chromatography (GC). In brief, 0.02 to 0.03 g of oil was weighed in triplicate into glass screw topped tubes. One mL of 0.5 N NaOH in methanol was added to each and the tubes were heated for 10 min at 85ºC in a water bath. After cooling, 1 mL of 14 % boron trifluoride in methanol (Sigma Chemical Corp., St. Louis, MO) was added to each tube. The tubes were capped, vortexed and returned to the water bath for 10 min. After cooling, 1 mL of water, followed by 1 mL of hexane was added to each tube. The tubes were vortexed for 30 sec and then
allowed to stand until layers formed. The top layer (organic) containing the fatty acid methyl esters (FAME) was removed and dried over sodium sulfate. The FAME were analyzed using a Perkin Elmer Autosystem XL GC (Shelton, CT) fitted with a capillary BPX-070 column (SGE Inc., Austin, TX). The column length was 30 m with an internal diameter of 0.25 mm and a film thickness of 0.25 mm. The temperature gradient was 60°C with a 2 min hold time, increased at 4°C per min to 180°C and then increased at 10°C to a final temperature of 235°C. The run time was 27.7 min. The carrier gas was helium at a flow rate of 40 psi. The injection was split at 150 mL/min. The results were reported as percent of the total fatty acids based on peak areas (AOCS Ce 1f-96) (Firestone, 2004). A standard mixture of fatty acid methyl esters (GLC-21A, NuChek Prep, Elysian, MN) was run with each sample set to establish retention times.

**Bulk Density, True Density and Porosity Measurement**

True density was obtained using an AccuPyc 1330 V2.03M Pycnometer (Micromeritics Instrument Corporation, Norcross, GA). True density, a moisture dependent characteristic, is defined as the ratio of the mass of all solids (oil and water are included as solids) in the seed to the solid volume of those solids (Aydin, 2003). Fifty gram samples were used and all samples were analyzed in triplicate.
Bulk density was defined as the ratio of sample weight to the volume of the entire sample including solids and gaseous materials. Bulk density was determined by a liquid displacement method. Toluene was used in the method instead of water because it is not absorbed by peanuts (Aydin, 2007). For the liquid displacement method, approximately 45 ml of toluene solution was placed into a 100ml graduated cylinder and the 50 grams of peanuts previously used in the pycnometer were placed into the graduated cylinder and true density was calculated from the observed displacement (Aydin, 2003; Aydin 2007).

Porosity (\( \varepsilon \)) was computed from true/particle density and bulk density using the relationship:

\[
\varepsilon = \frac{\rho_k - \rho_b}{\rho_k} \times 100
\]

[1]

where \( \rho_b \) is the bulk density and \( \rho_k \) is the true density (Aydin, 2007)

Scanning Electron Microscopy (SEM)

Samples were randomly selected from each moisture content for SEM analysis. Peanut cotyledons were washed with distilled water to remove surface material, patted dry and cut with a razor blade into 1-2 mm cross-sections. Slices
were trimmed to provide outer surface blocks that were 2-3 mm across. Samples were then fixed in 3 ml/100ml glutaraldehyde in 0.05 mol/l potassium phosphate buffer (pH 7.0, 4°C). Samples were washed in three 30 min changes of cold buffer followed by dehydration using 1 h changes of a graded series of ethanol (30, 50 and 70ml/100ml) at 4°C. Final dehydration intervals were 24 h each of cold 95 and 100ml/100ml ethanol, which were warmed to room temperature followed with three 24 h changes of room temperature ethanol. Samples were dried using liquid CO₂ (Tousimis-Samdri-795, Tousimis Research, Rockville, MD). The dehydrated tissue was mounted to aluminum specimen stubs using silver conducting paint. After drying overnight in desiccators, the stubs were coated with 5 nm of gold-palladium alloy with a Hummer 6.2 sputter system (Anatech USA, Union City, CA). Specimens were viewed with a Jeol JSM-5900LV Scanning Electron Microscope (JEOL U.S.A., Peabody, MA) at working distance of 15 mm with an accelerating voltage of 15 kV.

**Statistical Analysis**

Data were analyzed using PROC MIXED, a procedure for mixed models (fixed and random factors), in the SAS statistical software system (version 9.1, SAS Institute, Cary, NC). Analyses were evaluated through a randomized block design with roast day replication (day rep) as the blocking factor. The model terms being
evaluated included pre-roast moisture content (MC), day rep and the roast rep. Outliers were identified and deleted by looking for observations with studentized residuals over 2.5.

RESULTS AND DISCUSSION

Uptake/ Exchange of Oil

There are several potential modes of oil movement during oil roasting (Figure 1). Roasting oil may enter the peanut or accumulate on the surface of the peanut. Peanut oil has the potential to come out of the peanut into the roasting oil or accumulate on the surface of the peanut. All these may occur simultaneously during roasting. Net uptake is the sum of the various modes of oil movement and is measured by determining the difference in oil content of the raw and roasted peanuts. Uptake may be expressed as grams of oil per gram of wet weight or per gram of dry weight of sample. The mean oil contents of roasted samples were not significantly different among the pre-roast MC (Table 1). Raw samples were significantly different, however (Table 1). This despite the fact that all four MC lots came from the same original lot of peanuts and the only differences among them were the amount of drying used to create the four MC levels. This was attributable to the fact that wet weight, by definition, includes the weight of the solids, oil and
water. Thus, the drier (lower MC) samples, having less water, would appear to have more oil per g total wet weight. Oil uptake based on wet weight ranged from 4.5 to 6.6 % (Table 1). There was a large amount of variation among roast runs between the two day reps (Figure 2A). There appeared to be a slight negative correlation with pre-roast MC (Figure 2B), however, due to the variability among the roast runs on different day reps, the means for each MC level were determined to be insignificant (Table 1).

When oil contents were converted to a dry weight basis (dwb) the roasted samples ranged from 52.5 to 54.6 % oil but were not significantly different with respect to pre-roast MC (Table 1). The oil contents of raw samples ranged from 49.9 to 50.3% dwb and were not significantly different due to MC (Table 1). This was expected because all MC should have similar dry matter and oil content and conversion to dwb removed the differences due to water content. Uptake based on dry weight ranged from 2.3 to 4.7 % (Table 1). Uptake for the individual roast reps, like those based on wet weight, showed considerable variation among day reps (Figure 2C), however, the means for each MC were significantly different (Table 1) and showed a negative correlation with pre-roast MC (Figure 2D). The degree of differences among MC, although significant (Table 1), were very slight. It was unclear how strong the negative correlation of oil uptake and pre-roast MC might
have been if variability between day reps and analytical error from the oil extraction method had been better minimized. It was unclear why there were differences between the two day reps. In summary, although roast mean oil (dwb) and raw mean oil (dwb) for the pre-roast MC were not statistically different, the difference of the two, defined as net uptake, was significantly different by pre-roast MC. Higher MC were associated with lower net uptake.

**Monitoring Oil Movement with a Marker Fatty Acid in Fryer Oils**

The change in oil contents (dwb) due to roasting provide an estimate of net uptake but no information is gained about movement of fryer oil into the peanut or movement of kernel oil into the frying medium. A marker fatty acid was used in the frying oil that is not found in the peanut normally to estimate movement of fryer oil into the peanut. Coconut oil, containing 50% lauric acid (C12:0), was added so that the fryer oil was comprised of 10% coconut oil and thus approximately 5% by weight of C12:0. Figure 3A shows the fatty acid profile (FAP) of the oil extracted from raw kernels. This is a very typical FAP of a peanut with an oleic/linoleic acid ratio (O/L ratio) of 1.5 and was very similar to the peanut oil that was mixed with coconut oil to make the frying oil mixture. In Figure 3B, the same chromatogram is shown with the smaller end of the scale emphasized. It can be seen that no C12:0
fatty acid is found in the raw kernels (Figure 3B). The average C12:0% in fryer oils for each MC (mean of the 6 roasting reps over 2 day reps) were all close to 5% (Figures 4A and B). All C8:0, C10:0, C12:0, C14:0 fatty acids in the fryer oil mixtures were derived from the coconut oil (Figures 3B and 4B). The intention was to make the percentage of C12:0 identical in each frying oil but there was variation among the 24 total roasting reps (Table 2, fryer column) which ranged from 4.43 to 6.45% C12:0 with a mean of 5.36%. It is a reasonable assumption that, all other variables being equal, that movement of C12:0 from the fryer oil to the roasted peanut would be proportional to the C12:0 concentrations in the fryer oil. This is because we have no reason to believe that triacylglycerol molecules C12:0 fatty acids would behave differently than those without C12:0 fatty acids. Therefore, it seemed reasonable to adjust C12:0 percentages in oils collected from the roasted kernels by the C12:0 percentages in the oil in which they were fried. In Table 2, unadjusted C12:0% were values measured by the GC. Adjusted C12:0 percentages were calculated by dividing the C12:0% measured in the GC of any given sample by the C12:0% in the roasting oil for that sample and then multiplying by the average C12:0% in all roasting oils. These adjusted values represent what would have been measured had all roast reps had exactly the same fryer oil C12:0%.
After roasting, oil was expressed from the roasted kernels in a mechanical press. This oil fraction contained internal kernel oil as well as any oil remaining on the kernel surfaces. C12:0 was present in these oils at similar concentrations in each MC (Figures 5A and 5B) indicating that uptake into or onto the surface of the peanut had occurred. The C12:0% in roasted peanuts varied from 0.36% to 0.55% with a mean of 0.46 (Table 2, unadjusted, undipped column). After adjustment for fryer oil differences, the average was still 0.46 but with a range of 0.39 to 0.58 (adjusted, undipped column). The C12:0% did not vary with pre-roast MC (Figures 6A and 6B) ranging only from 0.43 to 0.47%. C12:0% was not significantly different among pre-roast MC. Unadjusted C12:0% appeared to be different between day reps with day rep 1 exhibiting an inverse relationship with MC (Figure 6A). However, adjustment for fryer oil C12:0 content made the day reps more similar with less indication of any predictable relationship to pre-roast MC (Figure 6B). The movement of C12:0 in the roasted peanuts was determined by dipping the roasted peanuts into hexane for approximately two seconds. The oil collected would be primarily from the kernel surface (Wambura et al., 2007). Using this method, oil on the surface was quantified and any C12:0 remaining in the dipped (cleared of surface oil) peanuts represented oil movement (uptake) into the kernel interior. The FAP of the surface oils (Figures 7A and 7B) were found to be identical to the frying
oils (Figures 4A and 4B). C12:0% in surface oils ranged from 4.68 to 6.41 with a mean of 5.55% (Table 2, unadjusted, surface column). Unadjusted values were not significantly different among MC (Figure 8A, Table 3). After adjustment for fryer oil C12:0%, values averaged 5.58% with a range of 4.95 to 6.63% (Table 2, adjusted, surface column) and there was much closer agreement between the day reps for surface oil C12:0% (Figure 8B). Adjusted values were positively correlated with pre-roast MC and weak significant differences existed among pre-roast MC (Figure 8B, Table 3). The highest pre-roast MC, 6.6%, had the highest surface oil C12:0% (Table 3) and was significantly different from the lower three pre-roast MC.

FAP of the dipped, roasted peanuts contained C12:0 but had 20 times less than found in surface oils (Figures 9A and 9B). Unadjusted C12:0% for roasted, dipped peanuts ranged from 0.22 to 0.47% with a mean of 0.31% (Table 2, unadjusted, dipped column). Adjusted C12:0% values ranged from 0.21 to 0.45% with a mean of 0.31% (Table 2, adjusted, dipped column). The variation among day reps and roasting reps for dipped peanut C12:0% was not changed much by adjustment for the fryer oil and thus any differences due to pre-roast MC were obscured and insignificant (Figures 10A and 10B, Table 3). The hexane used to rinse surface oil from the dipped peanuts was dried down and weighed to determine if pre-roast MC had any effect on the amount of surface oil (Figure 11). Pre-roast MC and surface oil weight were
strongly negatively correlated. The 4.2% sample averaged 0.336 g of surface oil, three times that found on the 6.6% samples. Pre-roast MC were strongly significantly different with any given pair of means being different. The results thus far may be summarized by the following:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>MC</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Uptake (dwb)</td>
<td>↑</td>
<td>↓</td>
<td>weak, negative</td>
</tr>
<tr>
<td>Undipped Kernel C12:0%</td>
<td>---</td>
<td>MC</td>
<td>---</td>
</tr>
<tr>
<td>Dipped Kernel Oil C12:0%</td>
<td>---</td>
<td>MC</td>
<td>---</td>
</tr>
<tr>
<td>Surface Oil C12:0%</td>
<td>↑</td>
<td>MC</td>
<td>↑</td>
</tr>
<tr>
<td>Surface Oil Weight</td>
<td>↑</td>
<td>MC</td>
<td>↑</td>
</tr>
</tbody>
</table>

Because there are no differences among pre-roast MC in undipped or dipped seeds, the weak negative correlation between MC and net uptake (dwb) may be explained by the increased weight of surface oil at the lower MC. The fact that the highest MC, 6.6%, had the highest C12:0%, and was similar to fryer oil and lower MC had less C12 content can only be explained if the surface oil on the lower MC samples was being diluted by a peanut oil with no C12:0 such as the oil inside the peanuts being roasted. This implies that at least some of the extra surface oil on the lower MC samples is endogenous in origin. It is possible that endogenous oil issues forth from lower pre-roast MC samples at a faster rate than in higher pre-roast MC.
Frying conditions and food characteristics may interact in unexpected ways. For example, in some foods oil uptake is localized near the surface due to crust formation (Farkas, et al., 1992). Similar phenomena may be at work in the present situation.

**True Density, Bulk Density and Porosity**

True density of raw samples was not different among the pre-roast MC (p=0.2297) (Figure 12). True density of raw samples ranged from 1.100 to 1.106 g/cm³. True density of roast samples were significantly different (p=.0047) among pre-roast MC and ranged from 1.056 to 1.060 g/cm³ (Figure 12). Roasted samples of higher pre-roast MC had lower true density than those of lower pre-roast MC (p=.0047). The true density of raw samples at any MC was higher than the corresponding roasted sample (p<.0001).

Bulk density in raw samples was significantly different among pre-roast MC (p= 0.0341) but the relationship between MC and bulk density was essentially level (Figure 13). In roasted peanuts, bulk density was different among pre-roast MC (p=0.0104) and with a drop from 1.030 (4.2%) to 1.008 (6.6 %) (Figure 13). As with true density, bulk density of raw samples at any MC was significantly higher than the corresponding roasted sample. The difference between raw and roast bulk
density was much smaller at lower pre-roast MC. There was noticeable variation among roasting reps at any given MC (Figure 13). Bulk density measurements were taken using a volume displacement technique which had an inherently higher degree of error than true density measurements taken with the pycnometer (compare Figures 12 and 13). The trends in true density were much clearer than those in bulk density due to the increased variability in bulk density measurements. Changes in true and bulk density, even if significant statistically, were quite small in magnitude. This is probably a reflection of the restricted range of pre-roast MC used in this study.

Porosity was calculated from true and bulk density using equation (1). As a result of the variability in bulk density numbers, the porosity values were also quite variable (Figure 14). Porosity in raw samples was significantly different among the pre-roast MC; however, as with bulk density, the trendline was nearly level (Figure 14). After roasting, porosity appeared to rise with increasing pre-roast MC but the statistical analysis did not bear this out (p=0.0911). One might expect porosity to increase more in higher MC due to two factors. First, the volume of water displaced would be higher at higher pre-roast MC. Also, if water exited in a violent manner, True density, bulk density and porosity data did not relate positively to uptake damage in the form of tears and fissures might actually increase more in higher MC.
Peanuts differ from many foods that are oil roasted (fried) largely by composition in that peanuts are high in fat and low in carbohydrates and water content. This makes it difficult to extrapolate research on other oil roasted foods to peanuts. The relationship between porosity and oil uptake is quite complicated. Higher initial porosity should result in increased oil uptake, resulting in reduced porosity in the finished product (Pinthus et al., 1995). Possibly, if the initial MC range of the peanuts had been larger, more significant changes would have occurred in density and porosity.

**Scanning Electron Microscopy**

A single peanut seed consists of two cotyledons each with a flat inner surface and an outer surface whose roundness defines the peanut shape. During roasting, the outer surface is completely exposed to the heating matrix, but the since the two parts are not sealed, roasting oil is able to contact the inner surface as well. Peanut seed will split apart due to mechanical handling, so a single batch will contain both intact seed and single cotyledons. For this work, both intact and split seeds were the low moisture was 0.41. This higher value would indicate a higher thermodynamic availability which is necessary for the nonenzymatic browning
indicative of roasting. This phenomena has been reported for microwave heating as well (Peterson, Tong, Tong, and Welt, 1994).

The microstructure of raw peanuts has been reviewed (Young and Schadel 1990). The exterior surface can contain areas of damage due to mishandling or poor growth conditions such as drought. These areas will appear as irregular shallow patches. The epidermal cells on the outer surface appear as raised ridges with rectangular outlines. Once the peanut is cooked, the surface is disturbed due to ruptures from the steam escaping. In Figure 15, this surface is seen for the sample with the low moisture after roasting. The ruptures appeared as random pock marks over the surface as indicated by the arrows. These are differentiated from surface damage that might be due to other conditions in that the edges of the ruptures are pushed upward from the surface. When the higher moisture sample was roasted, the surface is interrupted by a series of eruptions that appeared as elongated tears as seen in Figure 16. This could be logically explained by the need for higher amounts of steam to escape with the increase in temperature. Another view of the surface of the higher moisture sample is presented as Figure 17. It shows that the tears are randomly oriented and do not follow the pattern of the epidermal cells, which appear as rows of elongated rectangles. From the micrographs of the interiors, it is possible to study the changes that occurred within the cells both with the initial
drying and with the oil roasting.

Figure 18 shows the high moisture sample in the raw state. This level of moisture was characterized by the dense cytoplasmic network covering the cell interiors. This is compared to the low moisture sample before roasting (Figure 19), where the network was much sparser. It has been determined that the small spherical bodies contained within the cell walls are the lipid bodies (Young and Schadel, 1991). The large spheres are proteins and starch granules which cannot be distinguished from each other with SEM. In addition to this, the outer surface epidermal cells in Figure 19 appeared to be larger and emptier than those of the higher moisture sample (Figure 18). Although it has been seen that there is a reduction in cytoplasmic material and an increase in the size of parenchyma cells with maturity, the seeds in this study were all of the same maturity to eliminate that variability (Young, Pattee, Schadel and Sanders, 2004). The higher moisture sample also still had testa attached despite the rigors of preparing the sample for imaging.

Once the oil roasting occurred, both samples showed loss of the cytoplasmic network (Figures 20 and 21). This was more pronounced in the high moisture sample than the low, however, the lower moisture showed greater losses of subcellular organization, which was attributed to the longer heating time resulting in more internal damage. Also, both samples showed breakdown of the
parenchyma cell walls. Once this occurs, lipid bodies are free to move out of and between the cells. After the roasting, the moisture contents were found to be 1.19 +/- 0.08 g/100g for the lower moisture sample and 1.65 +/- 0.23 g/100g for the higher moisture sample, respectively. The lower moisture sample (Figure 20) showed the cellular contents packed together away from the walls after roasting. The material was beginning to lose the distinct shapes of the various components, but not to the extremes as seen in the previous work which used a longer cooking time of 10 minutes (Young and Schadel, 1991). The rounded bodies of starch, lipid and protein were becoming less spherical, more flattened and closely packed.

At the higher moisture, this was less apparent, as the cooking time was shorter (Figure 21). The internal cell contents were more spherical after cooking and did not appear to be moving away from the cell walls. This was attributed to the shorter heating time. The exterior color was achieved faster, so that the peanuts were removed from the hot oil sooner, causing less damage to the interior of the seed. The epidermal layer cells however; tended to be empty of cell contents compared to the lower moisture sample. This indicated that the cell changes were increased due to the need for more water to move out of the sample with heating.

Observations in this report indicate that moisture content of raw peanuts plays a major role in the quality of the finished product. Higher moisture seed takes
less time to reach desired outer color, but there is more damage to the exterior of the product. Available water is known to play a role in the non-enzymatic browning reaction, thus it would be advantageous to use seed that is not too dry for the production of oil roasted peanuts. It would then be possible to produce a finished product of the desired color with less heating time and less internal damage. Knowledge of the effects of such differences in composition in raw peanuts would be important in producing quality roasted product consistently.

CONCLUSIONS

Uptake of oil from the roasting matrix into peanuts is supported by C12:0 in the FAP of oil pressed from the peanut/coconut oil roasted peanuts. As moisture content increased, net uptake decreased marginally but the amount of surface oil increased dramatically. In addition, the percentage C12:0 in the surface was greater at higher pre-roast MC. This suggests that the peanut oil accumulating on the surface of lower MC samples was originating from endogenous oil in the kernel and not from fryer oil which contained C12:0. True density was not significantly different in raw samples. Bulk density was slightly significantly different among pre-roast MC but was not well correlated with MC. Both true and bulk density dropped with increasing pre-roast MC in roasted samples. Porosity values,
calculated from true and bulk density, showed a positive visual trend with pre-roast 
MC in roast samples but were not statistically different.

Roasting resulted in structural damage which appeared to be related to MC. 
High MC had more damage at the surface which potentially resulted in more oil 
filling the voids left by the frying processes. It was expected that the voids or 
available internal space could be calculated by porosity and would have a 
relationship to oil uptake; however, porosity data was not robust enough to draw 
these conclusions. Possibly the moisture contents used were too similar to observe 
significant relationships.

ACKNOWLEDGEMENTS

The assistance of Keith Hendrix and Jim Schaefer of the USDA, ARS, Market Quality 
and Handling Research Unit and Valerie Knowlton of the Laboratory for Advanced 
Electron and Light Optical Methods Facility at North Carolina State University is 
gratefully acknowledged.
Figure 1: Modes of oil movement during frying of peanut kernels in a generic frying medium.
Table 1. Mean Oil content and oil uptake by pre-roast moisture content of peanuts fried in peanut oil.

<table>
<thead>
<tr>
<th>Treatment MC (% wet wt)</th>
<th>Roast Mean Oil</th>
<th>Raw Mean Oil</th>
<th>Net Uptake</th>
<th>Roast Mean Oil</th>
<th>Raw Mean Oil</th>
<th>Net Uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2</td>
<td>53.4*</td>
<td>48.1a</td>
<td>5.2</td>
<td>54.0</td>
<td>50.3</td>
<td>4.0 ab</td>
</tr>
<tr>
<td>4.5</td>
<td>53.9</td>
<td>47.6b</td>
<td>6.6</td>
<td>54.6</td>
<td>49.9</td>
<td>4.7 a</td>
</tr>
<tr>
<td>5.8</td>
<td>51.8</td>
<td>47.3bc</td>
<td>4.5</td>
<td>52.5</td>
<td>50.2</td>
<td>2.3 b</td>
</tr>
<tr>
<td>6.6</td>
<td>52.2</td>
<td>47.0c</td>
<td>5.0</td>
<td>53.0</td>
<td>50.3</td>
<td>2.7 b</td>
</tr>
</tbody>
</table>

*Means in columns followed by the same letter were not significantly different.
Figure 2: Changes in net uptake in response to changes in pre-roast MC of peanuts fried in peanut oil.
Figure 3: EAP of Raw, Undipped, Whole Seed at Each Pre-Roast MC (A) and Detail Highlighting the Rarer Fatty Acids (B).
Figure 4: FAP of Fryer Oils Used at Each Pre-Roast MC (A) and Detail Highlighting the Rarer FA (B)
Table 2: Percent C12:0 in roast nuts, dipped roasted nuts, surface oil and frying oil by roasting and day replication.

<table>
<thead>
<tr>
<th>Pre-Roast MC</th>
<th>Day Rep</th>
<th>Roast Rep</th>
<th>Percent C12:0 in Fraction</th>
<th>Un-adjusted</th>
<th></th>
<th>Adjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Undipped</td>
<td>Dipped</td>
<td>Surface</td>
<td>Fryer</td>
</tr>
<tr>
<td>4.2 1</td>
<td>1</td>
<td>1</td>
<td>0.54</td>
<td>0.37</td>
<td>5.45</td>
<td>5.90</td>
</tr>
<tr>
<td>4.2 1</td>
<td>1</td>
<td>2</td>
<td>0.55</td>
<td>0.40</td>
<td>5.58</td>
<td>5.72</td>
</tr>
<tr>
<td>4.2 1</td>
<td>1</td>
<td>3</td>
<td>0.55</td>
<td>0.38</td>
<td>6.01</td>
<td>6.32</td>
</tr>
<tr>
<td>4.5 1</td>
<td>1</td>
<td>1</td>
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**min** 0.36 0.22 4.63 4.43 0.39 0.21 4.95  
**average** 0.46 0.31 5.55 5.36 0.46 0.31 5.58
Figure 5: FAP of Roast, Undipped, Whole Seed at Each Pre-Roast MC (A) and Detail Highlighting the Rarer Fatty Acids (B).
Figure 6: C12:0% in Roasted, Undipped Peanuts Determined By GC (A) and Same Values Adjusted For Fryer Oil Concentration (B).
Figure 7: FAP of Surface Oil From Roast, Dipped, Whole Seed at Each Pre-Roast MC (A) and Detail Highlighting the Rarer Fatty Acids (B).
Figure 8: C12:0% in Surface Oils Determined By GC (A) and Same Values Adjusted For Fryer Oil Concentration (B).
Table 3. C12:0% in roasted, undipped kernels, hexane-dipped kernels and surface oil.

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<th>Treatment MC (% ww)</th>
<th>Surface C12:0%</th>
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*Means in columns followed by the same letter were not significantly different.
Figure 9: EAP of Roast, Dipped, Whole Seed at Each Pre-Roast MC (A) and Detail Highlighting the Rarer Fatty Acids (B).
Figure 10: C12.0% in Roasted, Dipped Peanuts Determined By GC (A) and Same Values Adjusted For Fryer Oil Concentration (B).
Figure 11. Weight of surface oil washed from kernel surfaces with a 2-second hexane dip
Figure 12: True density of raw and roasted peanuts at different pre-roast MC.
Figure 13: Bulk density of raw and roasted peanuts at different pre-roast MC.
Figure 14: Porosity calculated from true and bulk density of raw and roasted peanuts of each moisture content.
Figure 15. Scanning electron micrograph of the surface of a peanut at the low moisture content of 4.2% demonstrating small pock marks in the surface from water escaping during oil roasting.
Figure 16. Scanning electron micrograph of the high moisture content 6.6% demonstrating large rips and tears at the surface created by escaping water during roasting.
Figure 17. Scanning electron micrograph of the high moisture content 6.6% demonstrating orientation of tears and epidermal cells.
Figure 18. Scanning electron micrograph of the interior of the high moisture content 6.6% in the raw condition.
Figure 19. Scanning electron micrograph of the interior of the low moisture content 4.2% in the raw condition.
Figure 20. Scanning electron micrograph of moisture content 4.2% at the cellular level.
Figure 21. Scanning electron micrograph of moisture content 6.6 % at the cellular level demonstrating a large rip at the surface where water has escaped.
REFERENCES


CHAPTER 4:

EFFECT OF MOISTURE CONTENT ON STORAGE QUALITY AND SENSORY ATTRIBUTES OF OIL ROASTED VIRGINIA-TYPE PEANUTS

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ABSTRACT

Moisture content (MC) is a physical characteristic that may cause adverse affects to peanut quality. Peanuts contain high levels of oil containing unsaturated fatty acids which makes them susceptible to degradation by oxidation. This study examined the effects of peanut pre-roast MC on chemical, physical and sensory descriptors developed in oil roasting. A large lot (454 kg) of virginia-type peanuts were dried in-shell to obtain seed mc’s of 4.2%, 4.5%, 5.8% and 6.6%. Extra large kernel (ELK) grade size peanuts were oil roasted, stored in glass jars at 30°C and sampled at eight time points over 48 weeks. With storage, OSI decreased; however, low MC roasted samples had higher OSI values and increased from 11.1 h in raw seed to 16.2 h in roasted seed compared to an increase from 10.3h to 10.7 h in higher moisture seed. MC did not have a significant effect on PV after 12 month’s storage. Descriptive sensory analysis indicated that roast peanutty descriptor intensity decreased in all samples over time and the painty descriptor was detected in all samples after 4 months, with higher intensities in the higher pre-roast MC samples. The higher MC peanuts had less oil seepage during storage than lower MC samples and higher initial MC resulted in higher levels of lipid oxidation.
INTRODUCTION

Roasted peanuts (*Arachis hypogaea* L.) are widely consumed because of the unique flavor created by the roasting process (Ahmed and Young, 1982). Virginia market-type peanuts are often used in oil roasted applications because of flavor, texture, and size (Heinis and Young, 1987). Moisture content (MC) of shelled peanuts, used for roast processing, generally ranges from about 5.5% – 7.5%. Research studies indicate that storage stability and preservation of quality are highly related to moisture content (Evranuz, 1993).

Peanuts have an oil content of approximately 50% and approximately 80% of the fatty acids in the oil are unsaturated (Ahmed and Young, 1982) and thus, susceptible to oxidation (Cobb and Johnson, 1973). Chemical indicators of lipid oxidation, such as peroxide value (PV), increase during storage of roasted peanuts. The intensity of flavor descriptors associated with lipid oxidation, such as cardboardy, have been found to increase during storage of fried, salted peanuts while desired flavors such as roasted peanutty decreased in intensity (Olmedo et al., 2008). Aldehydes such as pentanal and hexanal occur in storage due to lipid oxidation and contribute to off flavor (Reed et al., 2002). Samples with very low or
very high moisture content oxidized faster than those with intermediate moisture contents (Evranuz, 1993).

The objective of this research was to determine the effect of pre-roast MC on the physical characteristics, sensory attributes and storage quality of oil roasted virginia-type peanuts. The MCs used were 4.2%, 4.5%, 5.8% and 6.6% (wet weight basis). The MCs were selected because research has indicated that higher initial MC (6.6 - 7.5%) going into the roaster resulted in shorter measured shelf life (Woodroof, 1983). MCs between 6.6% and 7.5% are commonly encountered during peanut processing (Woodroof, 1983).

MATERIALS AND METHODS

Peanut Samples

Virginia 98R peanuts were supplied by the North Carolina Research Station, Rocky Mount, NC and were harvested and dried using accepted practices to a MC of approximately 12%. Peanuts were delivered to NC State University in Raleigh, NC and further dried using forced ambient air. Samples for each target MC were taken when MC was about 1-1.5% higher than the target. MC was determined on hand-shelled peanuts using a Grain Analysis Computer (GAC) 2000 (Dickey-John Corporation, Auburn, IL).
Samples were held in cold storage until shelling. For shelling, samples were tempered to room temperature and then shelled with a Model 4 peanut sheller. Shelled peanuts were sized using standard slotted hole grade screens and only the extra large kernel grade size (ELK) was used in the experiment. Blanching (seed coat removal) was accomplished by placing seeds in a forced air oven at 88°C for 45 min to loosen seed coats which were subsequently removed by hand. Peanuts with retained seed coats were excluded from the experiment. The final MCs of the four samples after blanching were 4.2%, 4.5%, 5.8% and 6.6% (ww). These moisture contents were lower than our target MCs of 5, 7, 9 and 11%. The blanching treatments and associated handling removed more moisture than intended. The 7 and 9 % samples were to have been considered to be within normal usage range for industry while the 5 and 11 percent were to be considered as outside acceptable range. Of the four levels achieved for this experiment, the 4.2 and 4.5 are outside normal range while the 5.8 and 6.6 in within the lower normal range. Peanuts were placed in double plastic bags and held at 4°C until use. Peanuts were tempered to room temperature before roasting.
Oil Roasting

Refined peanut oil used for roasting was supplied in bulk by Golden Peanut Company (Alpharetta, GA). Before the roasting of the samples each lot of oil was pretreated by roasting two 350 g samples of peanuts. Oil was heated to 177°C and 350 grams of peanuts were placed in a P-H-T Fryer model 500 (Henny Penny Corporation, Eaton Ohio) for 2-3.5 min. Each MC was randomly roasted over two consecutive days to obtain a Hunter L value of 48+/− 1 as determined on a HunterLab D25L DP 9000 colorimeter (Hunter Associates Lab Incorporated, Reston, VA). Roasted peanuts were removed from the fryer and placed on perforated metal racks to facilitate excess oil draining and to cool the peanuts to room temperature.

Storage and Sampling

Roasted peanuts were placed in nitrogen-flushed one quart glass jars and flushed with nitrogen a second time. Peanuts were placed in jars and placed in storage at 30°C in an Isotemp Incubator model 304R (Fisher Scientific, Pittsburgh, PA). For each pre-roast MC, three roasts (roast reps) from each of two roasting days (day reps) was stored and samples taken for analysis at 0, 4, 8, 12, 16, 24, 32, 40, and 48 wks. Samples were placed in frozen storage until analysis.
Moisture Content (MC) and Water Activity ($A_w$)

Water activity was determined using a Model 3TE Aqua Lab water activity meter (Decagon Device Incorporated, Pullman, WA). MC was determined gravimetrically on peanuts that were dried at $130^\circ$C for 6 hours using a Despatch Forced Air Oven LXD Series (Despatch industries, Minneapolis, MN).

Free Fatty Acid (FFA) and Peroxide Values (PV)

Oil for FFA and PV determination was obtained from approximately 160 grams of ground peanuts using a Carver Laboratory Press (Fred S Carver, Inc, Wabash, IN) for 10 min at 20,000 psi. FFAs were determined according to AOCS Method Ab 5-49 (AOCS, 2004). A solution of 7.05g of oil, 50ml of isopropyl alcohol (neutralized alcohol) and 1 ml of phenolphthalein indicator solution were mixed and titrated with either 0.25 or 0.0025 N NaOH until a faint pink color was obtained and was maintained for at least one minute. Samples were analyzed in triplicate. FFA was calculated using the formula:

$$\text{FFA (\% of oil wt)} = \frac{(\text{NaOH normality used}/0.25) \times (\text{mls used in titration})}{\text{FFA}}$$

Peroxide value was determined in accordance to AOCS CD 8-53 (AOCS, 2004). In brief, 5 grams of oil was titrated with sodium thiosulfate and a starch
indicator. PV is expressed as milliequivalents of active oxygen per kilogram of oil (meq/kg) and calculated with the formula:

\[ PV \text{ (meq/kg oil)} = (\text{ml of } \text{Na}_2\text{S}_2\text{O}_3)(\text{N of } \text{Na}_2\text{S}_2\text{O}_3)(1000)/(\text{g of sample}) \]  \[2\]

**Oxidative Stability Index**

Oil samples obtained from the peanuts were used to determine oxidative stability index (OSI) according to AOCS Method12b-92 (AOCS, 2004). Five grams of oil was weighed into glass tubes which were placed into a heating block at 110C. The oils were sparged with compressed air so that any volatiles generated in the oil were flushed out and trapped in 50 ml water in a lexan cell containing a conductivity sensor. The conductivity signal was monitored with a computer data acquisition system and continuously analyzed to detect the transition from the induction phase to the exponential phase of volatile production. OSI was defined as the number of hours after placement in the heating block until the rate of increase in conductivity became exponential. A shorter OSI time indicates low resistance to oxidation.
Total Oil Content

Approximately 15-20g of sample was ground and 4 grams were placed in a 25 X 30 mm cellulose extraction thimble which was placed in the extraction chamber of the Soxhlet Extractor (Lindber, Watertown, Wisconsin). Total oil was determined using a solvent extraction method in which oil was extracted using hexane at a rate of 5 or 6 drops per second and condensed for 6 hours continuously (Carpenter, 2003).

Hexanal/Pentanal

Volatile analysis was conducted on a Perkin Elmer Autosystem XL Gas Chromatograph (GC) equipped with a flame ionization detector and Turbomatrix autosampler (Perkin Elmer, Inc., Norwalk, CT). Approximately 4 grams of sample was added to a 15 ml vial with 2 ml of 2 heptanone in hexadecane as the internal standard. The vial was then capped and crimped tight using PTFE Silicone liner/spring crimp caps (Perkin Elmer Instruments, Shelton, CT). Sample vials were heated at 140°C for 30 min and the volatiles were injected using a auto injector onto a ZB-5, 30 m x 0.25 mm. 1.0µm deionized flame column. The temperature of the GC column was maintained at 35°C for 1 min and increased at a rate of 15°C/min to 300°C. The carrier gas was helium at 5.0ml/min and the detector temperature was
Triplicate analysis was conducted on each treatment sample. Hexanal and pentanal were quantified by means of curves over 3 orders of magnitude of authentic standards of hexanal and pentanal diluted with hexadecane (Sigma, St. Louis, MO).

**Descriptive Sensory Analysis**

A sensory panel consisting of 11 highly trained panelists each with between 100 and 1000 hours experience was used to apply descriptive sensory analysis to samples generated during the study. All panelists were trained in the Spectrum™ Descriptive Analysis method (Meilgaard et al., 1987) using a previously published peanut flavor lexicon (Johnsen et al., 1988 and Sanders et al., 1989).

In preparation for sensory evaluation, roasted peanuts (180 g) were chopped for approximately four seconds in a Cuisinart Little Pro Plus food processor (Cuisinart Corporation, East Windsor, NJ). Chopped samples were sifted through a series of three ASTM Sieves. Samples that fell through a 6.25 mm sieve and rode on two sieves ranging from 3.12 mm (#6) to 1.68 mm (#12) inches. Samples were mixed and used for analysis. Materials that rode on the top sieve (6.25 mm) were re-chopped for an additional 4 seconds and resifted. Chopped peanuts that fell through all sieves were not used for analysis. Samples were stored in one quart glass jars at -
22ºC until analysis. All samples were equilibrated to room temperature for approximately 1 hour prior to analysis. Each panelist was presented with approximately 5.0 g of each sample in cups labeled with three digit random numbers. Eight samples were evaluated in each session of approximately 45 min. All samples were evaluated in duplicate in a random order throughout the duration of the experiment. Samples were evaluated using the peanut flavor lexicon in which various attributes were scored on intensity. These attributes included: roast peanutty, sweet aromatic, dark roast, raw beany, woody-hull-skins, sweet, bitter astringent, painty, cardboardy, earthy, plastic chemical, metallic, fruity fermented and sour.

**Statistical Analysis**

Data were analyzed using the Proc Mixed and Proc GLM procedures of the SAS statistical software system (version 9.1, SAS Institute, Cary, NC). Analyses were evaluated using a randomized block design with roast day replication (day rep) as the blocking factor. The model terms evaluated included storage (wks), pre-roast MC, day rep and the interaction of MC x weeks. Outliers were identified and deleted by looking for observations with studentized residuals over 2.5. If there
were unequal variances among treatment groups, appropriate transformations were applied.

RESULTS AND DISCUSSION

Moisture Content (MC)

Moisture content and water activity were determined before and after roasting and at each time point during storage (Figure 1). Pre-roast sample preparation which included drying, shelling and blanching resulted in four samples with statistically different MC of 4.2%, 4.5%, 5.8% and 6.6% (ww). These values were lower than anticipated due to the excessive blanching required to remove all seed coats. Higher pre-roast MC required more effort to blanch. Blanching normally results in a MC drop of 1-1.5% (Sanders et al., 1999; Adelsburg and Sanders, 1997). MC in all samples decreased during oil roasting. Post roast MC’s were statistically different and ranged from 0.8 to 1.6% (ww) while retaining the same relative ranking as before roasting. During storage, MC increased slightly over time (Figure 1). Statistical analysis showed that post-roast MC was affected significantly by pre-roast MC and weeks in storage despite the fact that the differences among the means were relatively small. The weeks x MC interaction
term was also significant; however, the actual changes in rank over time were quite small (Figure 1). The fact that the post-roast MC’s were different may be important because MC can affect the rate of lipid oxidation and perhaps other reactions that may lead to off-flavor formation. In a study with unblanched peanuts, Evranuz (2000) found that increased MC resulted in an increase in the rate of oxidation.

**Water Activity (A<sub>w</sub>)**

A<sub>w</sub> of the raw peanut samples ranged from 0.448 to 0.694 and were statistically different. A<sub>w</sub> was highly correlated with pre-roast MC (r=.9914). During roasting, water activity (A<sub>w</sub>) decreased to a range of 0.100 to 0.310 (Figure 2). A<sub>w</sub> was highly correlated with MC after roasting (r=0.9152). As with MC, the post-roast A<sub>w</sub> rankings were the same as the pre-roast rankings. A<sub>w</sub> increased very slightly during storage just as MC did. Statistical analysis indicated that storage water activity was significantly impacted by pre-roast MC and weeks in storage. The MC x weeks interaction term was also significant; but, as with MC, the rank changes were relatively minor over time and appear to be of no practical importance. A<sub>w</sub> may affect the chemical and sensory properties of stored peanuts (Baker et al., 2002). Much research has reported lipid oxidation to be positively correlated with A<sub>w</sub> in
many foods (Leung, 1987, Rahman, 1995). Reed et al. (2002), however, reported that $A_w$ had little effect on oxidation during a 7 week storage study.

**Total Oil Content**

Total oil dipped very slightly in all pre-roast MC samples midway during storage (Figure 3) and analysis indicated total oil was significantly affected by weeks ($p= <0.0001)$ and the interaction of weeks and MC ($p = 0.0026$). Peanut samples at storage weeks 0 or 48 were not significantly different with an average oil content of 53%. However, oil content at 16 weeks of storage was 51% which was significantly different. The slight differences among weeks were not correlated with time and thus may have been due to analytical error. Total oil would not be expected to change after roasting under normal circumstances; however, oil loss from peanuts has been observed in certain industrial applications (Timothy Sanders, personal communication). Total oil data did not specify any visual trends; however, statistics did indicate differences (Figure 3).
Free Fatty Acids (FFA)

Raw peanuts, differing only in pre-roast MC, had significantly different FFA levels ($p=0.0005$). FFA ranged from 0.09 to 0.24 (Figure 4) and were positively correlated ($r=0.9674$) with pre-roast MC. The higher pre-roast MC had the highest FFA before roasting. All peanuts in this study received similar blanching and roasting treatments. Different pre-roast FFA levels at different pre-roast MC must have been created during the drying steps used to create the different pre-roast MC.

During roasting, FFA in most samples increased slightly, ranging from 0.15 to 0.35. Again, FFA were significantly different ($p<0.0001$) with higher pre-roast MC associated with higher FFA immediately after roasting. Only the 6.6% PV did not increase significantly from pre-roast levels. FFA may increase due to enzymatic hydrolysis via enzymes present in the peanut or from external agents such as fungi which attack the peanut surface with a mixture of hydrolytic enzymes such as lipases. High temperature treatments (e.g. oil roasting) can result in lipid hydrolysis which can lead to the release of free fatty acids (Penfield and Campbell, 1990). The fact that FFA rose during roasting but topped out around the same level (0.35) regardless of pre-roast MC may be an indication that the heat caused by roasting was stimulating FFA production. This however, was only up to the point that the enzymes became denatured.
During storage, FFA remained relatively constant ranging from ca. 0.01 to 0.4. The exceptions were a small increase between weeks 40 and 48 and a spike at week 32 in which 3 samples spiked to almost 0.8. It was not clear why the spike occurred but it was considered an aberration and was not included in the analysis. Statistical analysis indicated that there were significant differences due to pre-roast MC (p<.0001) over storage. Over the course of storage, pre-roast MC 6.6% (mean 0.252) average significantly higher FFA than pre-roast MC 5.8% (mean 0.193) or the two lower MC (4.5% mean 0.167 or 4.2% mean 0.149) which were not significantly different from one another. Analysis also indicated that weekly FFA means were significantly different (p<.0001) although this was mainly due to the small rise in the last 3 weeks of storage. In any event, no sample in the study ever exceeded the industry cut-off for rejection (FF > 2.0).

**Peroxide Value (PV)**

PV is a measure of the concentration of fatty acid hydroperoxides, the primary product of lipid oxidation. The range of PVs in raw samples was 0.41 to 0.76 mEq/kg and the range in roast PVs was 0.53 to 1.03. PV before (p=.9998) and after roasting (p=.3878) were essentially statistically identical for all pre-roast MC. This was in contrast to FFA which were already different in the raw samples prior to
roasting. Roasting did not produce any statistically significant increase in PV at any pre-roast MC.

In storage, PVs of roasted peanuts increased significantly during the period from week 0 to week 4 (Figure 5). Such an increase is expected during storage of roasted peanuts (Olmedo, 2008). The PVs from day rep 1 (solid lines, Figure 4) increased faster than PVs from day rep 2 but this difference disappeared by week 20. After week 4, PVs remained level for the duration of storage. This was likely due to nitrogen flushing of the storage jars which was done to mimic typical industrial practices. Pre-roast MC did not have an effect on PVs. Weeks in storage (p<0.0001) but not pre-roast MC (p = 0.2976) significantly impacted PV during the storage period.

The peanut industry generally accepts raw lots with PV < 2 mEq/kg. This ensures that products can be sold and consumed before formation of objectionable off-flavors. No sample in this study reached a PV of 25 meq kg⁻¹, a level at which some food products have been judged to still be acceptable (Evranuz, 1993). In the Market Quality Research Unit, the trained flavor panel generally does not detect painty off-notes (off-flavors formed due to downstream breakdown products of the peroxidated fatty acids) until PVs increase above 30 mEq/kg (Timothy Sanders, personal communication). In fact, several previous studies have shown that post-
roast PV increases are positively correlated to pre-roast MC. If oxidation was largely inhibited by nitrogen flushing, it is possible that PV of the different pre-roast MC did not diverge as much as might be expected.

**Oxidative Stability Index (OSI)**

OSI is a relative measure of the resistance to oxidation of a product. OSI in peanuts increased immediately after roasting (Figure 6). Prior to roasting, mean OSI values ranged from 10.0 to 10.7 but were not statistically different by pre-roast MC (p=.9847). Immediately after roasting, oils expressed from the peanuts exhibited a pattern of increase from raw levels that was strongly negatively correlated with pre-roast MC. The various pre-roast MC had significantly different (p<.0001) OSI values ranging from 11.15 (6.6%) to 16.33 (4.2%). Only the 6.6% sample did not significantly increase in OSI during the raw to roast transition. This is similar to the FFA data in which the 6.6% sample did not increase significantly in FFA during roasting while the lower three MC did increase in FFA. The increase in OSI may be due to composition changes that occur during roasting. The antioxidant effect did not persist over time and the 4.2 MC samples which had the greatest OSI increase during roasting, decreased fastest from week 0 to week 4 (Figure 5). After 4 weeks, OSI values decreased from 11 to 16 hours immediately after roasting, to 7 to 11 h at 4
weeks. From 4 weeks to 48 weeks there was a slow decrease in OSI values in all samples. In most instances, the lower pre-roast MC had higher OSI values. OSI values during storage were significantly related to weeks (p = <.0001) and pre-roast MC (p = <.0001). Pre-roast MC 4.2 and 4.5 were statistically separated but both were different from the 5.5 and 6.6 MC, which were also different from each other.

The decrease in OSI is due to lipid oxidation; the more oxidized an oil is when it is placed in the OSI instrument, the faster it reaches the exponential oxidation phase and thus OSI is smaller. Oil from lower pre-roast MC samples had greater resistance to oxidation over the entire study period.

**Volatile Analysis**

PV is a measure of the primary fatty acid oxidation product, fatty acid hydroperoxides. These peroxidated fatty acids are broken down leading to a cascade of potentially flavor-active chemicals. For example, oxidation of linoleic acid results in the production of 9- and 13-hydroperoxides, in which breakdown of the 13-hydroperoxide leads to hexanal formation (Ho and Chen, 1994). Accumulation of products from reactions downstream of the primary oxidation event would be expected to lag behind PV. In this study, we measured concentrations pf the aldehydes, pentanal (Figure 7) and hexanal (Figure 8).
was considerable variation in the data for both compounds but the means generally tracked between 15 and 50 ppm. Statistical analysis of pentanal content before and after roasting indicated no changes due to roasting of any pre-roast MC.

During storage, there were significant differences in pentanal due to weeks in storage (p<.0001) and pre-roast MC (p=.0002). The weeks x MC interaction term was also significant. Analysis of hexanal content over time indicated significant differences due to weeks (p<.0001) and pre-roast MC (p<.0001), and again, the weeks x MC interaction term was significant. Both hexanal and pentanal had peaks in concentration at 8 weeks which is 4 weeks after the time when PV reached maximum levels and leveled off during storage. Previous work has indicated that both MC and storage are significant factors affecting hexanal accumulation in peanuts (Abegez et al., 2004). In this study, the actual change in magnitude over time for either compound was quite small; however, and the significant interactions were due mainly to small rank changes among the pre-roast MC over time. The diminished upward trend in these compounds was likely due to the removal of oxygen by nitrogen flushing of the filled jars prior to storage. Peak values for pentanal and hexanal usually occur in step or lagging behind PV increases during storage (Abegez et al., 2004). If lipid oxidation is substantially inhibited, the accumulation of pentanal and hexanal will be delayed. In fact, if losses due to
volatilization of pentanal and hexanal match their rate of synthesis, no accumulation would occur.

**Descriptive Sensory Analysis**

Flavor attributes most relevant to the deterioration of peanuts are roasted peanutty, cardboardy and painty flavor and each is discussed below. Other flavor attributes in the lexicon were tested; however, statistical differences within them were small with sweet aromatic following the same decreasing trend as roasted peanutty (Table 1).

**Roast Peanutty Flavor**

Roast peanutty (RP) flavor is the signature flavor in roasted peanuts. It is thought to result from the interaction of many compounds. Many of these compounds are products of the Maillard reactions (Bett and Boylston, 1992) that occur during roasting. Using a trained sensory panel to monitor flavor changes during storage, RP was found to slowly but significantly (p<.0001) decrease over time (Figure 9) by ca. 0.2 to 0.3 flavor units. This phenomenon, termed by some as "flavor fade", has been described in the literature (Willliams, et al. 2006) and probably occurs universally during storage of roast peanut products. The specific
mechanism responsible for flavor fade is unknown (Abegaz et al., 2004). Reduction in RP resulted in enhanced perceptions of off flavors (Felland and Koehler, 1997). RP flavor is probably composed of several odorants and decrease in this these compounds may correlate with decreased perception of RP (Bett and Bolyston, 1992). A second hypothesis on flavor fade is that pyrazines and other RP-related compounds may be masked by off-flavor compounds derived from lipid oxidation (Warner et al., 1996). RP intensity of high and low pre-roast MC were significantly different. MC 6.6% had the lowest RP intensity (overall mean 4.27) which was ca. 0.25 units lower than the 4.2%, 4.5%, or 5.8% treatments (means 4.51, 4.48, 4.48).

**Cardboardy and Painty Flavor**

Cardboard intensity generally increased with time (Figure 10). Pre-roast MC significantly affected cardboardy flavor scores during storage but there was not a good correlation with pre-roast MC. Cardboardy intensities changed significantly (p<.0001) during storage (Table 1). Cardboardy scores averaged ca 0.35 at weeks 0 and 4; by week 24, scores had risen to 0.60 or higher. Only by week 48 did cardboardy scores begin to average near the threshold of 1.0. Despite an intensity below 1.0, which means that all panelists did not identify the descriptor in the sample, the increase in cardboardy was progressive over time (Table 1).
Painty intensity was very low for all treatment combinations (Figure 11). Analysis indicated that painty scores varied significantly by pre-roast MC (p<.0001) but not over time in storage (p=.2338) (Table 1). Average painty scores were 0.06, 0.09, 0.15 and 0.26 for the 4.2, 4.5, 5.8 and 6.6% treatments, respectively. Although the differences were small and intensity less than 1 indicates that not all panelists identified the descriptor, the data indicate that pre-roast MC had an effect on painty during storage. If nitrogen flushing was not used, painty scores, like PV values may have been much higher.

Physical Differences

Physical differences were observed within the first 8 weeks of storage. Lower moisture content samples were characterized by oil seepage from the peanuts (Figure 12). Moisture content 4.2 % appeared to have the largest amount of oil seepage. Moisture contents, 4.5% and 5.8% (dw), had progressively less oil seepage and 6.6 % had no oil seepage. Oil seepage decreased with increasing MC. These visual observations persisted throughout the 48 week storage period.

Oil present at the surface of the peanuts appeared to be oil that had not being completely drawn into the seed. After steam escapes from oil roasted products, a uniform sponge-like network should be present. The oil present at the surface is
drawn into these pores filling the area left by the water (Saguy and Dana, 2003). A
difference in these areas could explain the difference in the amount of oil left at the
surface.

CONCLUSIONS

MC is an essential part of food processing and affects shelf life of many
commodities. In this experiment, both PV and FFA, as measures of shelf life,
increased with storage time while OSI values decreased indicating decreased shelf
life. PV for the roasted samples increased and these data were supported by off
notes perceived by panelist in the sensory test. Over time both off notes, painty and
cardboard, increased. Further definition of shelf life decrease was evident in the
slow reduction in roasted peanut flavor. In conclusion, although this study was
limited in range of MC, it does suggest that MC of virginia market-type peanuts
prior to oil roasting is important to storage shelf life.

ACKNOWLEDGMENTS

The assistance of Keith Hendrix, Jim Schaefer and the descriptive sensory panelists
is gratefully acknowledged.
Figure 1: Average moisture content (ww%) of peanut samples representing each of the four preselected moisture contents throughout storage with both day replications (A&B).
Figure 2: Average water activity of peanut samples representing each of the four preselected moisture contents throughout storage with both day replications.
Figure 3: Average total oil content (%) for each moisture content for raw and 0, 16 and 48 weeks of storage.
Figure 4: Average free fatty acids (%) at two roast replications for each moisture content over 48 weeks of storage.
Figure 5: Average peroxide value (meq/kg) for each moisture content and day replication over 48 weeks of storage.
Figure 6: Average oxidative stability index (hours) for each moisture content and roast replication over storage.
Figure 7: Average pentanal content (ug/g) over storage time for each preselected moisture content.
Figure 8: Average hexanal content (ug/g) over storage time for each preselected moisture content.
Table 1: Statistical differences in sensory scores for peanut flavor attributes by pre-roast MC and storage week.

<table>
<thead>
<tr>
<th>Pre-Roast MC (%wb)</th>
<th>Roasted Peanuty</th>
<th>Sweet Aromatic</th>
<th>Dark Roast</th>
<th>Raw Beany</th>
<th>Cardboardy</th>
<th>Painty</th>
<th>Plastic Chemical</th>
<th>Sweet</th>
<th>Ashy</th>
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<tr>
<td>4.2</td>
<td>4.48 a</td>
<td>2.78 a</td>
<td>2.79 a</td>
<td>2.35 c</td>
<td>0.63 a</td>
<td>0.06 c</td>
<td>0.003 a</td>
<td>2.39 b</td>
<td>0.15 a</td>
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<td>4.5</td>
<td>4.51 a</td>
<td>2.81 a</td>
<td>2.80 a</td>
<td>2.35 c</td>
<td>0.44 b</td>
<td>0.09 bc</td>
<td>0.003 a</td>
<td>2.38 b</td>
<td>0.14 a</td>
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<tr>
<td>5.8</td>
<td>4.48 a</td>
<td>2.78 a</td>
<td>2.63 b</td>
<td>2.49 b</td>
<td>0.53 ab</td>
<td>0.15 b</td>
<td>0.000 a</td>
<td>2.43 b</td>
<td>0.10 b</td>
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<td>6.6</td>
<td>4.28 b</td>
<td>2.69 b</td>
<td>2.52 c</td>
<td>2.58 a</td>
<td>0.69 a</td>
<td>0.25 a</td>
<td>0.000 a</td>
<td>2.52 a</td>
<td>0.09 b</td>
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<table>
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<tr>
<th>Weeks in Storage</th>
<th>Roasted Peanuty</th>
<th>Sweet Aromatic</th>
<th>Dark Roast</th>
<th>Raw Beany</th>
<th>Cardboardy</th>
<th>Painty</th>
<th>Plastic Chemical</th>
<th>Sweet</th>
<th>Ashy</th>
</tr>
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<tr>
<td>0</td>
<td>4.58 a</td>
<td>2.84 a</td>
<td>2.71 ab</td>
<td>2.39 ab</td>
<td>0.36 d</td>
<td>0.12 ab</td>
<td>0.00 a</td>
<td>2.41 ab</td>
<td>0.10 ab</td>
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<tr>
<td>4</td>
<td>4.50 ab</td>
<td>2.73 bc</td>
<td>2.66 ab</td>
<td>2.48 ab</td>
<td>0.35 d</td>
<td>0.10 ab</td>
<td>0.00 a</td>
<td>2.39 b</td>
<td>0.09 c</td>
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<tr>
<td>8</td>
<td>4.52 ab</td>
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<td>2.66 ab</td>
<td>2.49 a</td>
<td>0.44 cd</td>
<td>0.09 b</td>
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<td>0.13 bc</td>
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<td>2.78 a</td>
<td>2.37 b</td>
<td>0.50 bc</td>
<td>0.14 ab</td>
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<td>2.76 a</td>
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<td>0.53 bc</td>
<td>0.10 ab</td>
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<td>2.63 b</td>
<td>2.49 ab</td>
<td>0.73 b</td>
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<td>0.00 a</td>
<td>2.46 ab</td>
<td>0.15 b</td>
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<tr>
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<td>2.44 ab</td>
<td>0.62 bc</td>
<td>0.16 ab</td>
<td>0.00 a</td>
<td>4.47 ab</td>
<td>0.10 bc</td>
</tr>
<tr>
<td>48</td>
<td>4.26 d</td>
<td>2.68 c</td>
<td>2.61 b</td>
<td>2.48 ab</td>
<td>0.99 a</td>
<td>0.12 ab</td>
<td>0.00 a</td>
<td>2.41 ab</td>
<td>0.22 a</td>
</tr>
</tbody>
</table>
Figure 9: Roast peanut flavor intensity of roasted chopped Virginia type peanuts of various initial moisture content (MC) during storage.
Figure 10. Change in cardboardy flavor intensity of roasted chopped Virginia type peanuts of various pre-roast moisture contents during storage.
Figure 11: Painty flavor intensity of roasted chopped Virginia type peanuts of various initial moisture content (MC) during storage.
Figure 12: Pictures of selected moisture contents representing a decrease in the amount of surface oil or oil seepage present with an increase in moisture content (mc).
REFERENCES


