ABSTRACT

STRASSER, HANNAH KATHLEEN. Influence of Pre-Roast Moisture Content and Post Roast Cooling Parameters on Salt and Oil Content of Oil Roasted Peanuts. (Under the direction of Dr. Lisa L. Dean).

Oil migration affects the appearance and quality of oil roasted peanuts and consequently has an impact on overall consumer acceptance. Exchange of oil may occur during or after oil roasting (deep fat frying) of peanuts but little is known about the factors contributing to this exchange. Studies on deep fat frying have mainly focused on foods with higher moisture levels. For foods with lower moisture content such as peanuts, inconsistencies reported between different theories, urge further investigation on the roasting process. Current available research reports explaining the mechanisms that ensue during roasting suggest that pre-roast moisture content and post roast cooling parameters are probable factors that influence the movement of oil. The purpose of this study was to monitor and determine the effect of raw seed moisture content and post roast cooling practices on the migration of oil or salt to or from peanut seeds, during the frying and post roast cooling processes.

To examine the effect of these factors raw high oleic peanuts were manipulated through forced air drying or the addition of moisture to achieve a range of moisture contents including: 3.3%, 4.6%, 6.1%, and 8.4% determined on a wet weight basis. Peanuts from each distinguished moisture level were then roasted in peanut oil containing 10% coconut oil. Lauric acid (C12:0) from the coconut oil served as a chemical marker to track oil movement from the fryer into or onto the peanut seeds. Upon removal from the roasting oil, peanuts were cooled using three different cooling parameters. Multiple analyses were utilized to trace and quantify oil migration and retention including the changes observed in seed moisture
content and mean oil, fatty acid analysis, bulk density, true density, and porosity, as well as structural damage observed through the use of scanning electron microscopy.

The results of these analyses revealed that pre-roast moisture content influences the transfer of matter during frying and post roast cooling influences oil migration after the seeds are removed from the fryer. As raw moisture levels increase the seeds experienced a greater and more violent expulsion of internal moisture upon entry into the hot frying oil. The turbulence and duration of the dehydration process was directly influenced by the amount of moisture present. High moisture seeds experienced more structural damage and loss of endogenous peanut oil and matter into the frying medium. SEM images confirmed these findings through the increased presence of cracks and voids in the peanuts’ surfaces. The determined presence of C12:0 found in the oil obtained from roasted seeds that had been rinsed of surface oil, confirmed that oil from the fryer migrated into the seed at some point in the process. Further differences reported between peanuts that were cooled in relation to those that were not cooled indicated that the majority of oil absorption occurs during the post roast cooling process. Peanuts that were not cooled showed a significant increase in amount of surface oil and decrease in oil the seed took up. Cooling at different rates did not show significant differences. Porosity data showed a slight increase as pre-roast moisture increased but was not determined to be statistically significant.
Influence of Pre-Roast Moisture Content and Post Roast Cooling Parameters on Salt and Oil Content of Oil Roasted Peanuts

by
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DEDICATION

Dedicated to my amazing parents, John and Kathleen Strasser, my grandfather, Elmer Linthicum, and in loving memory of my grandmother, Sybil Jean Linthicum. You have not only been phenomenal role models but have encouraged me to achieve anything I set my mind to by supporting me in every way that you possibly could.
BIOGRAPHY

Hannah Strasser was born April 27, 1992 in Takoma Park, MD. She graduated from Mount de Sales Academy in Catonsville, MD in 2010. Determined to develop premium ice cream, she continued her education at Delaware Valley University in Doylestown, PA where she studied Food Science and earned a Bachelor of Science degree in 2014. While earning her Bachelor’s degree she pursued her dream to work with ice cream products by working at a homemade ice cream shop then attained a Research and Development intern position at Just Born, Inc. expanding her passion to include confections. Upon graduation Hannah became a microbiology laboratory technician for the United States Department of Agriculture then moved back home to Maryland shortly after to work at McCormick and Company. In 2015, Hannah moved to North Carolina to further continue her education as a Master’s student under the direction of Dr. Lisa Dean.
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Peanuts (Arachis hypogea L.), can be utilized in a variety of ways including direct consumption, making them one of the world’s principal oilseed crops. Approximately 1.25 million metric tons per year (shelled basis) of peanuts are exported worldwide, while approximately 1.1 million tons of peanuts are consumed in the U.S. each year (American Peanut Council 2014; NASS 2016). Roasting is a popular practice for preparing whole peanut seeds for consumption and can be done through both dry and oil roasting. Oil roasted peanuts are one of the most consumed products worldwide. The unique sensory characteristics developed during the roasting of peanut seeds in hot oil gives oil-roasted peanuts a higher overall consumer acceptance than dry-roasted peanuts (Olmedo et al. 2008). Roasted peanut product quality and the consumer’s acceptance of the product are very important goals for the peanut industry. A number of factors determine the quality of oil-roasted peanut seeds including texture, flavor, and appearance as well as both the actual shelf stability of the product determined by the product manufacturer and the perceived shelf stability by consumers.

Oil roasting is a complex operation causing physical, chemical, and sensorial characteristic modifications to the raw peanut seed (Krokida et al. 1999). The frying or oil roasting process is simplified and briefly described as follows according to Mellema (2003): Oil roasting begins immediately upon the addition of the peanut to the hot oil. Heat transfers rapidly from the oil to the peanut surface instantly increasing the temperature of the peanut surface and causing the water at the surface to boil (Mellema 2003). As boiling commences convection is intensified by the turbulent escape of endogenous water vapors. Evaporation occurs causing the surface to dehydrate and form a crust. The turbulent evaporation of water
leads to changes in the surface pores including the creation of larger pores and tears along the surface. The water deeper inside the seed eventually heats as roasting continues through energy conducted from the surface causing the inside of the seed to cook as well. As roasting time progresses, the moisture content in the crust decreases, while the amount of damage to the seed surface increases. The simultaneous mechanism of heat and mass transfer causing vigorous evacuation of water vapor and other compounds from the food to the fat creates voids for oil to be absorbed into during the cooling process once the seed has been removed from the fryer.

Initial moisture content is an important quality attribute when investigating oil migration during the described oil roasting process. Numerous studies have been conducted to define the relationship between initial moisture content and oil absorption, however the reported results in the literature often contradict leaving the effect of pre-roast moisture content to remain unclear (Zhang et al. 2016). Ziaiifar (2009) stated that moisture loss during oil roasting acts not only as a mode of heat transfer, but also creates pores allowing oil uptake into the peanut seed. In addition, the theory that the amount and size of pore formation is mainly determined by initial moisture content is greatly supported in the current literature describing the mechanisms that occur during frying. Gamble et al. (1987) were some of the first to prove that oil content and moisture content were highly correlated. Their research demonstrated that foods that experience higher amounts of moisture loss also shows an increase in fat uptake. It has also been suggested that the total volume of moisture loss is equal to the total volume of oil absorbed (Pinthus et al. 1993).
The majority of research conducted regarding the mechanisms of deep-frying concentrates on foods with higher initial moisture levels such as breaded meats and potatoes comprised of approximately 50-75% water (Das et al. 2013; Pedreschi 2012). The composition of these foods is vastly different from the composition of peanuts. Peanuts are comprised of less than 10% water, therefore any findings regarding the oil holding capacity and surface or texture changes may be dissimilar for peanuts and needs to be explored exclusively.

Uptake of oil from the fryer to the food has been observed to take place most frequently during the post-fry cooling period once the food has been removed from the fryer. It is suggested that when the food is removed from the fryer, oil enters the food from the surface due to a vacuum created from the condensation of water vapors within the pores that occurs as the core temperature decreases (Moreira et al. 1997). The factors affecting oil uptake by fried food has been studied through a variety of different products. Ufheil and Esher (1996), used a heat stable dye to follow the absorption of oil at different times during frying of potato slices. Their study determined that more than 80% of the oil in the slices was absorbed post frying, when the potatoes were removed from the fryer oil. A similar result was found when looking at oil uptake in tortilla chips. It was shown that only 20% of the final oil content of the tortilla chips was absorbed during frying, while 64% was absorbed during cooling, leaving 36% on the surface (Moreira et al. 1997). These studies support the theory that the conditions of the environment that the peanut is exposed to upon removal from the fryer may have a significant impact on the amount of oil uptake. This impact may
also differ according to the composition of the food being fried or roasted, again making the specific analysis of peanuts necessary.

The evaporation of water and absorption of oil that occurs to peanut seeds during oil roasting creates a unique and appealing product for consumers. If roasted peanuts appear too dehydrated or overly saturated however, an opposite effect may occur. Oil roasted peanuts that appear excessively greasy or dry suggest that the product is defective and of poor quality. The purpose of this study was to investigate a quality defect reported by consumers to the peanut processing companies. This observed defect was described as oil or salt migrating from the inside or off the surface of peanuts and settling in the bottom of the container of oil roasted peanut seeds (cocktail peanuts) during storage. The specific objective of this research was to determine the influence of pre-roast moisture content and post-roast cooling parameters on this migration of oil or salt from oil roasted peanuts. To determine if and why oil/salt migration may occur, peanuts were prepared to a range of four sequential moisture contents, blanched, and oil roasted. Roasting oil was composed of peanut oil with the addition of coconut oil, which contained lauric acid (C12:0) to serve as a chemical marker. Once peanuts were removed from the fryer they were exposed to three different cooling parameters, no cooling, ambient or slow cooling, and forced or fast cooling. Physico-chemical analyses were conducted on peanuts from each moisture content exposed to all three cooling parameters and observation samples were monitored throughout the duration of the study.
REFERENCES


CHAPTER 2: LITERATURE REVIEW
PEANUTS

History and Importance

Roasted peanut seeds are a desirable food product with a pleasant and unique flavor (Ahmed & Young 1982). Peanut, also referred to as groundnut, is in the genus *Arachis hypogaea* of family *Leguminosae*. It is a native South American legume (Maiti 2002). Its species was known and developed widely throughout the tropical and subtropical areas in the New World and was discovered during European expansion. It has been documented that early Spanish and Portuguese explorers found peanuts were being cultivated by Indians in multiple locations including the West Indian Islands, Mexico, the northeast and east coast of Brazil, the warm areas of the Rio de la Plata basin, and extensively in Peru. The peanut was then cultivated in Europe, the African coasts, Asia, and the Pacific Islands (Hammons 1982).

Peanuts made their way to North America in the 1700’s. There, they were grown on commercial farms, but were not immediately popular due to slow and difficult growing and harvesting techniques. After the American Civil War, the demand for peanuts increased rapidly due to advances in harvesting, shelling, and processing techniques, which occurred along with the development of new production equipment. This 20th century technology led to a demand for peanut products such as oil, roasted and salted peanuts, peanut butter and confections (American Peanut Council 2014). According to the Food and Agriculture Organization of the United Nations the US is ranked as the fourth largest producer of peanuts following China, India, and Nigeria (American Peanut Council 2012). In contrast to the utilization of peanut crops worldwide, peanuts grown in the United States and South America are mainly sold as food for human consumption (Stalker 1997).
In 2014, U.S. peanut farmers produced 1.9 million tons of peanuts annually on 1.44 million acres of farmland (American Peanut Council 2014). The current main peanut producing states include Georgia, Texas, Alabama, North Carolina, Florida, Oklahoma, Virginia, New Mexico, and South Carolina. Figure 1 displays the peanut certified acres in these dominating states on the United States map. These states are ideal because peanuts grow best in sandy, loamy, soils from April through October depending on their variety and require 120-160 frost free days. The four commercially produced market types of peanuts in the United States are Runner, Virginia, Spanish, and Valencia. Each type has a unique size and flavor, lending themselves to different functionalities (American Peanut Council 2014; Ahmed & Young 1982; Adule et al. 1989). Visual representations of the four market types are shown in Figure 2.

These four market types belong to two distinct botanical types, the hypogaea botanical type, *Arachis hypogaea* L. subsp. *hypogaea*; and the fastigiata botanical type, *Arachis hypogaea* L. subsp. *fastigiata*. In the hypogaea botanical type, the seed ranges from medium to large and usually has two seeds per pod. Their growth habit varies between spreading, intermediate, or erect. Pod distribution is scattered rather than concentrated near the base of the mainstem. This botanical type consists of the Runner and Virginia market types. In the fastigiata botanical type, the seed is small to medium and pods contain two to four seeds. The growth habit is an upright (bunch) and the pod distribution is usually concentrated near the base of the mainstem. The Spanish and Valencia market types are included in the fastigiata botanical type (Sholar et al. 1995).
Runner market type peanuts have become dominant in the United States due to the introduction of a new variety in the 1970s, called Florunner. (American Peanut Council 2012) This cultivar allowed a large increase in peanut yields. Runners demonstrate a range of kernel sizes and a large proportion are roasted and ground for peanut butter. Runners are mainly grown in Georgia, Alabama, Florida, Texas, and Oklahoma, and account for approximately 70% of total U.S. peanut production. (American Peanut Council 2012; Sholar et al. 1995) Virginia market type peanuts, have the largest kernels and account for the majority of roasted in shell peanuts. Larger kernels attained from shelled Virginias are sold as salted peanuts. Virginia-type account for about 22% of total production in the U.S. (American Peanut Council 2012) Spanish-type peanuts have a characteristic reddish-brown skin covering the kernels. These kernels are smaller and are used predominantly in confections. They have the highest oil content and account for 4% of U.S production. Valencia market type peanuts usually have three or more small kernels to a pod. They are very sweet and are commonly roasted and sold in the shell. They are also often boiled in the South. Valencias account for less than 1% of U.S. production and are grown mostly in New Mexico (American Peanut Council 2014).

**Structure and Vegetative Growth**

Peanuts are self-pollinating, low-branching, annual legumes bred for edible seed (Astor et al. 2015). Peanut growth is very low and close to the ground with its fruit production below the soil surface (Figure 3). In the United States, peanuts are planted in April or May when soil temperatures reach a range of 65-70°F (20°C) after the last frost.
Seeds are planted 1.5-2 inches deep and 1-4 inches apart in the Southeast and Southwest, and 4-6 inches apart in the Virginia Carolina Area. The seeds are planted in rows that are situated about three feet from each other (Figure 4). However, row spacing can vary and is dependent upon the planting and harvesting equipment utilized (American Peanut Council 2014). Planting peanuts in the correct soil type is imperative to their success and little has changed in soil and land selection for peanuts since commercial peanut production in the U.S began. The ideal peanut soil as mentioned previously has either sand, loamy sand, or sandy loam texture and is well drained with a light color (Scholar et al. 1995; Henning et al. 1982).

The best crops are developed in areas where the climate is free of frost for 200 days (American Peanut Council 2014). Crop rotation is important as peanuts like most legumes are subject to issues introduced by other crops immediately preceding them in rotation such as diseases and nematodes. To reduce the risk of potential issues other legumes should not be included in the rotation (Sholar et al. 1995). Farmers typically follow a three-year rotation pattern with corn, small grains, or cotton to reduce impending disease problems (American Peanut Council 2014). When peanuts are integrated into an appropriate rotation there is an apparent increase in crop yield. This increase is the result of more effective use of natural soil fertilizer from residual nitrogenous compounds, improved weed control, and the reduction in soil-borne disease and nematodes (Sholar et al. 1995). Many farmers also try to limit crop stress by utilizing irrigation systems allowing the opportunity for high quality peanut production (American Peanut Council 2014).

Peanut plants typically develop one to six seeds, which form in a subterranean pod (Astor et al. 2015). The flower, is borne above the ground and is the plant’s most
distinguishing visible characteristic (Figure 5). The flower wilts following fertilization and after 5-7 days a peg or ovary emerges (Simpson 2001). The peg curves toward the earth meaning it is positively geotropic and it penetrates the soil to a depth of between 2 and 7 cm once situated. It assumes a horizontal position allowing the pod to form below the surface (Astor et al. 2015). The peg is an expanded intercalary meristem from the base of the basal ovule (Gregory et al. 1973). This structure is unique to the genus. The pod is a result from peg expansion and is called a lomentiform carpel, containing 1 to 5 segments that each contain a single seed. Leaves and above ground parts of the plant that are visible in the first 2-3 weeks of life are all present in the undeveloped seed prior to continued development (Gregory et al. 1951).

The seed of *Arachis hypogaea* is a dormant plant in itself containing the shoot (plumule), leaf, and primordia and the root initials or radicle (Gregory et al. 1973). More specifically it is comprised of two seed leaves or cotyledons, an upper stem axis, young leaf primordia known as the epicotyl, a lower stem axis or hypocotyl, and a primary root. The primary root in combination with the hypocotyl, make up the radicle. The epicotyl, hypocotyl, and primary root form a system involved in all parts of the peanuts functionality and growth. These structures including the cotyledons, make up the peanut embryo. The peanut seed contained inside its colored seed coat, is an entire plant complete with leaves containing stored food and grown out of size proportion to its remaining plant parts (Gregory et al. 1951). The seed coat is a papery enclosure whose function is to act as a protective layer from the microbes present in the surrounding soil. It may vary in color from white to tan to black and some shades of pink to red (Gregory et al. 1973).
The initial stages of growth are clearly described by Gregory et al. as follows: When a peanut seed is planted in suitable conditions the radicle starts to grow. The hypocotyl portion of the radicle elongates and quickly pushes the cotyledons above the ground. This process takes from 4 to 7 days. Once above ground, the cotyledons split open exposing the shoot primordia which extends to form the epicotyl containing the first true leaves and forming the main stem. The lower hypocotyl then elongates to form the tap root (Gregory et al. 1973; Zobel & Waisel 2010). The lateral roots usually require two or three days after germination to appear and are generally fully developed by the fifth day (Moss & Rao 1995). The germinating peanut has different sets of roots that can be categorized into three different groups. The first group is lateral, long, and thin, with limited secondary thickening. The second group are higher-order roots with a simpler anatomy and little to no secondary growth. Of these two groups the first-order lateral roots are considered the skeleton of the root system and the second-order roots are considered the feeders. The third set of roots are adventitious roots that can be seen when stems come in contact with the soil (Moss & Rao 1995; Munger et al. 1998).

The stems are angular structures that can be either pubescent or glabrous and are typically green but are sometimes pigmented in certain types of peanuts. It has been shown that pubescence and pigmentation on stems limit damage from insects and pests that feed on leaves (Sharma et al. 2003). Mature peanut plants typically reach around 1-1.5ft (0.3-0.46m) tall with branches stretching wide about 1ft (0.3m) laterally (Stalker & Wilson 2016).
Reproductive Structure and Development

In the past, the uniqueness of the flower and fruit in peanuts have led to much confusion (Gregory et al. 1973). Peanut is a member of the tribe Dalbergiaea that is a subfamily Papilionoideae in the family Fabaceae. It has an indeterminate flowering pattern and is day-neutral regarding flower initiation, meaning it will flower with no dependence on exposure to light (Ketring 1979). Flowers are hermaphroditic containing both male and female parts allowing peanuts to self-pollinate (Stalker & Wilson 2016). Peanut inflorescence is a reduced simple or compound monopodium that appears as a cluster of flowers (Rao & Murty 1994). The inflorescences are borne in the axils of leaves of primary or secondary branches. They have a spike-like appearance and contain up to five flowers with three flowers per inflorescence being the most common (Moss & Rao 1995). The flowers are papilionaceous and have five brightly pigmented petals: one petal is the large standard, there are a pair of wing petals, and two fused keel petals (Stalker & Wilson 2016). The flowers look as if they are stalked due to the presence of an elongated tubular hypanthium, known as the calyx tube. Two bracts extend under the flower to support it. One of these bracts is attached to the inflorescence branch (Norden 1980).

The calyx has five total lobes with one lobe opposite the keel and the other four fused except at their tips on the back side of the standard. The standard ranges in color from light yellow to deep orange but may also occasionally be white or have red veins on the inner face. The wings surrounding the keel are typically yellow and the keel is almost colorless enclosing the anthers and stigma. The androecium is a basic monadelphous structure bearing eight functional stamens and two smaller sterile ones (Stalker & Wilson 2016). The calyx
tube contains a hollow style that is attached at the base of the ovary (Periasamy & Sampoornam 1984). The tip of the style is called the stigma. It is found at the same level or protrudes slightly above the anthers. The stigma is of the dry papillae type has an absence of hairs and the accommodation of up to 15 pollen grains (Moss & Rao 1995). It has been observed that there is a difference in the stigmatic surfaces between annual and perennial Arachis species. Perennial species have a much smaller stigmatic surface with unicellular hairs allowing a maximum accommodation of three pollen grains. This difference likely leads to lower seed set and complications in serving as female parents for interspecific hybridization (Moss & Rao 1995). The peanut ovary is unilocular, superior, and usually contains one to three ovules with two being the most common. Consequent to fertilization, each present ovule develops into a seed and the ovary becomes the pod (Stalker & Wilson 2016).

Pollen matures approximately 6-8 hours before anthesis (Gregory et al. 1973; Pattee & Stalker 1991) Normally one flower at an axil reaches anthesis on any given day. At that time, the mature pollen grain is two-celled with two generative nuclei (Xi 1991). The mature embryo sac is comprised of an egg with the endosperm nucleus surrounded by starch grains. When fertilization occurs, starch grains disappear and a multicellular proembryo is formed upon syngamy (Pattee & Stalker 1991). The dissolved starch grains provide nutrition for the formed proembryo after syngamy, allowing it to grow into a mature seed. The fertilization process takes about 18-24 hours to fully complete from anthesis to syngamy (Pattee & Stalker 1991). Once fertilized a peanut pod is developed and reaches maturity within 60-80
days. Maturity levels differ at the time of harvest because peanut plants are indeterminate and flowering occurs over an extended period of time (Stalker & Wilson 2016).

**Physiology**

Research concerning physiological aspects of peanut growth and development has allowed us to better understand the nature of the plant (Ketring et al. 1982). Peanut physiology is very similar to the physiology of many other legumes. Their productivity relies on the number of various plant structure formations, the rate that they expand in size, and their total mass. (Williams & Boote 1995).

Physiological changes that occur as peanuts mature are much more complex. Peanut seed maturation is very important when determining the yield and income gained or lost, directly linked to specific crops utilized in the peanut industry. A number of studies have been completed in an effort to establish a seed maturity index for peanuts as well as to gather information about the physiological and structural changes that occur during the maturation process since peanuts are indeterminate flowering crops (Young et al. 2004). Two major methods to determine relative physiological maturity have been developed. Both are based on internal or external physical and morphological characteristics of the hull, seed coat, and seed (Sanders et al. 1982).

Young et al. processed seeds at four different developmental stages or categories for SEM and TEM evaluations of cotyledon growth stages to describe the changes that occur during maturation. The images captured from this study were analyzed and indicated the nature and degree of changes that occur throughout the progressive stages of peanut seed
development (Young et. al 2004). In the very immature peanut, starches and lipids are the principal substances synthesized as the protein bodies begins to form. As the seed continues to develop the protein body and lipid bodies continue to develop as well until the seed is completely mature. It has been shown and confirmed that starch accumulation is the primary energy source for immature peanuts. This source is then converted to lipid accumulation as the peanut reaches the more mature stages in its life cycle and starch levels become more constant (Young et al. 2004). From this knowledge and by further understanding of the maturation process, farmers are able to harvest at an appropriate time, allowing maximum marketability for their crop.

**Harvesting and Curing**

Harvesting is a broad term that includes the multiple operations involved in removing peanut pods from the soil and preparing them to be sold. The peanut plant’s unique growing pattern and indeterminate fruiting pattern result in a range of kernel maturities and moisture levels making harvesting a relatively complex process. The typical processes currently included in harvesting are: pre-harvest field preparation, vine clipping, digging, shaking, windrowing, and combining (Mills & Samples 1973; Young et al. 1982). Timing is a key component in the harvesting process to minimize losses. Peanuts should be harvested when the soil is in the correct condition, meaning it is dry enough to fall freely from the stems and pods but not excessively dry or crusted which would cause stress and potential pod break off in the soil (Asiedu 1994).
Harvesting occurs in two stages (American Peanut Council 2014). The first is
digging, which begins when about 70% of the pods have reached maturity (Figure 6).
Digging occurs using a mechanized digger that is pulled by a tractor between peanut rows
while simultaneously driving a horizontal blade four to six inches below the surface of the
soil. This mechanism is essentially loosening the plant while cutting the taproot. A shaker
follows the digger and lifts the plant from soil then gently shakes the soil from the plant
leaving it inverted on top of the soil in its respective rows (American Peanut Council 2014).
Proper synchronization of travel speed along the rows with shaker speed is essential.
Incorrect travel speed may result in the dragging of the plants forward or snatching them
backward out of the soil. The shaker speed should be set to a pace slightly faster than the
speed of forward motion (Robertson 2013). The inverted rows of plants allow the pods to be
exposed to the sun for drying in the field. This process is called windrowing (Figure 7).

Combining is the second stage of harvesting. After seeds have dried in the field for
two or three days during the windrowing process, a thresher or peanut combine comes
through and separates the pods from the vines. During this separation, the thresher collects
the pods in a hopper that sits on top of it and the vines are returned to field to improve soil
fertility and organic matter. Freshly harvested peanut pods are then temporarily held in
drying wagons for curing (American Peanut Council 2014) (Figure 8).

Once peanuts have reached the curing wagons they must be immediately dried to a
moisture level that is considered safe for storage. Upon removal from soil at harvest, peanuts
typically have a moisture content around 40% on a wet basis (w.b.). By harvesting at such a
moisture there is a reduced risk of high field loss and weather damage since many
physiological processes are still operative at these moisture levels (Dickens & Pattee 1973). Failure to reduce the moisture content to a safe and marketable level of less than 10% (w.b.) within a period of 2 or 3 days however, may result in biological activity and a reduction of quality (Young et al. 1982). Peanuts are typically cured in large perforated containers by forced heated or ambient air which allows control over the curing process. Curing methods are set to rapidly and uniformly cure the peanuts according to conditions of the environment and climate in the production area at that time. Proper curing is directly related to overall peanut quality (Dickens & Pattee 1973).

**Pre-Process Storage**

After peanuts are harvested and cured they are ready for storage but usually contain a wide variety of foreign materials and most times require pre-cleaning before storage. These readied peanuts are known as “farmers stock peanuts” meaning they have been picked and threshed but not yet shelled, crushed, cleaned, or otherwise altered (Smith et al. 1995). The foreign material in farmer stock peanuts is reduced to yield a more marketable product through a program of prevention and removal. A typical pre-cleaning facility usually consists of a dump pit, cradle hoist, pre-cleaner, elevators, and some type of enclosure to contain and cover the equipment. Upon arrival, the peanuts are dumped into the dump pit when one end of the wagon container is lifted by the cradle hoist. They are then elevated from the dump pit to the roll feeder, located on the pre-cleaner. Once there the peanuts pass through the pre-cleaner, then are elevated and sent into a holding bin or transport vehicle ready for storage. The described process is only about 85% efficient making further cleaning
necessary before shelling the peanuts (Davidson et al. 1982). The majority of peanuts are not fully cleaned before storage due to equipment and labor expenses. However, peanuts that contain more than 10% foreign material are usually cleaned before marketing. The best conditions for normal dry-bulk storage of unshelled peanuts are a temperature of 10°C and 7.5% kernel moisture content (w.b.). If these conditions are properly controlled and maintained, good quality peanuts can be stored for about 10 months without any quality loss (Smith et al. 1995). Stock peanuts are usually stored in flat-type storage systems but can also be held in almost any other type of structure that will shelter them from the weather and outside environment. Peanuts are also sometimes held in round metal bins and concrete silos common to the grain industry. There are three types of flat-storage warehouses. These include the conventional, the conventional with doghouse, and the muscogee with doghouse. All three have sloped roofs but the muscogee is slightly different because it utilizes a lighter framework and as a result is a bit more limited when choosing a ventilation method (Smith et al. 1995). Ventilation is needed to ensure peanuts remain at the same level of quality during storage. Farmer’s stock peanuts are priced based on a 7% (w.b.) kernel moisture content, but are legally allowed to be stored at moisture levels up to 10.49% (w.b.). If peanuts are stored at such a level, they will mold within a few days if not properly ventilated (Smith et al. 1995).

**Grading and Shelling**

Farmer’s stock peanuts are inspected and graded to establish product quality and value after curing (American Peanut Council 2015). The inspection and grading process
takes place at buying stations or shelling plants usually in close proximity to where they were harvested and is conducted by the Agricultural Marketing Service (AMS) of the United States Department of Agriculture (USDA). A sample is taken to representative the lot of the peanuts and the inspector determines the meat content, size, amount of damage, foreign material, and moisture content of the kernel, then establishes a grade. The determined grade is then used to decide the value of the peanuts according to USDA price support schedules (Whitaker & Dowell 1995; American Peanut Council 2014).

Once graded, peanuts can be cleaned and shelled. Cleaned peanuts, free from the majority of all foreign material, are transported by conveyor to shelling machines where they are forced through perforated grates to be de-hulled. From there, the peanuts are passed through updraft air columns separating the kernels from the hulls. The kernels and pods are separated through use of a specific gravity machine. Kernels are passed over grading screens as a final step to be sorted by size and market grades to be sold (American Peanut Council 2014).

COMPOSITION

Moisture Content

The variation of flavor characteristics of peanuts during roasting is largely influenced by the initial moisture of the raw kernels (Sanders et al. 1995). The range of moisture contents of raw peanuts in storage includes moistures between 5% and 7% (w.b.). In roasting, regardless of if it is done through the dry or oil process, the first effect is the reduction of seed the moisture content. The roasting process reduces the moisture content to
a level below 2%. This reduction prevents mold and reduces potential staling and rancidity (Woodroof 1983a). In general, it has been observed that peanuts with lower moisture contents have a more pronounced flavor and peanuts with higher moisture contents have a less pronounced and short-lived flavor that changes to some sort of off flavor within a few days (Woodroof 1983b).

**Protein**

Peanut protein also has an effect on quality perception including seed physiology, seed agronomic performance, human and animal nutrition, flavor development in processing, and peanut allergies (Stalker & Wilson 2016). The protein content of peanuts is the most valuable aspect in regards to human nutrition. The amount of protein increases during ripening and maxes out at 9 weeks then becomes approximately stable (Basha 1991). It has been reported from the USDA National Nutrient Database for Standard Reference that peanut protein content is commonly around 25.8% (Davis & Dean 2016). The nutritional quality of protein depends on the amount of essential amino acids present. There are twenty common amino acids relative to human nutrition and nine of these are essential because the body cannot synthesize them on its own. The limiting factor in protein utilization is deficiency of one of those essential amino acids. Like the majority of vegetable proteins, peanut protein does not contain adequate levels of all nine of these essential amino acids (Davis & Dean 2016). Peanut protein is deficient in methionine, lysine, and threonine (Miller & Young 1977). These deficiencies can be balanced when peanuts are consumed in combination with alternate complementary sources of protein. At least 16 amino acids are present in peanut
seed and all are involved in peanut roasting reactions. During roasting the proteins are denatured but their nutritive value remains the same even through their exposure to moderate heat (Woodroof 1966).

Completeness of absorption and digestion are also important factors (Watts et al. 1959). The digestibility of peanuts is very high in both raw and processed seeds. The coefficient of digestibility of peanut protein is 89% and they provide a slight acid effect on digestion (Woodroof 1983b). Total protein content of the seed increases as it matures while concentration of free amino acids decrease (Basha et al. 1976).

**Lipids**

Lipids (oils) are the predominate macro-component in peanuts (Davis & Dean 2016). Peanut seeds have been found to range in oil content from 44-56% with an average of 50% (Cobb & Johnson 1973). Oil content is influenced by the growth environment, maturity, seed size, cultivar, and market type. Monitoring the amount of oil in the seed before processing is necessary to control final product quality (Dean & Davis 2016).

The majority of peanut lipids are triglycerides meaning three fatty acids are esterified to a glycerol backbone. In mature peanuts triglycerides account for about 97% of the total lipid content (Yoshida et al. 2005). Peanuts oil is made up of at least eight nutritionally essential fatty acids (Fore et al. 1953). Peanut lipids contain 76-82% unsaturated fatty acids, and of those 40-45% are unsaturated oleic and 30-35% are polyunsaturated linoleic. It was also observed that Spanish-type peanuts contain higher amounts of polyunsaturated as well as total saturated fatty acids. Runner and Virginia types are higher in monounsaturated fatty
acids, which are mostly oleic. There seems to be no correlation between polyunsaturated fatty acids and methods of harvest and curing, or types of damage. This suggests that the nature of peanut oil remains constant when subject to certain types of damage (Fore et al. 1953). Peanut oil is closely related to the flavor of the product and flavor is accentuated by heating, typically with dry or oil roasting (Woodroof 1983b).

**Carbohydrates**

Peanut cotyledons naturally contain about 18% carbohydrates while peanut skins contain about 1%. The amount of starch found in the seeds tends to vary from 0.5-5% depending on the type, growing condition, and stage of maturity (Woodroof 1983b). When carbohydrate calculation is measured by difference, peanuts have total carbohydrate levels of approximately 16% (USDA 2015).

Starch and sugar development are directly linked to seed maturation. Starch reaches its maximum just beyond the middle stages of maturity then remains constant while sugar content decreases throughout maturity (Ahmed & Young 1982; Pattee et al. 1974). The most abundant sugar found in all genotypes of peanuts is sucrose followed by stachyose and raffinose. Glucose is also present but at the lowest concentration. (Oupadissakoon et al. 1980). Sugars are a large part of the reactions that occur during processing that affect the flavor and color of peanuts and ultimately determine overall roast quality. To ensure optimal production, commercial roasters should constantly monitor sugar concentration in all raw materials before processing (Davis & Dean 2016).
Shelled Stock Storage and Transportation

Raw peanuts are classified as a food ingredient and must follow the guidelines implemented by the FDA to maintain their quality and safety during all storage and transportation processes. As previously described, peanuts are a high-fat food product requiring extra attention during post-harvest processes to reduce the risk of oxidation reactions that may occur to the double bonds in the mono-saturated fats. As mentioned previously, peanuts are typically stored in the shell close to where they were harvested at ambient temperatures and with proper ventilation prior to shelling. (Davidson et al. 1882) This storage period may last from 0-12 months depending on shelling schedules. Once shelled, peanuts must be handled with greater care and moved to cooler storage conditions with less humidity (Cowart et al. 2016).

Shelled peanuts are more susceptible to damage due to the removal of the protective structure. Peanut oil becomes semisolid when the ambient temperature drops to below 5°C, therefore any damage occurring prior to that point allows oil to seep from damaged cells in any breaks or bruises affecting the quality of the peanut (Woodroof et al. 1947). Shelled peanuts and those to be sold in the shell are often refrigerated for multiple reasons. Refrigeration preserves natural color and flavor by impeding staleness and rancidity and it allows the control of insects and mold. Plus, refrigerated storage can provide relief in periods of short supply by holding quality for up to three years (Woodroof 1983a). In commercial refrigerated storage, it is necessary to maintain the temperature between 1-5°C.
and a relative humidity between 55-70% for a kernel moisture content of 7-7.5% (w. b.). The storage space must have adequate air flow with peanuts being stored in containers stacked with space between walls, ceiling, other peanuts, and the floor for circulation. The space should be free of odors and products that emit odors as peanuts easily absorb odors from other products. Insects are not typically a problem due to refrigeration but rodents can be a major problem requiring preventative actions and procedures to be in place at all times in combination with routine inspection of storage facilities (Smith et al. 1995). The main objective of cold storage is to prevent peanut spoilage after shelling and until processing (American Peanut Council 2009). Cold storage practices are very important and are consequently improving as research progresses further determining the best possible practices.

When peanuts are removed from cold storage for retail or transport, they must be removed slowly or in stages to avoid condensation on the kernels, which could result in texture damage or mold (Woodroof 1983a). This process is called tempering. The tempering area must be well ventilated but also provide full protection for the product. Tempering is more important in warm, humid climates than in cooler drier areas due to potential rapid mold growth (Smith et al. 1995).

Raw peanuts must be transported under sanitary conditions. To ensure the safety and quality of the peanuts (Cowart et al. 2016). Peanuts are usually transported in bulk by fiberboard box, nylon tote bag, or burlap bag depending on their destination. Transport vehicles must be inspected before loading commences. Peanuts should not be in direct contact with the floor or walls and handlers must exercise care in order to avoid damage of
the peanuts or their containers. Good air circulation is important during transportation and carriers should never act as storage once the determined destination is reached. Raw shelled peanuts are a semi-perishable product and should be handled properly during transportation to ensure quality is maintained (Smith et al. 1995).

**Oil Roasting**

Peanuts account for about 80% of the nut market due to their nutritional attributes and price advantage (He et al. 2005). Food use of peanuts takes on various forms. Snack food is a major form of peanut consumption (He et al. 2005). Peanuts are commonly consumed as snack food after boiling, dry roasting, or deep fat-frying (oil roasting). The objective in roasting peanut seeds is to optimize roasted flavor, texture, and appearance in a stable finished product. In the roasting process desirable flavors develop through the Maillard reaction pathway when reducing sugars and amino acids are released during protein denaturation. Roasting also provides the seeds with a crunchy texture due to moisture loss and structure changes of seed constituents such as storage proteins (Smyth et al. 1998).

Deep fat-frying is the process in which food is cooked by being completely immersed in frying fat or oil at a temperature above the boiling point of water, typically between 150-200°C (Yamsaegsung & Moreira 2002; Hubbard & Farkas 2000). It is one of the oldest and most common operations used in food preparation and originates from the Mediterranean region due the influence of olive oil (Bouchon 2009). This method is classified as one of the most complex food processing operations due to the numerous interactions that take place inside the food. The most important factors affecting these interactions include oil
temperature, frying time, initial moisture content, and shape/size of the food being fried (Wu et al. 2013; Moreira et al. 1997). The mechanisms involved in the frying process revolve around heat and mass transfer (Chen & Moreira 1997). When a food enters into the fryer oil, the surface temperature of the food rapidly increases causing the water present on the surface to immediately begin to boil and evaporate (Mellema 2003). Upon the evaporation of surface moisture, water in the external layers moves to the surrounding fryer oil causing dehydration and the formation of a crust. As frying continues, heat is transferred through the seed and internal water begins to heat and work its way out of the food and into the frying medium as well. Figure 9 displays a simple schematic of the transfers that occur during oil roasting. The high temperature required to power this process acts as a catalyst to the food components promoting both chemical and physical changes to take place (Chen & Moreira 1997). The roasting process in total creates the unique fried flavor and texture that consumers desire (Mellema 2003).

In most cases one of two types of fryers are utilized to conduct the described mechanism, a smaller static batch fryer or an industrial continuous fryer shown in Figure 10. Most batch fryers are used for catering or restaurant food preparation while continuous fryers are used in the food industry to produce larger volumes of fried product (Chen & Moreira 1997). Peanuts are most commonly roasted in continuous fryers after being passed directly from the blancher, where the skins are removed. Oil temperatures vary according to the configuration, ranging from approximately 125-200ºC but are most commonly around 150ºC (Davis & Dean 2016). Since the oil surrounds the peanuts and is the sole heating medium, oil roasted peanuts, heat more evenly and at a quicker rate than dry roasted peanuts. The main
disadvantage of oil roasting is maintaining fryer oil and equipment which can be quite costly (Davis & Dean 2016).

**Oil Migration**

The frying process can be simply described in four steps: moisture transfer, fat or oil transfer, crust formation, and cooking of the food interior (Paul & Mittal 1997). According to Pinthus et al. (1993), the basic physical effect of deep fat-frying is water replacement by oil. Replacement or uptake of oil has been observed to occur into two structures including the outer crust and the core (Aguilera & Gloria-Hernandez 1997). The absorbed oil has been described by Bouchon et al. (2003) as three different fractions. The first is the oil absorbed during frying, termed structural oil. The second is penetrated surface oil which is oil absorbed into the food during the post-fry cooling process. This leaves the oil that remains on the surface, simply identified as surface oil. Most of the penetrated surface oil is contained in voids or blisters along the surface (Lisinka & Golubowska 2005). This fact supports the result reported in numerous studies that a higher initial moisture content results in elevated oil uptake (Gamble et al. 1987; Chen & Moreira 1997; Moreira et al. 1997; Pinthus et al. 1993). Substantial research has been conducted to explain the thermodynamics and kinetics of oil degradation that occur during deep-fat frying but more work needs to be done in determining the changes that frying causes in the complete system, including the oil, food, and frying equipment (Blumenthal & Stier 1991). In addition, dissimilar food materials respond to the frying process differently. Most studies on these mechanisms to date, focus on
are chips, and other potato type products and higher moisture foods, leaving research on peanuts which contain much less moisture to be a necessary advancement.

Chen and Moreira (1997) described oil migration to be a result of increased porosity and other structural changes in their research on potato chips. Their data explained how water evaporated immediately from the chip in the first 10 seconds of frying causing the product to become harder and form a crust. Faster water evaporation resulted in the formation of small pores on the surface and frying allowed the continued expansion of the pores until the final stage of frying due to the increase in the complex viscosity of the matrix.

Dana and Saguy (2006), conducted a review to attempt to provide a complete description of the oil absorption phenomenon. They found that although there were three solid theories on roasting mechanisms proposed and tested over time throughout the literature that included water replacement, the effect of the cooling-phase, and surface active agents, none was consistent or substantial enough to be a complete answer or description. There are also some contradictory early conclusions that reported that oil uptake and water removal are synchronous mechanisms. These were disproved with additional potato chip research by Bouchan et al. in 2003. Their research proved that water vapor as described previously, evaporates immediately in hot oil and the majority of oil absorption occurs when the food is removed from the fryer and the cooling process begin (Bouchon et al. 2003).

After the food is removed from the oil, a high temperature difference occurs between the surface and the interior. This temperature difference generates negative pressure. A small vacuum pulls the surface oils in through the pore space that was created during crust formation during the forced evaporation of water vapors in the fryer. The result is oil
absorption into the food. In fried potatoes, the computed oil absorption that took place
during post fry cooling was nearly 78% (Wu et al. 2013). In conclusion, it is clear from the
literature that more research must be conducted to fully understand and quantify these
mechanisms in peanuts.

**Engineering Properties**

After reviewing the current literature, it has been determined that both pre-roast
moisture content and physical properties of the peanut kernel influence its behavior during
roasting and absorption of oil upon removal from the fryer. In addition, the physical
properties of the kernel itself are found to be moisture-dependent as well (Aydin 2007;
ElMasry et al. 2009). These properties include shape, size, bulk density, true density, and
porosity. A number of studies have been conducted to determine these properties in peanuts
(Aydin 2007; Payman et al. 2011; ElMasry et al. 2009; Dilmac & Altuntas 2012) and various
other crops such as hazel nuts (Aydin 2002); almonds (Aydin 2003); sunflower seeds (Gupta
& Das 1997); cashew nuts (Balasubramanian 2001); and soybeans (Despande et al. 1993).

A study by Dilmac & Altunas (2012) compared these engineering properties for a
peanut and its kernel, determining that the kernel geometry, volumetric properties, and
frictional properties are different between the two. Further research by Aydin (2007),
Payman et al. (2011), and ElMasry et al. (2009) measured the differences of these properties
in relation to initial kernel moisture content. The reported differences found by ElMasry et
al. (2009) determined that as moisture increased the seed expanded in all directions leading
to increases in all measured geometrical features, while the strength of the seeds in terms of
ability to be ruptured decreased as moisture increased, due to the creation of a softer seed.

The same findings with the addition of information regarding seed bulk density, true density, and porosity was reported by Payman et al. (2011). In both cases, bulk density displayed a linear decrease as initial moisture content decreased, due to the fact that there was an increase in mass from the gain of moisture which was lower than the volumetric expansion that took place (Payman et al. 2011). As a result, when the initial moisture content increased, true density and porosity also increased. These results summarized and compared to those of the various other previously mentioned crops are displayed in Table 1.

**Scanning Electron Microscopy**

Numerous analytical techniques are now available for material characterization depending on the what type of information is desired. For high resolution observations of the surface of a material, scanning electron microscopy is often utilized (Russel et al. 2001). A scanning electron microscope or SEM provides an image that appears three dimensional. In brief, the microscope utilizes a two to three nanometer spot of electrons that continuously scans the specimen surface which generates secondary electrons from the specimen that are then detected by a sensor. As the image is constantly scanned an image is eventual produced (Bozzola & Russel 1999). Scanning electron microscopy is a very important tool to examine microstructural changes that occur to peanuts and numerous other commodities in both the raw and processed states. As previously noted, Young et al. (2004) was also able to observe structural differences in peanuts seeds during different stages of development due to the use of scanning electron microscopy.
Looking beyond the development of raw seed structure, the structure of processed seeds including the core and surface of peanut cotyledons have been exposed to the oil roasting process is the result of multiple alterations that occur at the cellular and subcellular levels (Aguilera & Gloria-Hernandez 1997; Bouchon 2009). The post-fry characteristics of these structures such as geometrical irregularities and surface roughness are essential in understanding oil absorption kinetics (Moreno et al. 2010).

SEM imaging was utilized by Young & Schadel (1990, 1991, and 1993) to compare the microstructure of peanut cotyledons after roasting. All three studies reported principle observations and descriptions of the thermal modifications that occurred during roasting to the cytoplasmic network, protein bodies, lipid bodies, starch, and cell junctions. The first in 1990, focused on these modifications as a result of dry roasting, while the next in 1991 investigated the same effects due to oil roasting. In 1993, both roasting methods were examined but changes were compared as a result of increased processing time. The results of the third study showed differences in the amount of time required for modifications of the cytoplasmic network, protein bodies, and cell junctions to occur. In addition, it was found that the listed modifications were found to consistently occur at a slower pace when oven roasted compared to when oil roasted (Young & Schadel 1993). Similar structural changes were observed during the roasting of hazelnuts (Saklar et. al 2003) and chickpeas (Koksel et al. 1999).

A study done by Shi (2015), expanded the information on microstructural changes due to the roasting mechanism by describing the differences found when peanuts are not only dry and oil roasted traditionally but also blister-fried. Like Young and Schadel, this research
included effects due to increased processing time but included each different roasting method. The SEM images of the roasted peanuts samples determined that peanuts that are blister-fried had the most amount of damage due to roasting followed by oil roasting and then dry roasting. The lower final moisture contents for the peanuts that were roasted longer was due to the increased amount of time for water to evacuate during the roasting process.

Differences in the microstructure of the surface and internal cross sections of peanut seeds after oil roasting was observed to be affected by initial moisture content in a study by Dean et al. (2014). It was determined that samples of higher moisture required less heating time to attain a pre-determined Hunter L-value. In addition, high moisture samples also experienced greater amounts of visible surface damage due to the large amount of steam that escaped from the surface during oil roasting. It was also reported that lower moisture samples seemed to experience more internal damage.

**Consumer Opinions and Expectations**

RTE or ready to eat foods are becoming increasingly popular with consumers due mainly to their convenience, value, attractive appearance, and texture. Ready to eat foods are defined by the Food Standards Agency as any food ready for consumption without further heating or processing (Brennan 2013). This definition puts snack peanuts in the RTE category. Peanuts, as previously mentioned are commonly consumed as snack foods after dry-roasting, oil roasting, or deep fat frying (Miyagi 2012). Quality plays a huge role when deciding which snack or even type of selected snack to purchase and consume. To understand why food quality is so important, it is first important to understand what quality is
and how it relates to the consumer perception of food. Quality is described as continuous conformance to consumer expectations. This includes the presence of the product’s dimensions that defines both its usability and character (Civille 1991). Once these attributes are defined for a food, it must then conform to those required attributes in a consistent manner. Maintaining the quality of food highly impacts the food’s acceptability. Maintaining quality through storage time is essential for peanut product acceptance (Lee & Resurreccion 2006; Civille 1991).

Food acceptance is also influenced by the consumer attitudes and opinions about the nutritional characteristics (Costell et al. 2010). In the processing of oil roasted peanuts, particularly during the roasting process and post-fry cooling period, a significant amount of oil is absorbed in the crust that was formed during roasting. This uptake of oil introduces a potential negative attribute in relation to health (Primo-Martin & van Deventer 2011). The addition of salt, although as an ingredient can provide a variety of health benefits to humans, also presents global concern as a prominent reason for health issues if overconsumed (Chokumnoyporn et al. 2016). Because of this, the appearance of excess salt in the peanut products packaging often provides the product with unnecessary negative associations.

In contrast peanuts have also been reported to have a positive influence on human nutrition due to their high calorie and protein content. Oil roasted and salted peanuts were recently certified as heart-healthy by the American Heart Association as a part of an overall healthy diet (Georgia Farm Bureau 2013). To capitalize on this certification, a health-focused campaign marketing the “Power of the Peanut” was promoted through television commercials and the creation of a website showing how the protein and nutrients from
peanuts help improve all aspects of people’s life (Forbes 2013). With current consumers searching for snacks with perceived health benefits, the increase in positive affirmation towards peanuts as a part of a healthy diet has lifted consumer attitudes toward oil roasted snack peanuts commonly known as cocktail peanuts. To preserve consumer acceptance of these legumes, the appearance of the roasted peanuts must meet consumer expectations for what they perceive and remember cocktail peanuts to be from past consumption experiences as well as the provided or product description.
Table 1. Summary of changes in engineering properties of peanut kernels and various other commodities in relation to an increase in their initial moisture contents

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Volumetric Properties</th>
<th>Bulk Density</th>
<th>True Density</th>
<th>Porosity</th>
<th>Rupture Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peanut Kernel 1</td>
<td>Increase</td>
<td>No Report</td>
<td>No Report</td>
<td>No Report</td>
<td>Decrease</td>
</tr>
<tr>
<td>Peanut Kernel 2</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td>Increase</td>
<td>Decrease</td>
</tr>
<tr>
<td>Peanut Kernel 3</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td>Increase</td>
<td>Decrease</td>
</tr>
<tr>
<td>Peanut Kernel 4</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td>Increase</td>
<td>Decrease</td>
</tr>
<tr>
<td>Hazelnut 5</td>
<td>Increase</td>
<td>Decrease</td>
<td>Decrease</td>
<td>Increase</td>
<td>Decrease</td>
</tr>
<tr>
<td>Almonds 6</td>
<td>No Report</td>
<td>Decrease</td>
<td>Increase</td>
<td>Increase</td>
<td>Decrease</td>
</tr>
<tr>
<td>Sunflower Seeds 7</td>
<td>No Report</td>
<td>Decrease</td>
<td>Increase</td>
<td>Increase</td>
<td>No Report</td>
</tr>
<tr>
<td>Cashew Nuts 8</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td>Decrease</td>
<td>No Report</td>
</tr>
<tr>
<td>Soybeans 9</td>
<td>Increase</td>
<td>Decrease</td>
<td>Decrease</td>
<td>Decrease</td>
<td>No Report</td>
</tr>
</tbody>
</table>

1 Dilmac & Altunas (2012)  
2 Aydin (2007)  
3 Payman et al. (2011)  
4 ElMasry et al. (2009)  
5 Aydin (2002)  
6 Aydin (2003)  
7 Gupta & Das (1997)  
8 Balasubramanian (2001)  
9 Despande et al. (1993)
Figure 1. Peanut certified acres located in production regions in the U. S. (National Center for Peanut Competitiveness 2016)
Figure 2. Peanut market types (Virginia-Carolinas Peanut Promotions 2016)
Figure 3. Display of peanut fruit production below the surface (Lavender 2015)
Figure 4. Peanut plants growing in planted row formation (McGhee 2015)
Figure 5. The peanut flower (National Peanut Board 2017)
Figure 6. The digging process which is the first stage of peanut harvesting (Ethredge 2012)
Figure 7. The windrowing process (National Peanut Board 2014)
Figure 8. Drying wagons where harvested peanuts are held for curing (American Peanut Council 2015)
Figure 9. Schematic of simultaneous heat and mass transfer during deep fat frying (Moreno & Bouchon 2008)
Figure 10. Two common examples of the types of fryers used in the oil roasting of peanuts: Static small batch fryer (A), continuous fryer (B) (Henny Penny 2017; Heat and Control 2017)
REFERENCES


CHAPTER 3: THE INFLUENCE OF PRE-ROAST MOISTURE CONTENT AND POST-ROAST COOLING PARAMETERS ON OIL AND SALT MIGRATION DURING OIL ROASTING OR POST ROAST COOLING OF COCKTAIL PEANUTS
INTRODUCTION

The uptake and exchange of oil that occurs with oil roasted peanuts “cocktail peanuts” during and after roasting was brought to the attention of the USDA Market Quality & Handling Research Unit at North Carolina State University (Raleigh, NC) in 2008 through private communication with an industry representative. The representative described two specific problems that generate consumer complaints. The first problem, was that a substantial amount of oil was found collecting at the bottom of cocktail peanut cans. This collection was observed when the peanuts were poured out of their retail package upon opening revealing a pool of oil that remained on the can bottom. The second problem, was that salt was not consistently adhering to cocktail peanuts. This was observed in cans that were opened revealing seeds with a dryer appearance and lack of salt on the seed surfaces. When the peanuts were found as described, the salt was seen scattered over the can bottom. It was determined that both problems occurred within the first two months of storage after processing. Product sampling and observation that was done by the industry representative also revealed that the problems could not be attributed to the date or location of peanut harvesting or processing.

Because the problems were not determined to be results of harvesting or storage practices, it was logical to explore what processing parameters influence oil or salt migration. The process of oil roasting begins with the rapid transfer of moisture and fat, followed by the formation of a crust as moisture is depleted and the food interior is heated and cooked (Paul & Mittel 1997). The loss of moisture and gain of oil are directly related as oil reportedly replaces water lost from dehydration during the frying process (Dana & Saquy 2006). The
described exchange makes pre-roast moisture content a prospective cause for product inconsistencies regarding oil and salt movement after roasting. In addition, research has shown that the majority of oil migration to the food being fried takes places during the post roast cooling period (Bouchon et al. 2003; Wu et al. 2013). This phenomenon highlights the potential for migration differences due to changing cooling parameters. In an attempt to solve or determine what was causing the problems encountered in peanut processing regarding quality inconsistencies, the current study investigated the influences of both pre-roast moisture content and post-roast cooling parameters.

**RESEARCH OBJECTIVE**

The goal of this research is to determine the influence of pre-roast peanut seed moisture content and post-roast cooling practices on post-roast oil or salt migration from the internal seed or seed surface of oil roasted peanuts.
MATERIALS AND METHODS

Georgia 13M Runner type peanuts (high oleic variety) were supplied by the National Peanut Research Laboratory (Dawson, GA). The seeds were planted, grown, harvested, shelled, sized and stored according to standard industry practices but curing was modified to retain a higher moisture content prior to arrival at the USDA ARS Market Quality & Handling Research Unit at North Carolina State University (Raleigh, NC). Peanuts were delivered with a moisture content of approximately 12%. Upon arrival they were divided into four separate containers for later moisture adjustments to include four different moisture contents. The peanuts designated to be the highest moisture content were sampled to obtain the exact moisture content, then placed in closed containers under refrigeration in an effort to retain their moisture. The two sets of peanuts designated to be the middle two moisture content samples were stored in closed containers at ambient temperature for natural moisture equilibration, and the final set designated to be the lowest moisture content was stored in an open container and further dried using forced ambient air.

Sample Preparation

Samples designated to obtain the highest moisture content were removed from refrigerated storage and remained sealed but were tempered to room temperature for approximately 48 hours immediately prior to seed coat removal or blanching. The blanching process began by heating skin on seeds in a forced air oven at 88°C for 45 minutes to loosen seed coats (skins). After heating, the seeds were cooled with forced ambient air until they returned to room temperature. Once cooled, the skins were removed using a pilot scale
blancher with counter-rotating grit rollers. Seeds were placed in the hopper then fed gravimetrically onto four horizontal grit rollers that were continuously counter-rotating. As the seeds struck the rollers and rebounded through the blancher, skins were loosened and separated in a catch bin below. Skinned seeds continued through, then were dispatched from a metal ramp at the front of the blancher into a separate collection bin. Starting moisture contents were determined post blanching by weight loss on drying using a LDX Series Despatch forced air oven (Despatch industries, Minneapolis, MN) at 130°C for 6 hours according to a method developed by Young et al. (1982). The moisture contents determined for the four different moisture samples at this step were 4.8%, 5.8%, 5.9%, and 6.0% (wet weight basis). These values were closer than intended due to blanching and storage so the two lowest moisture sample sets were further dried by forced ambient air and the highest moisture set was further increased by the addition of water using a process described by Payman et al. (2011). In brief, samples were conditioned by the addition of distilled water, manual mixing, then sealing in polyethylene bags under refrigeration. This process allowed the seeds to absorb the additional moisture to attain a desired new level of moisture using the following formula:

\[
Q = \frac{Wi(Mf - Mi)}{100 - Mf}
\]

where \(Wi\) is the initial mass of raw peanut seed, \(Mi\) is the initial moisture content of raw peanut seed based on a % wet weight basis, and \(Mf\) is the final (desired) moisture content of raw peanut seed based on a % wet weight basis. The remaining sample set was un-altered.
but raised slightly before roasting due to ambient humidity. The final pre-roast moisture contents of the four moisture samples were 3.3%, 4.6%, 6.1%, and 8.4% (wet weight basis). Peanuts were placed in double, polyethylene bag lined, sealed containers, and stored under refrigeration at 4°C until immediately prior to roasting when they were brought to room temperature.

**Peanut Oil Roasting**

Prior to roasting, all moisture content samples were removed from refrigeration and brought to room temperature. Peanut oil purchased from Stratas Foods (Memphis, TN) was heated to 177°C in a P-H-T Fryer model 500 (Henny Penny Corporation, Eaton, Ohio) for 3 minutes. Coconut oil (Tropical Traditions, Springville, CA) was added by weight to the peanut oil to a level of 10% to serve as a marker substance. Fryer oil was sampled prior to the roasting of peanuts and samples were set aside in refrigerated storage for later analysis. Fryer oil was then pretreated by roasting 3 batches of 1000 g samples of peanuts divided in half then placed in two identical baskets (500 g each) and roasted simultaneously. Following these three smaller scaled replicates, a full-sized roast of 4800 g was divided in half and roasted simultaneously in separate baskets to determine and record the appropriate roast time to achieve a Hunter L color value of 48 +/- 1 and complete the oil pretreatment process. Color was measured using a HunterLab D25L DP 9000 colorimeter (Hunter Associates Lab Incorporated, Reston, VA). All peanuts used to pretreat the oil were discarded after being roasted. Fryer oil was again sampled and stored for later analysis after the pretreat roasts were complete. All raw peanuts from each of the four moisture levels were pre-divided into
4800 g samples the day before roasting occurred. Each 4800 g sample set was separated evenly between the two fryer baskets for each roast replication. Three replicates of each of the four moisture content samples (pre-weighed 4800 g) were roasted on one day and three more replicates were roasted on the day immediately following. Samples were roasted to obtain an approximate Hunter L color value of 48 +/- 1 determined by the time estimated from the full-sized oil pretreat roast. Roasted peanuts were removed from the fryer and gently shaken then allowed to drain for approximately ten seconds. Oil roasted peanuts were divided for the remaining experimental processing by salting, cooling, or hexane rinse dipping treatments.

**Post-Roast Salting**

800 g of roasted peanuts were salted by adding 1% by weight of nut and popcorn salt (Cargill, Minneapolis, MN) to peanuts by weight in a hollow cylinder. The cylinder was then rotated constantly and as consistently as possible by hand for five minutes. Once samples were coated, they were divided evenly between 4 separate quart glass jars, packed, and stored at 25°C in a So-Low Incubator model SCO31 (So-Low Environmental Equipment Co., Inc., Cincinnati, OH) for later observation. Samples were observed and images were captured by taking pictures of samples in containers at two-week increments for 26 weeks, then again at 52 weeks out of the storage container. Color was measured on stored seeds out of the storage container with a HunterLab D25L DP 9000 colorimeter (Hunter Associates Lab Incorporated, Reston, VA).
Cooling Parameters

Roasted peanuts were cooled using three different cooling parameters or techniques. After 800 g of roasted peanuts were removed for both salting and the immediate hexane rinse dip, the remaining 1600 g in each basket were placed on perforated, wire mesh, metal racks to facilitate the drainage of any excess oil and allow a necessary flow of air through peanuts as they cooled. One of the filled racks was placed in the middle of a blower box constructed with closed top and sides, and open bottom for use in this experiment. Inside the box a Lasko box fan (Philadelphia, PA) blew directed air downward on the peanuts, at a constant rate of 2500 CFM. The second rack was placed on a perforated stand to allow ambient air flow around the cooling peanuts. Thermocouples lined the bottom of the racks to determine when the roasted seeds were brought to room temperature so they could then be dipped in a hexane rinse (Thermo Fisher Scientific, Waltham, MA) and packed for observation storage samples. The third cooling parameter was the immediate dip or no cool peanuts. These were removed and dipped in the hexane rinse, immediately after being removed from the fryer. Once undipped samples were cooled, they were divided evenly between 4 separate quart glass jars, packed, and stored at 25°C in a So-Low Incubator model SCO31 (So-Low Environmental Equipment Co. Inc., Cincinnati, OH) for later observation. Samples were observed and images were captured in containers at two week increments for 26 weeks, then again at 52 weeks out of the storage containers. Color was measured on stored seeds out of the storage container with a HunterLab D25L DP 9000 colorimeter (Hunter Associates Lab Incorporated, Reston, VA).
Hexane Rinsing for Surface Oil Collection

Roasted peanuts seeds were rinsed immediately after removal from the fryer as well as after the samples were cooled to room temperature using either the forced or ambient cooling technique. The rinsing method was as identical as possible for each hand dipped sample. 100 g of roasted peanuts from each experimental roast were placed in closed wire mesh cylinders. The closed cylinders were dipped in 600 mL of hexane for 2 seconds to rinse off and collect any oil from the exterior of the roasted peanut seed. Each sample was dipped in triplicate. Rinsed peanuts were removed from cylinders and placed in glass pint jars and sealed for storage until later analysis. The hexane including the collected surface oil was decanted into 500 mL glass amber bottles for storage. To analyze and quantify the collected surface oil, the rinse was decanted into a round bottom flask and the hexane was 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 amount of oil collected and remaining after hexane evaporation was determined by weight gravimetrically. Collected surface oil was used for fatty acid analysis.

Determination of Moisture and Total Oil Content

Moisture content and total oil content were determined for both raw and roast seeds. Moisture content measurement was done gravimetrically on peanuts that were dried at 130°C for 6 hours in a LXD Series Despatch forced air oven (Despatch Industries, Minneapolis, MN) according to a method developed by Young et al. (1982). Total oil was measured using a Minispec MQ One Seed Analyzer (Bruker Corporation, Billerica, MA). The instrument
was calibrated using a reference standard, according to the manufacturer’s specifications and instructions. 5 g samples were then loaded into glass tubes. Total oil content was determined using time domain nuclear magnetic resonance. All samples were run in triplicate.

**Fatty Acid Analysis**

Fatty acid profiles were determined for the pre-roast coconut oil and peanut oil, the oil blend before and after roast replications, the hexane extracted surface oil, the oil expressed from roasted ground peanuts as well as the oil expressed from raw peanuts. Oil from raw and roasted peanuts was expressed using a Laboratory Carver Press (Fred S. Carver, Inc. Wabash, IN) for 10 minutes at 20,000 lbs. Lipids from all expressed and previously collected oil were hydrolyzed to fatty acids and converted to their methyl esters using the fatty acid methyl ester (FAME) method according to Bannon et al. (1982). These were then analyzed using gas chromatography (GC).

Samples ranging between 0.02 and 0.03 g of oil per collected oil sample were weighed into glass culture tubes with screw caps in triplicate. To begin the methylation process, 1 mL of 0.5M methanolic sodium hydroxide was added to each tube. The methanolic sodium hydroxide was prepared by weighing 20 g of sodium hydroxide (Thermo Fisher Scientific, Waltham, MA) into a 1000 mL volumetric flask, then filling the flask halfway with methanol (Thermo Fisher Scientific, Waltham, MA). The mixture was then stirred mechanically with a stir bar until solids were completely dissolved. No heat was utilized. After dissolving, methanol was added to dilute the solution to volume, then it was
transferred to a screw-capped plastic bottle for storage at room temperature. Following the addition of the prepared methanolic NaOH, tubes were capped and heated in a water bath at 85°C for 10 minutes. Once removed and slightly cooled, tubes were uncapped and 1 mL of BF$_3$ (14% in methanol) (Sigma-Aldrich Corporation, St. Louis, MO) was added to each tube. The tubes were then capped and returned to the 85°C water bath for an additional 10 minutes. After heating, the tubes were removed and cooled slightly, then uncapped for the remainder of the process. Each tube then received 1 mL water followed by 1 mL of hexane (Thermo Fisher Scientific, Waltham, MA). The tubes were then vortexed vigorously for 15 seconds and then allowed to stand until distinct visible layers had formed. At this point, the hexane (top) layer was extracted from the sample tube using a Pasteur pipette and placed into a small glass culture tube containing a few grams of sodium sulfate (Thermo Fisher Scientific, Waltham, MA). Once added, the culture tubes were vortexed to ensure all water was removed from the solvent. The hexane was then transferred to a crimp top GC vial for analysis. Two fatty acid methyl esters standard mixtures were analyzed with the samples to establish retention times. Kel-Fir FAME-5 Standard was purchased from Matreya LLC (Pleasant Gap, PA). GLC-21A Standard (Nu-Check Standards, Elysian, MN) was prepared by diluting one ampule to 50 mL with hexane. An aliquot of both was transferred to separate vials with crimp top caps for analysis.

The samples were analyzed on a Perkin-Elmer Autosystem XL gas chromatograph (GC) (Shelton, CN) fitted with a BPX-070 capillary column (SGE Analytical Science, Austin, TX). The column was 30 m in length with an internal diameter of 0.25 mm and a film thickness of 0.25 µm. The GC utilized a flame ionization detector (FID) set to 250°C. The
temperature program parameters were as follows: 60°C for two minutes, increased to 180°C at a rate of 10°C/min, then increased again to 235°C at a rate of 4°C/min for a total run time of 27.75 minutes. The carrier gas was helium at 20 psi with a split flow ratio of 40:1 (76.9 mL/min). The values for peak area percentages were normalized according to AOCS Official Method Ce 1f-96 (AOCS, 2004) and reported as percent of the total fatty acids.

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

Density is simply defined as the ratio of mass to volume (g/cm$^3$). Density of a material with an irregular shape, such as a peanut, presents some complications. To avoid these complications, a technique known as pycnometry can be utilized by immersing the peanut in liquid, gas, or powder and measuring the volume of the displaced medium. Pycnometry techniques are used to determine three different types of density (Micrometrics 2001). In this experiment, measurements of true density and bulk density were utilized to calculate sample porosity.

True density can be defined as the ratio of the mass of all solids to the solid volume occupied by the sample (Deshpande et al. 1993). True densities for peanut samples were obtained using an AccuPyc 1330 V2.03M gas displacement pycnometer (Micrometrics Instrument Corporation, Norcross, GA) with helium gas as the medium being displaced. To ensure the highest level of accuracy approximately 60 g of raw and roasted peanut samples from each moisture level were used to fill the instrument sample chamber without the use of an insert. Peanuts were not compacted in any way and analysis was non-destructive allowing the same samples to be utilized to determine bulk density.
Bulk density is determined when pore spaces within the material particles are included in the volume measurement (Micrometrics 2001). The peanut volume and bulk density measurement were determined by the liquid displacement method described in Aydin (2007), based on the Archimedes’ Principle. Toluene was used instead of water as the displacement liquid to lessen the amount of liquid absorbed. In brief, approximately 25 mL of toluene solution was placed into a 50 mL graduated cylinder. 10 g of the peanuts previously used to determine true density in the pycnometer were placed in the graduated cylinder and the end volume of toluene was observed and recorded. Bulk density was calculated from the observed volume of liquid displaced. Peanuts were not compacted in any way but samples were discarded after bulk density analysis. All samples were analyzed in triplicate for both bulk and true density measurements.

Porosity ($\varepsilon$) was calculated utilizing the results from both density measurements according to the following relationship given by Mohsenin (1970):

$$\varepsilon = \frac{\rho_k - \rho_b}{\rho_k} \times 100$$

where $\rho_k$ is the true density and $\rho_b$ is the bulk density.

**Scanning Electron Microscopy (SEM)**

Raw and roasted peanut cotyledon samples were selected at random from each moisture content to be viewed and analyzed using scanning electron microscopy (SEM). Fixation and preparation were done following a method described by Young and Schadel
(1991) with some slight modifications. Each seed was rinsed with distilled water to remove any surface material then patted dry. Seeds were then sliced with a single edge razor blade into 2 mm cross-sections and seed surface samples. Once cut, samples were trimmed to provide specimens approximately 2-3 mm across. Trimmed samples were then fixed in 3.0% glutaraldehyde (3 mL glutaraldehyde (Ladd Research, Williston, VT) in 100 mL 0.05M potassium phosphate buffer (Thermo Fisher Scientific, Waltham, MA) at pH 7.0 and 4°C) for 24 hours. Next, samples were washed three times in 0.05M potassium phosphate buffer (pH 7), for changes of 1 hour each at 4°C. Following fixing, samples were then dehydrated using 24 hour changes of graded series of ethanol (Decon Labs, Inc., King of Prussia, PA) at 30%, 50%, 70%, and 95%. Final dehydration took place at 4°C for two 24 hour changes of 95% and 100%, then after a second change in 100% at cold temperature, the samples were brought and held at room temperature for another 24 hours. One last 100% change took place at room temperature to complete the dehydration process.

Dehydrated samples were dried using liquid carbon dioxide (Airgas, Radnor, PA) for 15 minutes in a Tousimis-Samdri-795 critical point dryer (Tousimis Research, Rockville, MD) then secured to specimen mounting stubs (Ladd Research, Williston, VT) for sputter coating. Stubs were prepared in advance with Spot-o-glue tabs (Ladd Research, Williston, VT) and silver conducting paint (Ladd Research, Williston, VT). Additional silver paint was applied around the base of each sample piece to ensure proper adhesion. Samples were allowed to dry overnight in a desiccator then coated with 5 nm of gold-palladium using a Hummer 6.2 sputter system (Anatech USA, Union City, CA). Prepared specimen stubs were stored in a desiccator until and between viewing with the microscope. All samples were
viewed with a Jeol JSM-5900LV Scanning Electron Microscope (JEOL U.S.A., Peabody, MA) at a working distance of 15 mm with an accelerating voltage of 15 kV.

**Statistics**

Data were analyzed using the GLIMMIX procedure for generalized linear mixed models through the SAS statistical software system (version 9.4, SAS Institute, Cary, NC). The GLIMMIX procedure fitted a linear mixed statistical model to data that have constant variability and where the response is normally distributed (SAS Institute 2017). Statistical analysis for the dependent variables including: net oil uptake, mean moisture content, O/L ratio, and % C12:0 considered: moisture, cooling treatment, and their interaction, as fixed effects in the model. The model random effects included: day, moisture rep, dip treatment, and dip treatment rep. The dependent variables of true density, bulk density, and porosity, were analyzed by day, with fixed effects defined as roast treatment (raw or roasted) and pre-roast moisture content nested within roast treatment. Model random effects included moisture rep and roast treatment rep. The Pairwise Tukey-Kramer Studentized Range Test, for unequal number of observations, was used to compare predicted mean responses for pre-roast moisture effect when significant, looking into homogeneous responses among pre-roast moisture levels, at a significance level of $\alpha = 0.05$. Dunnett’s test for multiple comparison with a control, was used to compare cooling treatment levels to the specified control cooling treatment at $\alpha = 0.05$. All identified negative data points were attributed to mechanical error during analysis and deleted prior to performing statistical analysis.
RESULTS AND DISCUSSION

Moisture Content

After adjustment of raw samples to the desired moisture contents, the lots were blanched in preparation for oil roasting. Post Blanch raw moisture contents were determined to be statistically different (p<0.0001) at 3.3%, 4.6%, 6.1%, and 8.3% when calculated on a wet weight basis. Achieving and maintaining a range of this proportion was challenging due to the inadvertent loss of moisture that occurs during the blanching process as well as the potential for sample destruction due to mold growth when working with seeds that have been introduced to additional moisture. Sanders et al. (1989), reported the typical decrease in moisture of raw samples due to blanching to be between 1.0 and 1.5 % less than the raw un-blanched seeds. For this reason, samples were adjusted to higher moisture contents than required prior to blanching to control for over drying therefore maintaining an appropriate range of moisture values for the experiment.

The moisture contents of the peanut seeds were determined prior to and post roasting of all samples roasted and then cooled utilizing each of the three different cooling methods (fast, slow, and no cooling). Moisture loss due to the dehydration of seeds during oil roasting occurred in all samples. The moisture lost due to roasting was positively correlated with initial raw moisture content (Figure 1). Post roast moisture contents were also statistically different (p<0.0001) but employed a more compact range from 0.92 to 1.37 (%ww). The total calculated amount of moisture lost from each sample due to dehydration during the roasting process increased as pre-roast moisture content increase. Meaning, samples with more moisture to lose, lost more moisture when roasted for the same amount of time. These results
provide information regarding the speed and nature at which moisture is expelled during the frying process which will be further investigated and discussed in later sections.

**Oil Uptake**

The uptake of fryer oil that occurs during and after oil roasting is a complex phenomenon resulting from interactions that occur between the fryer oil and the peanuts being cooked. Oil roasted peanuts undergo numerous chemical, physical, and structural changes during frying (Ziaiifar et al. 2007). Oil uptake has been observed through absorption into two distinctive structures described by Aguilera and Gloria-Hernandez (1997). The first is an outer crust formed during roasting by the dehydration of cells which allow a larger amount of oil uptake to take place. The other is a core which makes up the majority of the peanut structure but allows uptake to a much lesser degree. It has been further reported in the current literature that oil absorbed into these regions can be identified as three different oil fractions. These fractions include: structural oil, which is the oil absorbed during frying, penetrated surface oil, which is the oil suctioned into the food during post-fry cooling, and surface oil, or oil that remains on the surface (Figure 2) (Bouchon et al. 2003). Most of the penetrated surface oil that is held in the crust region is contained in voids or blisters along the surface. Structural oil is held further inside the peanut seed at the core in addition to the pre-existing endogenous oil contained in intact cells. This oil is composed of fewer and smaller droplets. Net uptake is calculated by computing the difference in mean oil content between the raw and roasted peanuts. It can be reported as grams of oil per gram of dry weight (% dw) or per gram of wet weight (% ww) of the sample.
Raw mean oil contents were determined to be significantly different (p<0.0001) from the mean oil contents of the roasted samples for all moisture levels when determined on both a wet and dry weight basis. The difference in mean oil after roasting proves that peanuts experience some amount of oil migration during the roasting and cooling process. The mean oil contents of raw samples displayed a slight but significant decrease in mean oil as pre-roast moisture content increased when analyzing the samples on a wet weight basis however this increase was determined to be insignificant once converted to dry weight (Table 1). The change in significance observed when calculating by different weight expressions is logical, because moisture content determined by % ww utilizes the total sample weight including all moisture present in the seed. Because of this, samples with lower moisture contents include more oil per gram, leading to an observed increase in mean oil determined by % ww. Raw sample mean oil contents ranged from 48.7 to 51.4% when determined by % ww and from 53.1 to 53.3% when determined by % dw (Figure 3). Net uptake showed a significant increase as pre-roast moisture increased when calculated on a wet weight basis but no trend or significance was determined when calculated on a dry weight basis (Table 1).

The lack of correlation between oil uptake and pre-roast moisture content on a dry weight basis contrasts results obtained from similar studies done on foods with higher initial moisture contents. These studies determined that foods with higher initial moisture contents also had higher final oil contents. (Chen & Moreira 1997; Moreira et al. 1997). The variation between study results confirms the need for analyses of foods with different physical and chemical properties.
Cooling treatment played a role in mean oil content when analyzing the roasted peanut seeds. This discovery was expected as numerous studies suggest that the majority of oil migration into the food occurs during the post-fry cooling period (Bouchon & Pyle 2005; Ufheil & Escher 1996; Moreira et al. 1997; Aguilera & Gloria-Hernandez 2000; Bouchon et al. 2003). The absorption mechanism is described to be caused by the decrease in the core temperature of the seed upon removal from the fryer. The temperature change causes steam to condense while the initial pressure within the core region abruptly declines. The difference between the internal and outer pressures creates a vacuum like effect resulting in the suction or absorption of oil into the peanut seed (Ziaiifar et al. 2007; Gamble & Rice 1987; Moreira & Barrufet 1998).

Peanuts that were not cooled, consistently contained less oil than those that were cooled slowly to ambient temperature for all moisture levels (Figure 4). The roasted peanuts that were subjected to forced air cooling and were cooled faster, showed the greatest increase in mean oil as pre-roast moisture content increased creating the largest range of mean oil amount measured after roasting (Figure 4). In short, the forced cool samples with the lowest pre-roast moisture content contained the lowest post roast mean oil and the forced cooled samples with the highest pre-roast moisture content contained the highest post roast mean oil when compared to the samples that were cooled using the other two methods. Similar results were observed when determined on both a wet and dry weight basis.

A model frying study done by Yamsaengsung and Moreira (2002) determined that cooling temperature has the largest effect on oil absorption, and higher cooling temperatures lead to lower oil absorption due to lower capillary pressure differences. This provides a
potential reason to explain why samples subjected to forced air showed the greatest increase in amount of mean oil. In the current study ambient cooled seeds were not subjected to any type of increased air circulation for cooling so heat released from the hot kernels during cooling kept immediate surrounding air at a higher temperature longer. The described increases are visible graphically but were not substantial enough to be statistically significant (Table 1).

The results from the dipped seeds (without surface oil) determined that the peanuts that were not cooled contained significantly less oil than those cooled at either speed (Figure 4). In addition, peanuts that were not cooled contained roast mean oil contents that were very similar to the mean oil determined to be in the corresponding raw samples. This suggests that some amount of cooling is required for seeds to absorb a detectable amount of oil during or after roasting. It also further confirms the ideas in previously mentioned reports that suggest that the majority of oil absorbed comes from the surface and is absorbed during the post-roast cooling period (Bouchon & Pyle 2005; Ufheil & Escher 1996; Moreira et al. 1997; Aguilera & Gloria-Hernandez 2000; Bouchon et al. 2003).

When the mean oil results were compared between the samples without surface oil (dipped seeds) to those with surface oil (undipped seeds), with cooling at either speed, it was found that the dipped seeds contain more mean oil after roasting than the seeds that had surface oil (undipped seeds) across all pre-roast moisture levels (Figure 4). This finding was somewhat unexpected as it seems logical that samples analyzed with surface oil would have higher oil contents than those without. A potential reason for this could be that after the post-fry cooling period and during initial storage, surface oil may migrate and drain off the seed.
surface. The described migration could cause desorption by pulling internal oil out and off due to the effect of gravity and the cohesive properties of oil. The action of removing surface oil after cooling seemed to have limited the migration/desorption and may have caused oil to adhere or harden inside the seed. By lowering the amount and rate of desorption the removal of surface oil allowed the seeds to retain more absorbed oil. The described differences are clearly observed visually, but were not determined to be significant. In conclusion the differences due to cooling at either speed do not affect the rate or amount of migration or desorption.

The cooling speed and pre-roast moisture content do not seem to provide a substantial impact on amount of oil uptake from the undipped seeds. Uptake of oil into samples that were dipped showed slightly more exaggerated results (Figure 5). Samples analyzed without surface oil (dipped) showed a broader range of uptake from 1.39% to 8.20% when expressed as % ww and from 0.18% to 4.28% when expressed as % dw (Figure 5). Samples that were not cooled absorbed significantly less oil then those that were cooled at either speed (Figure 5). The ambient (slow) cooled samples showed the steepest increase in relation to pre-roast moisture content as oil was allowed a longer cooling period for oil to be absorbed (Figure 5). The substantial decrease in uptake displayed for peanut samples that were rinsed of surface oil prior to cooling was expected as seeds were allowed minimal time to absorb oil from the surface. The dipped seeds showed a significant increase in uptake amount when expressed as % ww but no significance was determined when calculated as % dw in relation to pre-roast moisture content.
Surface Oil Content

Surface oil was removed from the roasted peanuts by rinsing the samples in hexane and allowing the oil from the surface to remain dissolved in the hexane rinse while peanuts (lacking surface oil) were removed. The rinsed seeds were stored in glass jars and the remaining surface oil collected in the hexane rinse was stored separately in glass amber bottles. The hexane rinse was dried down and weighed to determine the amount of surface oil that was collected gravimetrically. The seeds that were not cooled had a larger amount of oil on the surface then the seeds that were cooled for all pre-roast moisture levels (Figure 6). The increased amount of surface oil collected from samples that were not cooled again suggests that oil is absorbed into roasted peanuts seeds during the post-fry cooling period. When seeds were not allowed to cool, oil did not have time to penetrate through the remaining intact surface cells.

Samples that were cooled at both speeds forced (fast) and ambient (slow) were very similar (Figure 6). By allowing samples to cool the effects from the vacuum mechanism caused by pressure difference can be observed as less oil was collected in the rinse from the cooled samples. Roasted samples that were not allowed to cool were also allowed no time for excess oil to drip off or drain as it was all immediately collected in the hexane rinse. A slight decrease in surface oil was observed as pre-roast moisture content increased. Cooling parameters had a much greater effect on the amount of surface oil. The effects due to cooling parameters provide important insight regarding the post-roast processing of oil roasted peanuts. Findings suggest that as long as peanuts are cooled at any rate, the amount of oil on the surface which is available for migration during storage is limited compared to those that
are not cooled. In addition, because there are very slight differences between cooling rates, the data suggests that cooling speed should not cause a processing time issue in industry as peanuts that were forced cool showed nearly the same decrease in surface oil amount as those that were allowed to slowly cool to ambient temperature.

**Oil Migration**

The changes observed in total oil uptake and amount of oil on the surface demonstrated that the pre-roast moisture content and cooling method have an impact on migration but do not elucidate to the specific movement of oil from the fryer to the peanut seed or from the peanut seed to the fryer. To further examine this movement, the fryer oil used in this study was modified with coconut oil which contained 50% lauric acid (C12:0), a fatty acid that is not naturally found in peanut seeds or peanut oil. The fatty acid modifier was added to the fryer oil at a quantity to achieve a level of approximately 10% coconut oil and therefore approximately 5% C12:0 by weight. The fatty acid profile (FAP) of the peanut oil before the addition of the coconut oil marker displays the absence of C12:0 (Figure 7A). The FAP of the coconut oil used as the fatty acid marker displays C12:0 as the principal fatty acid at a level of approximately 45% (Figure 7B). The FAP of the frying oil used in this study containing both the peanut oil and added coconut oil marker displays the actual quantity of C12:0 present in the frying oil after the coconut oil marker addition was around 3% (Figure 8A). It also shows approximate quantities of C12:0 between batches of fryer oil used to fry peanuts at each moisture level were consistent represented by the different color bars. Fatty acid profiles of the fryer oils were analyzed both pre- and post-roasting and there
were no significant differences between the percentage of C:12 before or after roasting replications (Figure 8B). The average C12:0% in the fryer oil used to roast each sample set determined by calculating the mean of the oil batches utilized in roasting replications of all moisture levels across both days was 3.21%. The range was determined to be from 3.0 to 3.6% confirming an accurate level of coconut oil was added for each oil batch throughout the study and suggesting that once heated and thoroughly mixed, the fryer oil was close to completely homogenous. The described marking technique was utilized by calculating the mean C12:0% of the fryer oil and comparing it to the C12:0 concentration of the collected surface oil and expressed oil from the roasted peanut seeds.

The fatty acid profile of the oil expressed from the raw peanut seed is used to not only display that there is no C12:0 found in the raw seed but also to give information about the type of peanuts used in this study through the oleic (C18:1) to linoleic (C18:2) ratio (O/L ratio) (Figure 9). Peanuts are considered high oleic if they have an O/L ratio higher than 9%, making it apparent that the peanuts used in this study were high oleic (Jung et al. 2000; Klevorn et al. 2016). This is important when determining if endogenous peanut oil moves from the peanut kernel into the fryer oil. The analysis of the pre- and post-roast fryer oil showed that the O/L ratio of the post-roast oil had a slight but significant increase from the pre-roast fryer oil. Research conducted by Ziaifar (2007) reported a similar phenomenon and determined that in addition to oil absorption, there is also a desorption period where endogenous oil from fried foods migrates from the food to the surrounding fryer oil due to capillary forces in the pores. These forces along with the vigorous escape of moisture limit the ability of frying oil to enter the seed while immersed in oil during roasting, further
supporting the post roast absorption theory (Wu et al. 2013). The significant increase in O/L ratio found in post-roast fryer oil from pre-roast fryer oil confirms the migration of endogenous or internal oil from the peanut seeds to the fryer since they are high oleic. The described results endorse Ziaiifar’s findings.

Fatty acid profiles were obtained from the surface oil collected in the hexane rinse from the dipped peanut samples after roasting and cooling using all three different cooling parameters (Figure 10). The amount of C12:0 found in the surface oil of the roasted peanuts that were cooled at either speed ranged from 3.10 to 3.68% with a mean of 3.41%. There were no significant differences found for surface oils between cooling parameters or moisture contents and the FAPs of surface oil showed slight to no variation from the FAPs of the fryer oil, which as previously discussed had a mean C12:0% of 3.21. This reveals that the majority of oil on the surface was picked up from the frying oil upon the peanuts removal from the fryer.

To determine if the fryer oil not only migrated its way onto the surface of the seed but also breached the surface and penetrated the inside of the seed, FAPs were obtained from oil that was expressed from the seeds that were rinsed in hexane leaving kernels free of surface oil (Figure 11). The FAPs of the dipped seed all display the presence of C12:0 confirming the fryer oil did penetrate the surface and was absorbed into the internal portion of the samples. The differences in concentration of C12:0 in the expressed oil was not determined to be significant and showed no concrete trends in relation to pre-roast moisture contents of peanuts that were cooled at either speed. Percent C12:0 determined in expressed oil from dipped samples ranged from 0.22 to 0.28% with a mean of 0.25%. These amounts are less
than 0.10% of the percentage of C12:0 found both on the surface of the samples and in the fryer oil. The peanuts that were not cooled however, displayed a significant decrease in C12:0 concentration across moisture contents with a mean of 0.14% and ranging between 0.12 and 0.16%. The observed decrease determined that no cool peanuts contained less oil from the fryer than those that were cooled, regardless of cooling speed (Figure 11). This finding was expected according to uptake results and again suggests that the majority of oil was absorbed during the cooling period.

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

True density is the ratio of the mass of all solids to the solid volume of the sample (Deshpande et al. 1993). The true densities of the raw samples were determined to be significantly higher (P<0.0001) than the true densities of roasted samples for all four moisture levels (Figure 12). The raw densities were higher because the raw seeds had less mass than the roasted samples since oil outweighs water, plus higher volume due to the shrinking of roasted samples as a result of dehydration during roasting (Murakami et al. 2013). When considering the true density of the samples in the raw and roasted states independently, pre-roast moisture content was determined to have a significant impact on both sample sets with p values of <0.0001 and 0.0349 respectively. The true density of the raw samples ranged from 1.09 to 1.110 g/cm³ and the true density of the roasted samples ranged from 1.041 to 1.046 g/cm³. Results displayed weak linear trends corresponding to pre-roast moisture content. The raw samples displayed a slight decrease as pre-roast moisture content increased, while after roasting the samples showed the opposite, displaying
a slight increase in true density as pre-roast moisture content increased. The decrease found in relation to the initial moisture content when looking at the raw seeds is logical as seeds with additional moisture increase in volume more than mass. The slight increase found in relation to initial moisture content when evaluating the roasted seeds was attributed to an increase in mass from the uptake of oil into or onto the kernels in combination with the decrease in volume from seed dehydration during roasting (Payman et al. 2011). Signs of the decrease in volume due to roasting are shown in the microscopy images of cross sections (Figures 19-22). By comparing raw and roasted samples a decrease in the size of internal cell wall organization and increase in the compression/compaction of inner structures is observed.

Bulk density is the ratio of the mass of all solids to the total volume of the sample including vacant pore spaces (Micrometrics 2001). When comparing the bulk densities of raw and roasted samples, the raw samples were determined to be significantly higher (p<0.0001) than the bulk density of roasted samples for all pre-roast moisture levels (Figure 13). The difference shown is a result of higher mass determined for the roasted samples from the presence of oil and higher volume attained by the raw samples from the presence of moisture. The raw samples had bulk densities that were determined to be significantly different (p=0.0006) among pre-roast moisture levels that ranged from 1.051 to 1.073 g/cm³. The bulk densities of the roasted samples showed no significant differences (p=0.1353) among pre-roast moisture levels and ranged from 1.015 to 1.037 g/cm³. Bulk density measurements showed a subtle increase as pre-roast moisture content increased for both the raw and roasted samples (Figure 13). The observed slight increase in bulk density is a result
of the increase in mass from the increase in moisture present in relation to more constant sample volumes. Similar trends were observed by Aydin (2007) and Payman (2011) who saw an increase in density determined by liquid displacement in relation to the increase of initial moisture content.

Both the true and the bulk densities show slight variation in the described differences of seemingly small magnitude but were determined as statistically significant. When comparing the two different density measurements, the data collected for true density shows much less variation than the bulk density data. The highlighted difference in variation amount of the results is due to the level of accuracy attained by collecting data using a pycnometer for true density in comparison to the variation found when measuring bulk density by liquid displacement, which has a much larger margin for error. In addition, the true density measurements were lower than the bulk density measurements for both sample sets across all moisture levels (Figures 12 & 13). The lower true density measurements are a result of the lower volume measurements attained when measuring the solid volume as opposed to the total sample volume including pore spaces.

Porosity was calculated using the results from both the true and bulk density measurements according to the relationship described by Mohsenin (1970) where porosity equals the difference between true and bulk density, divided by true density, then multiplied by 100. Porosity results showed variability between replication days for the roasted sample values. Result variability may also have been caused by the potential error when measuring the bulk density of samples using the liquid displacement technique that is not consistently precise. Porosity of raw samples was determined to be significantly different (p<.0001)
among pre-roast moisture levels while no significance was detected for the roasted samples 
(P= 0.3534). Raw samples displayed a range of porosities between 2.405 and 4.882 g/cm³. 
There was a visible linear increase in porosity as pre-roast moisture content decreased 
(Figure 14). Roasted samples displayed a range of porosities between 1.270 and 2.577 
g/cm³. No robust linear trends could be determined from these samples in relation to 
porosity when evaluating the day replications separately, however if days were averaged a 
slight visible decrease in porosity was shown as pre-roast moisture content increased (Figure 
14). Porosity effects due to cooling parameters were not analyzed in this study.

Porosity results as reviewed in this section were unexpected but agree with the 
insignificant relation between raw moisture contents and oil uptake. After reviewing and 
understanding the mechanisms of roasting and damage that peanut seeds encounter through 
the roasting process, it was hypothesized that peanuts with higher initial moisture levels 
would be found to have greater porosities and therefore greater uptake. Although this seems 
logical, if the post roast processing or cooling is considered it can be suggested that upon 
removal from the fryer these hypotheses may be true, however, as the samples cooled their 
physical properties may have been modified.

The following sections describing the differences observed in the physical appearance 
of the sample pores is necessary to further confirm suggested migration mechanisms 
regardless of the porosity results.
Scanning Electron Microscopy

A peanut embryo consists of a small radicle and plumule known as the heart, along with two cotyledons (Young & Schadel 1990a). The two cotyledons have rounded outer surfaces and flatter inner surfaces (Young et al. 2004). They are composed of epidermal, vascular, and parenchyma tissues with the epidermal tissue covering the rounded outermost surfaces and flatter inner surfaces in a single layer of cells (Young & Schadel 1990a). The epidermal cells covering the outer surface have been observed to have a rectangular shape outline. In a review of the microstructure of peanut seeds by Young and Schadel (1990b), it was reported that the microstructure of a peanut seed has the potential to be affected by several factors including seed maturity, the environment in which the peanuts are grown, and post-harvest handling and processing practices. Images of the surface of the samples with the two lower pre-roast moisture contents (3.3% and 4.6%) in the raw condition depict the rectangular outline of the epidermal cells on the round outside surface of the cotyledon (Figure 15). The surface of the samples with the two higher pre-roast moisture contents (6.1% and 8.4%) show less detail of the epidermal cell organization (Figure 16). The micrographs of the raw surfaces also all display some irregularities which could be due to minor damage that occurred during handling or could potentially be debris found on the surface that was picked up before preparation for imaging took place. More extensive damage is shown by an exposed shallow logically due to damage that occurred during growth stages from environmental stresses (Figure 16A). The presence of mold is displayed on the raw cotyledon surface of the sample with the highest pre-roast moisture content (Figure 16B). The moisture of this sample was at 8.4% determined on a wet weight basis (wwb).
making it 2.3% higher than the next closest moisture content sample at 6.1% wwb. Peanuts are typically harvested and dried to a moisture level below 12%, then dried further to approximately 7.5% wwb once they are shelled to prevent aflatoxin and other molds from growing on them (Davidson et al. 1982).

When peanut seeds are oil roasted, the outer surfaces of the cotyledons are entirely exposed to the heating medium as the seeds are immersed in hot fryer oil (Dean et al. 2014). As the frying process continues, the initial amount of moisture and oil present in the peanut seed becomes very important. Internal seed moisture evaporates first from the surface until it is depleted. Following this depletion moisture begins to exit from deeper inside seed (Wu et al. 2013). The rate at which the peanut is heated is influenced by the internal seed moisture content. The internal moisture is observed exiting the peanut seed and moving into the frying medium in a forceful and turbulent manner resulting in physical damage to the internal and external peanut cotyledon (Baker 2002). In a study by Dean et al. (2014), the microstructure of oil-roasted peanuts was compared to determine the effect of initial moisture content. Although their study observed samples with a smaller range of initial moisture levels it was found that moisture had a role in the amount of time required to reach a determined and consistent final roast color of 48 L (± 1). In the current study, peanut seeds with different pre-roast moisture contents were roasted for the same amount of time to eliminate any effects due to length of heat exposure. The set roasting time allowed the observation of amount of damage caused by differences in initial seed moisture, independent of heating time. The surface of the sample with lowest pre-roast moisture content of 3.3% showed elongated and random tears or ruptures due to the rapid emission of steam, resulting in the exposure of
internal parenchyma cells (Figure 17A). Although the organization of the epidermal cells is no longer visible in the micrographs of the roasted samples, it appears that the tears on this particular sample may be close to the pre-roast shape and orientation of the cells observed when looking at the raw surface. Similar tears were observed in the surface of the sample with a moisture level just above that at 4.6% (Figure 17B). These tears are less elongated but seem to follow a similar pattern that still resemble the original orientation of the rectangular cell structures on the cotyledon surface. The samples with higher moisture contents appear to have experienced a greater amount of surface damage, characterized by the reduction in visible smooth outer epidermal surface cells observed on the cotyledon surfaces (Figure 18). The sample with the highest initial moisture level at 8.4% experienced the most amount of damage determined by area of visible ruptured surfaces (Figure 18B). When collectively looking at the full range of all moisture levels, it appears, as initial moisture increased, damage to the surface that occurred during roasting also increased. The roasting method used in this study exposed samples to the heating matrix for the same amount of time to control for effects due moisture loss that increased with the time the samples were exposed to heat to reach a pre-determined roast color (Shi 2015). The current results suggest that samples with higher pre-roast moisture content experienced more surface damage due to the increased amount of moisture leaving the sample during roasting rather than duration of heat exposure. To further support this finding, the range in pre-roast moisture contents compared to post-roast moisture contents is reviewed. The initial or pre-roast moisture contents of the studied samples was from 3.3%-8.4% wwb. This range was lowered to be between 0.90% and 1.45% wwb showing that although the samples had a relatively large range in raw
moisture content, that sizeable range did not exist after the raw samples were oil roasted. This suggests that due to the increase in available moisture to transfer heat through the peanuts during roasting, greater amounts of moisture are allowed to escape within the same period of heat exposure time. Therefore, it did not take much longer for greater amounts of moisture to leave peanut seeds during roasting since the final moisture levels displayed a substantially more compacted range. With the development of visible damage, the structure and organization of epidermal tissues on the cotyledon surface are no longer apparent in the micrographs of the roasted sample cotyledon surfaces (Figures 17 & 18). There is also a visible texture found on the un-ruptured portions of the surfaces which have no pattern but are present on all roasted seed surfaces.

Shi (2015) found the interior structure beyond the outermost layer of epidermal cells along the cotyledon surfaces in the raw condition, composed of inner surface epidermal tissue, vascular tissue, and parenchyma cells, displayed observable differences between samples with varying initial moisture levels. Similar differences are also displayed in images of roasted sample cross sections in the current study (Figures 19 & 20). The lowest initial moisture content (3.3%) sample displayed easily distinguishable difference between the smaller epidermal cells closer to the cotyledon surface and the larger isodiametric parenchyma cells possessing the greatest volume of the total cotyledon further inside the seed (Figure 19A) (Young et al. 2004). The parenchyma cells shown in the mid region of this low moisture sample consist of a dense cytoplasmic network that appears clustered toward the center of the cell creating a separation from the cell walls. This sample shows the greatest separation distance between these structures when comparing them to the remaining samples.
with higher initial moisture levels. The cross section image of the sample with the pre-roast moisture content of 4.6% shows a similar network with less distinguishable differences or presence of the outer epidermal cells along the outermost edge of the cotyledon (Figure 19B). In this sample, the separation between the dense inner cytoplasmic network and cell wall was reduced but was still obvious compared to the raw microstructure of the higher moisture samples. The small spherical bodies present in the cytoplasmic network were determined to be lipid bodies and the larger bodies could potentially be proteins or starches having no distinguishable characteristics between the two available when utilizing SEM imaging independently from other microscopy techniques (Dean et al. 2014). The microstructure of the interior of the raw sample with a moisture content comparable to that of a seed that would be typically processed or roasted commercially at 6.1% as well as the sample with the highest pre-roast moisture level in the raw condition at 8.4% had apparent voids within the cytoplasmic network cell walls (Figure 20). These voids can plausibly be explained as potential vacancies from where the starches, lipids, proteins, and other cytoplasmic structures may have been rinsed out during sample preparation for microscopic imaging. The small outermost epidermal cells that had a visible organized linear structure along the edge of the curved surface are no longer evident in the micrographs of the raw samples with higher moistures. The visible deconstruction of the cell walls as well as the inability for the further interior structures to retain their natural contents during rinsing could be due to the addition of excess moisture. Adding moisture may have forced the cells to swell resulting in structures with less rigidity. The higher moisture samples also showed much less structural organization. Their internal parenchymal cells show an intact cytoplasmic network that is
more abundant with substantial network presence from wall to wall. When comparing the prevalence of the cytoplasmic network in all four pre-roast moisture level samples, the increase in initial moisture content affects the cytoplasmic network making it less dense and causing increasing destruction to the structure of the interior cells walls. The sample with the highest initial moisture content again displays mold on the cotyledon surface but reveals no internal structural changes due to mold presence (Figure 20B).

Internal structural variations observed between raw and roasted samples reveal the occurrence of thermal modifications during oil roasting. The structural tissue changes that evolve from the roasting process are specified to include evaporation of water, a transformation from β-starch to α-starch, denatured protein, and cell membrane destruction (Miyagi 2013). Roasting also mobilizes chemical reactions in the seed. Most notably non-enzymatic browning caused by the Maillard reaction occurs. This reaction takes place between the carbonyl group of reducing sugars and the free uncharged amine groups of amino acids or protein with the loss of moisture (Ozdemir et al. 2001). Because this reaction requires the loss of moisture coupled with the fact that moisture is a vehicle for mobilizing it, browning rate depends strongly on moisture content (Baker 2002; Peterson et al. 1994). In the micrographs of the cross sections of the roasted peanuts at all pre-roast moisture levels, a consistent loss in cytoplasmic network presence and apparent breakdown of the outer surface epidermal cell walls was observed (Figures 21 & 22). The walls of the interior parenchyma cells also showed some destruction following similar patterns to those seen in the micrographs of roasted peanuts seeds from the prior mentioned study by Dean et al. (2014). In the current study, post-roast moisture contents were determined to have an average range
from 1.08% to 1.25% respectively. This proves that during roasting the seeds were able to expel significant amounts of moisture resulting in similar final moisture contents. This proposes that the moisture exits the seeds at different rates since the highest moisture samples were able to release a much larger amount of moisture during the same duration of heat exposure as the lowest moisture samples. The force required and actual action of the moisture released had to have been more intense for samples with increased moisture levels suggesting more internal and external damage occurred to the seeds with higher pre-roast moisture contents. Confirmation of this effect can be found in the previously reviewed micrographs of the cotyledon surfaces as well as by observing differences seen in the micrographs of roasted sample cross sections (Figures 21 & 22). The interior cell walls of these samples show a definite decrease in organization as pre-roast moisture content increases. Cells become deformed and misshapen with breaks and bends in previously rigid looking structures. The presence of the larger subcellular structures inside the walls are also altered. There is much less size variation and lipid bodies are more prominent after roasting. These lipid bodies could be remaining endogenous lipids or new structures that were introduced and absorbed into the cotyledons during the roasting or post-roast cooling period. Any present voids that were observed between inside cell networks and their holding structures in the raw cross sections now seem to be filled in the roasted samples. This finding contrasts what was found in Dean et al. (2014) which shows differences in the level of separation between interior networks and cell walls, but could be credited to the utilization of different roasting times. Overall when comparing all micrographs of roasted samples, this study shows that more damage occurs to the surface of the cotyledon then to the inner
networks in relation to initial moisture content. Drastic changes were observed in both interior and exterior cells, however, the surface displayed more visible evidence of the damage caused by rapid moisture loss during frying.

**Physical Differences**

Physical differences between samples that were salted or cooled at experimental rates were observed through clear glass jars and captured at two week increments for 26 weeks of storage. Visual observations continued throughout the remainder of the 52-week storage period and final images of the roasted seeds removed from the storage containers were captured again at its completion. Images were compared to identify differences in the physical appearance of the sample surfaces (Figures 23 & 24).

The samples subjected to post roast salting displayed more apparent differences when comparing seeds in relation to pre-roast moisture content (Figure 23). Samples that had the highest pre-roast moisture content (8.4%) displayed a more evident presence of salt on the seed surfaces. There was also a slight presence of salt on both the sides and bottom of the glass jars that they were stored in. In addition, the salt on the seed surfaces fell free with little effort or agitation of the glass storage jar. The samples with an initial moisture content closest to the pre-roast moisture of commercial cocktail peanuts at 6.1% showed a decrease in visible salt adhered to the seed surface. These samples did not demonstrate complete salt adherence but had a less visible presence of salt collected on the jar bottom and demonstrated less salt being released from the surface when mechanically agitating the storage jar. The second driest sample with a pre-roast moisture content of 4.6% was characterized very
similarly. The only discernable difference between the two mid-range moisture samples was increased salt adherence to the dryer seed surface as almost no salt fell from the surface upon jar agitation. The sample with the driest initial moisture level of 3.3% displayed an apparent reduction in amount of visible salt on the surface with no excess salt found in its storage jar. Slight to no salt was observed falling freely from the surface when the container was agitated. Samples from both roasting days were evaluated but no visible differences were observed between day replications.

Unsalted samples also showed differences in relation to pre-roast moisture content although significant seepage of oil did not occur (Figure 24). The glass jar containers displayed a slight increase in amount of oil droplets collected on the sides and bottom as pre-roast moisture content decreased. There was no pooling of oil or presence of visible oil droplets on sample surfaces at any moisture level. The color and texture differences found between the sample’s surfaces gave the most information pertaining to the oil roasting process. The highest moisture samples (8.4%) appeared to have a much rougher textured surface. The color of their surfaces was more beige than yellow or golden with Hunter L values of 52.5 and 52.84 for ambient and forced cooled samples respectively. This indicated that although they were roasted for the exact same time, they may have technically experienced less roasting or browning during frying since it took longer to dehydrate and heat them. Surface roughness was characterized by the presence of areas with lighter color giving the samples the illusion of being much dryer. The dry appearance was logically due to the violent expulsion of larger amounts of moisture increasing the amount of surface damage to the point of becoming visible not only through SEM imaging but also with the
unaided eye. The mid ranged moisture samples (4.6 and 6.1%) showed very little differences. They were both a yellow/golden roast color with a much smoother surface than the highest initial moisture sample. The appearance of their surfaces was more matte like and seemed fairly consistent. Most color variation was from seed to seed rather than between different regions of a single seed. There was a slight darkening in color from the higher mid-range MC sample (6.1%) with Hunter L values of 51.58 and 52.67 to the lower mid-range MC sample (4.6%) with Hunter L values of 49.90 and 52.11 for the ambient and forced cooled seeds respectively. The sample determined to have the lowest pre-roast moisture content (3.3%) was noticeably darker than the others with Hunter L values of 48.02 and 51.10 for forced and ambient cooled seeds respectively. The observed darkening of color correlating to the decrease in initial seed moisture demonstrates that lower moisture peanuts allow more browning reactions to take place such as the Maillard reaction and to a lesser extent carmelization (McDaniel et al. 2012). Because there is less moisture present in the raw seeds when being dropped into the hot oil, moisture was depleted from the seed faster allowing the temperature of the oil in contact with the seed to be higher. Higher oil temperature directly around the frying seed decreases the induction period that occurs before browning (Peterson et al. 1994). The addition of moisture has also been reported to dilute the reactants involved in browning which lowers the rate of reaction as a result (Peterson et al. 1994). Samples that were cooled using both cooling speeds were analyzed but there were no visible differences detected between samples cooled at different speeds.
CONCLUSION

Pre-roast moisture content plays a critical role in the heat and mass exchanges that occurs during the oil roasting of peanut seeds. Seeds with higher initial moisture dehydrated at an increased rate upon entry to the fryer causing more damage to the seed microstructure. The escape of excess moisture from high moisture seeds also provided a temporary barrier between the seed and oil/heat, producing a lighter roasted sample. Raw moisture content was not determined to have any significant impact on porosity or amount of oil uptake.

Migration of oil from the peanut to the frying oil was supported by the increase in O/L ratio of the post roast fryer oil. Variation in O/L levels were not determined to be correlated to pre-roast moisture content. Uptake of oil from the fryer into seed was determined by the presence of C12:0 in the FAP of the oil expressed from the samples that were rinsed of surface oil (dipped seeds). Net uptake and the percentage of C12:0 from the dipped seeds showed no significant correlation to pre-roast moisture content. True density of raw samples a showed slight significant decrease while roasted samples showed a slight significant increase as pre-roast moisture content increase. Bulk density showed a slight significant increase for both raw and roasted samples as moisture content increased. Porosity values calculated from the two density measurements determined a significant increase in raw porosity as moisture content decreased while no significance was observed for the roasted samples.

Cooling parameter showed the greatest impact on migration of oil. Seeds that were not cooled consistently contained less oil than those that were cooled and displayed the greatest amount of surface oil collected from the hexane rinse. Peanuts cooled at different
rates showed no significant differences. Understanding the importance of cooling after roasting and before packing in combination with the finding that cooling speed does not show significant differences in oil presence in or on peanuts is crucial information to industry leaders who are always looking to optimize their processing rates while maintaining product quality.

SEM images revealed the amount of structural damage caused by roasting was related to pre-roast moisture content. Samples with higher moisture levels displayed larger areas of surface damage and increasing loss of internal structural organization. These findings suggested that high moisture samples would have higher porosity values and amount of uptake but the results proved this was not true.

Images of post roast storage samples revealed excess salt is less prevalent and better adhered to seeds with lower pre-roast moisture contents. This correlates with surface oil results as samples with lower pre-roast moisture contents showed more oil present on the surface giving the salt something to adhere to. Images of unsalted samples showed sample color got increasingly darker as pre-roast moisture content decreased. This suggests that moisture content influences the browning reactions that occur during roasting.

**SUGGESTIONS FOR FUTURE WORK**

Additional work to investigate the movement of oil during specific time periods of the cooling process or at modified cooling temperatures would be beneficial. Better understanding of oil movement during cooling would provide information to industry to further optimize their processing techniques.
Figure 1: Changes in moisture content of raw (A) and roasted (B) samples in relation to predetermined moisture range
Figure 2: A diagram showing the three oil fractions post-frying (Bouchon et al. 2003)
Table 1. Mean oil content and oil uptake by pre-roast moisture content of oil roasted peanuts, separated by cooling treatment

<table>
<thead>
<tr>
<th>Cooling Treatment</th>
<th>Pre-roast MC (% wet wt)</th>
<th>Roast Mean Oil (% wet weight)</th>
<th>Raw Mean Oil (% wet weight)</th>
<th>Net Uptake (%)</th>
<th>Roast Mean Oil (% dry weight)</th>
<th>Raw Mean Oil (% dry weight)</th>
<th>Net Uptake (%)</th>
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</thead>
<tbody>
<tr>
<td>Immediate (No Cool)</td>
<td>3.3</td>
<td>54.2 a</td>
<td>51.4 a</td>
<td>2.9 a</td>
<td>54.8 a</td>
<td>53.3 a</td>
<td>1.5 a</td>
</tr>
<tr>
<td></td>
<td>4.6</td>
<td>54.6 a</td>
<td>50.6 b</td>
<td>4.0 b</td>
<td>55.3 a</td>
<td>53.1 a</td>
<td>2.1 a</td>
</tr>
<tr>
<td></td>
<td>6.1</td>
<td>54.2 a</td>
<td>50.0 c</td>
<td>4.3 b</td>
<td>54.9 a</td>
<td>53.2 a</td>
<td>1.7 a</td>
</tr>
<tr>
<td></td>
<td>8.4</td>
<td>54.5 a</td>
<td>48.7 d</td>
<td>5.7 c</td>
<td>55.1 a</td>
<td>53.2 a</td>
<td>1.9 a</td>
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<th>Raw Mean Oil (% wet weight)</th>
<th>Net Uptake (%)</th>
<th>Roast Mean Oil (% dry weight)</th>
<th>Raw Mean Oil (% dry weight)</th>
<th>Net Uptake (%)</th>
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<tr>
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<td>50.6 b</td>
<td>3.8 b</td>
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<td>53.1 a</td>
<td>2.0 a</td>
</tr>
<tr>
<td></td>
<td>6.1</td>
<td>54.4 a</td>
<td>50.0 c</td>
<td>4.4 b</td>
<td>55.1 a</td>
<td>53.2 a</td>
<td>1.9 a</td>
</tr>
<tr>
<td></td>
<td>8.4</td>
<td>54.5 a</td>
<td>48.7 d</td>
<td>5.8 c</td>
<td>55.2 a</td>
<td>53.2 a</td>
<td>2.0 a</td>
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<th>Raw Mean Oil (% dry weight)</th>
<th>Net Uptake (%)</th>
</tr>
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<tbody>
<tr>
<td>Ambient (Slow Cool)</td>
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<td>54.7 a</td>
<td>51.4 a</td>
<td>3.3 a</td>
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<tr>
<td></td>
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<td>5.9 c</td>
<td>55.3 a</td>
<td>53.2 a</td>
<td>2.0 a</td>
</tr>
</tbody>
</table>

* Means in columns within blocks followed by the same letter were not significantly different
Figure 3: Changes in mean oil content of raw samples in response to changes in raw moisture content
Figure 4: Changes in mean oil amount in response to changes in pre-roast moisture content and post-roast cooling parameters of oil-roasted peanuts that were undipped (A&C) and dipped (B&D)
Figure 5: Changes in amount of uptake in response to changes in pre-roast moisture content and post-roast cooling parameters of oil-roasted peanuts that were undipped (A&C) and dipped (B&D)
Figure 6: Changes in surface oil amount in response to changes in pre-roast moisture content and post-roast cooling parameters of oil-roasted peanuts.
Figure 7: Fatty Acid Profile of pre-roast peanut oil (A) and pre-roast coconut oil marker (B)
Figure 8: Fatty acid profile of pre-roast fryer oil (A) and the post-roast fryer oil (B) containing both peanut oil and added coconut oil marker.
Figure 9: Fatty acid profile of raw whole peanut seed at each pre-roast moisture content
Figure 10: Fatty acid profiles of surface oil extracted from peanuts that were oil roasted and cooled using each cooling parameter: immediate/ no cool (A), forced/ fast cool (B), ambient/slow cool (C)
Figure 11: Fatty acid profiles of oil roasted dipped peanut seeds at each moisture content level and cooled using each cooling parameter: immediate/no cool (A), forced/fast cool (B), ambient/slow cool (C)
Figure 12: True density of raw and oil roasted peanuts at different pre-roast moisture contents
Figure 13: Bulk density of raw and oil roasted peanuts at different pre-roast moisture contents
Figure 14: Porosity of raw and oil roasted peanuts at different pre-roast moisture contents
Figure 15. Scanning electron micrographs of the cotyledon surface of raw peanut samples with low pre-roast moisture contents of: 3.3% (A) and 4.6% (B) demonstrating the shape and orientation of epidermal cells
Figure 16. Scanning electron micrographs of the cotyledon surface of raw peanut samples with high pre-roast moisture contents of: 6.1% (A) and 8.4% (B) demonstrating the decrease in epidermal cell visibility and displaying surface portions containing pre-existing surface damage (A) and mold (B)
Figure 17. Scanning electron micrographs of the cotyledon surface of roasted peanut samples with low pre-roast moisture contents of: 3.3% (A) and 4.6% (B) demonstrating damage that occurs to the surface epidermal cells during roasting due to the escape of moisture.
Figure 18. Scanning electron micrographs of the cotyledon surface of roasted peanut samples with high pre-roast moisture contents of: 6.1% (A) and 8.4% (B) demonstrating the increase in damage that occurs to the surface epidermal cells during roasting due to the escape of greater amounts of moisture.
Figure 19. Scanning electron micrographs of cross sections of the cotyledon surfaces of raw peanut samples with low pre-roast moisture contents of: 3.3%(A) and 4.6%(B), these display a more intact structures cellular networks than the samples with higher pre-roast moisture contents.
Figure 20. Scanning electron micrographs of cross sections of the cotyledon surfaces of raw peanut samples with high pre-roast moisture contents of: 6.1% (A) and 8.4% (B). These display voids due to the loss of materials during sample preparation for imaging.
Figure 21. Scanning electron micrographs of cross sections of the cotyledon surfaces of roasted peanut samples with low pre-roast moisture contents of: 3.3%(A) and 4.6%(B)
Figure 22. Scanning electron micrographs of cross sections of the cotyledon surfaces of roasted peanut samples with high pre-roast moisture contents of: 6.1%(A) and 8.4%(B).
Figure 23. Images of salted oil roasted peanuts at each moisture content representing a decrease in visible salt on the seed surface with a decrease in pre-roast moisture content: 8.4% (A), 6.1% (B), 4.6% (C), 3.3% (D)
Figure 24. Images of unsalted oil roasted peanuts cooled using two different cooling methods displaying changes in surface characteristics including texture and color. The top row includes peanuts that were allowed to cool slowly while the bottom row includes those that were fast cooled. The letters represent the corresponding pre-roast moisture contents: 8.4% (A), 6.1% (B), 4.6% (C), 3.3% (D)
REFERENCES


