

## Abstract

MEHROTRA, MINOO. Application of Color Sorting Technology for Reduction of Fruity Fermented Off-flavor and Improvement of Flavor and Shelf Life of Roasted Peanuts. (Under the direction of Dr. Timothy H. Sanders.)

A range of maturity stages is present in peanut pods at any harvest date due to an indeterminate flowering habit. Since the size-maturity relationship is not absolute, immature peanuts are found in all grade sizes. Immature peanuts are associated with increased fruity fermented off-flavor potential at high curing temperatures ( $>35^{\circ}\text{C}$ ). Upon roasting immature peanuts acquire a darker roast color and have lower roast peanutty flavor than mature peanuts.

The objective of this study was to determine the effectiveness of a novel application of machine color sorting for reduction of fruity fermented off-flavor and improvement of flavor and shelf life of roasted peanuts.

Two fruity-fermented peanut lots of Flavor Runner 458 from the years 2002 and 2003 and a non-fruity fermented lot of Georgia Green (65 kg each) were roasted to a target Hunter L value of  $49 \pm 1$ , blanched, and subdivided into 3 sub-lots. Each sub-lot was color sorted using a Sortex color sorter. The sensitivity parameter of the color sorter was increasingly adjusted to separate about 5, 20 and 30 % of the darkest peanuts (rejects) from the lighter ones (accepts). Hunter L values of  $40 \pm 2$ ,  $43 \pm 2$  and  $45 \pm 2$  were recorded for the first, second and third reject fractions (dark peanuts) respectively for all peanut lots. All rejects had lower Hunter L values than the corresponding accept fractions by  $(8 \pm 2)$  units.

A panel highly trained in peanut flavor descriptive sensory analysis evaluated the unsorted and color sorted fractions for all flavor attributes. Statistical analysis indicated significant differences among the light and dark color-sorted peanuts ( $p < 0.0001$ ). The third accept (2002 and 2003 fruity fermented crops) formed after removing ca. 30 % dark peanuts had the highest roast peanutty intensity (4.63 and 4.69). The first reject (2003) consisting of 6.6 % of darkest peanuts received the lowest score for roast peanutty (3.7) and the highest score for fruity off-flavor (3.1). In both the 2002 and 2003 lots there was a reduction in the intensity of fruity fermented off flavor from 2.4 and 2.76 respectively in the unsorted peanuts to 0.48 and 0.41 respectively in the third accept. Dark roast flavor and bitter taste decreased significantly ( $p > 0.0001$ ) with removal of higher percentage of dark peanuts in the fruity-fermented 2003 crop. No significant differences were established in the descriptive flavor analysis among the accept fractions in the non-fruity fermented lot.

Results from chemical analysis demonstrated that the first reject with ca. 5 % of darkest peanuts had significantly lower percentage of oil content (45-46%), higher free fatty acid values (0.22-0.26) and lower O/L ratio (11.48-11.58) in the fruity fermented lots. The rejects from the non-fruity fermented lot had significantly lower O/L ratio (1.54-1.60), higher free fatty acid value (2.45-2.58) and higher sugar concentration (75-82 mg/g). No significant differences were established in the shelf life characteristics among the accept fractions in all peanut lots.

The results indicated that fruity fermented off-flavor decreased with the removal of successively higher percentage of darker-roasted immature peanuts. This technology provides a method of remediation of peanuts, which have the fruity fermented off-flavor.

**Application of Color Sorting Technology for Reduction of  
Fruity Fermented Off-flavor and Improvement of Flavor  
and Shelf Life of Roasted Peanuts**

by

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A Thesis submitted to the Graduate Faculty of

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in partial fulfillment of the

requirements for the Degree of

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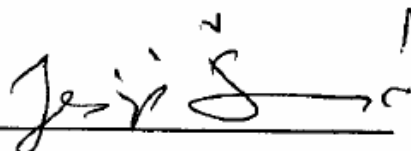
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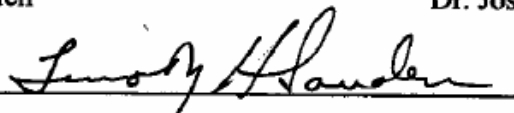
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## **Dedication**

*For my wonderful daughter Shivani who is wise beyond her years.*

*Her love, endurance and sweet charm have helped me to be the nicest person I can be.*

## Biography

Minoo Mehrotra was born the second child of S.N. Varma and Rama Varma on May 8, 1966. She grew up in India with two brothers. Her parents still live in India. She was in boarding school for most of her academic life. She attended Loreto Convent School and Loreto College in India. She was captain of her school and was involved with several club activities. She loved to attend camps at Nirmala Bhavan, in Calcutta, India where Mother Teresa worked. She received her Bachelor of Science degree in biological sciences (Botany, Zoology and Chemistry) in 1988 from University of Allahabad, India. She enrolled in 1989 to pursue her Master's Degree in Anthropology. She was employed in a public school in New Delhi, India for two years where she taught English and Science. She married Sanjay Mehrotra, a software developer and came to South Carolina in 1994. They resided in Columbia for 6 years. When they moved to Raleigh, she joined North Carolina State University to pursue Master's program in Food Science in 2002 and worked as a Graduate Research Assistant under the guidance of Dr. Tim Sanders. She enjoyed being a member of Food Science Club and the Phi Kappa Phi Honor Society. She is passionate about traveling and her favorite places are Disney World, the Niagara Falls and the Taj Mahal. She loves to indulge in gourmet cooking for her friends and family. She considers her biggest blessing to be her beautiful daughter, Shivani Mehrotra who was born on July 31, 1997. Spending time with family and friends is her favorite pastime!

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I would like to specially acknowledge the love and blessings of my parents who reside in India. They always told me I could be anything I wanted. When you grow up in a household like that, you learn to believe in yourself. I would like to express my deep gratitude to my husband, Sanjay Mehrotra for the inexpressible comfort of making me feel safe, secure and loved. I would like to thank my beloved daughter, Shivani Mehrotra for being a source of great strength and willpower. Her maturity, patience and endurance give me the will to not only to do the job but also to do it well. She has brought so much sunshine to my life!

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CHAPTER 1

**LITERATURE REVIEW**

## **1.1 Brief History of *Arachis hypogaea* L.**

The peanut (*Arachis hypogaea* L.) is one of the oldest and most important food legumes in the world (Ory and Flick, 1991). It is an annual herb of the Leguminosae family and is indigenous to the Andes in South America. Preserved fruits of the peanut dating back to 750 B.C. have been recovered from the Peruvian coast (Hammons, 1982).

Peanuts were cultivated in the West Indian Islands, Mexico, Brazil and the Rio de la Plata basin including Argentina, Paraguay and Bolivia (Hammons, 1982). Early Spanish and Portuguese explorers wrote a historical account of the peanut in 1527 and were responsible for disseminating the peanut to Europe, Africa, Asia and the Pacific Islands (Hammons, 1982). Peanuts reached the colonial coast of North America from Africa via the slave trade route between 1707 and 1725 (Hammons, 1982).

## **1.2 The Peanut Industry**

Peanut production, concentrated in the southeastern and southwestern regions of the United States, generates an annual crop value of about \$700 million (ERS/USDA, 2002). The direct consumption of peanuts is about 70 percent of the total domestic use. Shelled peanuts include those used for peanut butter (about 45 percent of peanut food use), snack peanuts (23 percent), and peanut candy (21 percent). Roasted in-shell peanuts account for about 9 percent of U.S. peanut food use. The proportion of peanuts crushed for animal feed and vegetable oil is small, especially when compared with other oilseeds (e.g., soybeans). Lower quality peanuts used for crushing make up only 18 percent of domestic consumption. Seed and residual uses account for the remaining 12 percent (ERS/USDA, 2002).

In 1989, domestic food use of peanuts peaked at 2.32 billion pounds (in-shell basis), or about 9.4 pounds per person. But, in the early and mid-1990s there was a steady decline in



demand. U.S. peanut consumption has turned around since 1995 as food use rose almost without interruption to a projected record of 2.34 billion pounds in 2001/02. Some observers have attributed it to reduced concern about fat in foods, a growing awareness of studies linking peanut consumption to improved health, the introduction of new products (e.g., flavored in-shell peanuts), and increased retail promotion by peanut product manufacturers and industry associations (ERS/USDA, 2002).

The most common variety, runners, accounts for about three-quarters of U.S. peanut production and is used mainly to make peanut butter (52 percent of runners in 2000/01) but also in peanut candy (26 percent) and as snack peanuts (20 percent). The large, high-quality virginia peanuts account for about 15 percent of domestic production and are more favored as snack peanuts (e.g., roasted in-shell peanuts and salted or honey-roasted peanuts). Spanish peanuts, with smaller kernels and higher oil content, are used mainly in peanut candies. The least common, valencias, also have small kernels and are known for their sweetness. They are produced almost exclusively in New Mexico, and are usually roasted and sold in the shell. Peanut production is concentrated in a small number of states and is a key contributor to local economies. Virtually all peanut production takes place in just nine states in three regions: the Southeast (Georgia, Alabama, Florida, and South Carolina), with 55 percent of national production; the Southwest (Texas, Oklahoma, and New Mexico), with 30 percent; and the Virginia-North Carolina region, with 15 percent (ERS/USDA, 2002).

### **1.3 Composition**

The investigations by Hoffpauir and Guthrie (1945) recognized the need for an exhaustive study of the composition and characteristics of the peanut components to understand and improve the quality of peanut products. Sensory studies have demonstrated

that peanut composition affects peanut quality and shelf life. (Sanders *et al.*, 1989 a, b; Pattee *et al.*, 1989; Pattee *et al.*, 1990; Sanders *et al.*, 1990).

High oil and protein content and lower percentages of carbohydrates and ash characterize peanut composition. In the four major market types (runner, virginia, valencia and spanish) total oil content was found to vary from 44–56 % (Pancholy *et al.*, 1978; Hoffpauir, 1953; Cobb and Johnson, 1973; Holaday and Pearson, 1974; Ahmed and Young, 1982). Peanut oil has low viscosity, a light yellow color and slightly nutty taste. Conditions of maturity, variety and local environmental conditions influence the oil content. Rapid changes in oil percentage were found to occur in early maturity stages (Sanders, 1980 a; Sanders *et al.*, 1982). Apparently there are no studies which indicate a direct correlation between the amount of oil in peanuts and their shelf life but many studies have indicated a positive correlation of oil content with maturity which in turn is associated with flavor and shelf life (Ahmed and Young, 1982; Pattee *et al.*, 1974; Sanders, 1980; Hinds, 1995; Sanders *et al.*, 1989 a, b). The concentration of the various components of peanut oil has been found to influence oxidative stability and shelf life (Fore *et al.*, 1953; Holaday and Pearson, 1974; Young *et al.*, 1974; Sanders, 1980 a). Mature peanuts contain 95 % triacylglycerol with oleic (C18:1), linoleic (C18:2) and palmitic (C16:0) fatty acids present in the highest concentration (Hoffpauir, 1953). The high degree of unsaturation makes peanut oil susceptible to lipid oxidation, which contributes to quality deterioration during storage (Sanders *et al.*, 1993). Total oil and oleic/linoleic acid ratio (O/L) increase and free fatty acids (0.02-0.6%), polar lipids, monoacylglycerols and diacylglycerols decrease with peanut maturity (Sanders, 1980 a; Sanders *et al.*, 1982).

The protein content of peanuts ranges from 22-33 % with an average of about 25 % (Hoffpauir, 1953; Pattee et al., 1982; Ahmed and Young, 1982). Production location affects the total protein and oil content (Holaday and Pearson, 1974). Peanuts also contain about 4.0 % starch and 2.0-5.0 % of sucrose (Hoffpauir, 1953). Lower concentrations of glucose, fructose, raffinose and stachyose are also present (Pattee et al., 1982). Peanuts contain approximately 50 % moisture at the time of harvest. During windrow curing or field drying the moisture content is generally reduced to about 20 %. Subsequently, peanuts are mechanically cured or dried with heated air to further reduce the moisture content to 8-10 %. Pattee *et al.*, (1982) suggested that with increased moisture content, protein and starch hydrolysis could significantly change peanut composition.

Other important peanut components include minerals such as calcium, magnesium, phosphorous, sodium, potassium, iron, copper, zinc and manganese and vitamins A, B, C and E (Ahmed and Young, 1982).

Peanut maturity has consistently been shown to be crucial in determining chemical composition, grade and oil stability (Young *et al.*, 1972; Young *et al.*, 1974; Pattee *et al.*, 1974; Basha *et al.*, 1976; Sanders *et al.*, 1982; Sanders *et al.*, 1989b).

#### **1.4 Maturity**

Peanut maturity is significantly related to quality characteristics such as flavor and storability (Sanders *et al.*, 1989 a, b; Sanders and Bett, 1995; Bett and Boylston, 1992). The peanut plant has an indeterminate flowering habit. Flowers bloom over an approximately 60-day period and result in fruit with a range of maturity at any harvest date. Therefore an accurate crop maturity prediction results in harvest of more mature peanuts. The hull scrape maturity method developed by Williams and Drexler (1981) is a widely used method for

visually predicting the optimum harvest date for maximum yield. It is a non-destructive maturity classification based on the changes in color and structure of the pod mesocarp. With maturation the pod mesocarp changes through white, yellow, orange, brown and black color. After abrasive removal of the exocarp peanuts of these various colors are placed on a maturity profile board and the optimum harvest date is determined (Williams and Drexler (1981). Sanders *et al.* (1989 b) showed that the correlation between maturity and peanut size is not absolute but maturity differences are most apparent in large versus small peanuts. Because the size-maturity relationship is not absolute peanuts of different maturities are sized together during shelling (Mc Neill and Sanders, 1996). Therefore, each commercial size category contains peanuts from each maturity class. Research by Pattee *et al.* (1974, 1982) and Sanders *et al.* (1987, 1989 a, b) showed that the degree of maturation influences the biochemical composition and the overall quality regardless of the size of peanuts. The relative percentages of peanuts of each maturity class in a given commercial size influence lot characteristics such as storability, roast color variation, flavor/off-flavor potential and other quality characteristics related to seed maturity (Sanders *et al.*, 1980 a, b; 1989 a, b; Bett and Boylston, 1992; Sanders & Bett, 1995; McNeil & Sanders, 1998). Sanders *et al.* (1982) demonstrated compositional dissimilarities among the different maturity stages. Lipids, proteins and sugars in immature peanuts are not compositionally or structurally at the state of metabolic quiescence indicative of maturity (Basha *et al.*, 1976; Pattee *et al.*, 1974; Sanders *et al.*, 1982). Higher percentages of immature peanuts in any given lot can therefore have a negative impact on quality (Sanders 1989 a).

## **1.5 Harvest**

Harvesting refers to the operations necessary for the removal of peanut pods from the soil. The timing of harvest is critical since it greatly impacts the yield and grade and therefore the dollar value of the crop (Dickens and Pattee, 1973; Sanders and Williams, 1978; Pattee *et al.*, 1980; Sanders *et al.*, 1980; Williams and Drexler, 1981; Sanders and Bett, 1995). Only a narrow window of time exists for harvest where total crop yield is high and losses are minimized (Pattee and Young, 1982). Optimum harvest time ensures more mature pods, which results in higher percentages of mature seed in commercial grade sizes. The yield in an early harvest has a higher percentage of immature pods and a very late harvest incurs a greater loss of mature pods: both conditions affect the overall quality of harvested peanuts (McNeill, 1996).

## **1.6 Curing**

After peanuts are harvested, the curing process begins. The term curing includes biochemical changes as well as reduction of moisture content to preserve quality (Dickens and Pattee, 1973). Freshly harvested peanuts are subjected to windrow and mechanical curing to reduce moisture content on a wet basis, from approximately 50 to 10%. Wet basis moisture content is expressed as weight of water divided by the collective weight of the water and the weight of the dry matter. The drying rate depends on the initial moisture content, equilibrium moisture content, relative humidity, and curing temperature (Young *et al.*, 1982). Maintaining a low level of moisture in storage is important to inhibit mold growth and prevent quality deterioration during storage (Dickens and Pattee, 1973).

In artificial curing the temperature of the heated air, the relative humidity and the airflow rate controls the efficiency of the drying process. In standard recommended practice, the drying air temperature may be increased up to 95°F (35°C), without exceeding 15°F above the ambient temperature. Thomas *et al.*, (1968) observed that peanuts cured at 49 °C in a forced draft-drying bin were significantly inferior in quality to both bag-cured and field-cured peanuts. They recommended that the airflow rate should be greater or high enough to create a thick drying zone but not so great or high that the exit air remains unsaturated. Maintenance of proper air temperature, airflow and relative humidity during the curing process result in good milling quality, reduced numbers of split kernels and seeds with intact testa (Troegoer, 1982; Chai et al., 1995). Peanuts have been shown to develop off-flavors at air temperatures greater than 95°F (Beasley et al., 1963; Sanders et al., 1989 a).

Sanders *et al.* (1989 a) investigated the interaction of maturity and curing temperature on descriptive flavor attributes in roasted peanuts. In comparison to mature peanuts, immature peanuts cured at higher temperatures (above 38°C) were reported to have decreased intensity for roasted peanutty and sweet aromatic flavor attributes and increased intensity for fruity fermented, painty, sour, and bitter attributes (Sanders *et al.*, 1989 a, b).

## **1.7 Flavor**

The unique flavor of roasted peanuts is the cornerstone for the billion dollar peanut industry. Achieving and maintaining consistent roast flavor and roast color are essential factors for determining product quality and consumer acceptability. Peanuts are roasted in dry heat or oil at 138-180°C for 3-20 minutes to produce the pleasant aroma and nutty flavor (Woodroof, 1983; Leunissen *et al.*, 1996). During roasting a mixture of flavor, antioxidant and color compounds is produced following a sequence of complex reactions (Bailey, 1992).

In the first step of Maillard browning, a reversible reaction occurs between a reducing sugar, namely glucose, fructose or lactose and an amine to produce glycosylamine (Bemiller and Whistler, 1996). This compound undergoes an Amadori re-arrangement and subsequently forms a variety of carbonyl intermediates and flavor compounds (Bailey, 1992). Pickett and Holley (1952) first showed that amino-carbonyl reactions produced derivatives of tetrahydrofuran, ammonia, hydrogen sulfide, and diacetyl with detectable browning and aroma compounds in peanuts. They hypothesized that the two major globulin proteins, arachin and conarchin, along with sucrose were the precursors of peanut flavor. Pickett and Holley (1952) reported 120 °C as the minimum required temperature for producing flavor compounds. In another study by Mason and Waller (1964), a slightly higher temperature of 132°C was considered essential for formation of flavor compounds. Mason *et al.* (1966) identified a pyrrole and several pyrazine compounds as flavor constituents. A previous study by Hodge (1953) showed that pyrazines and pyrroles were produced from heated mixtures of sugars and amino acids. Newell *et al.* (1967) identified the amino acids responsible for typical and atypical peanut flavor. The authors reported that aspartic acid, glutamic acid, glutamine, asparagines, histidine and phenylalanine were associated with typical peanut flavor while threonine, tyrosine, lysine and an unidentified nitrogen containing compound were precursors of atypical flavor. The volatile components responsible for peanut flavor were also studied by Pattee *et al.* (1969 a, 1970), Brown *et al.* (1972), Bett and Boylston (1992) and reviewed by Cobb and Johnson (1973), Pattee and Singleton (1981), Sanders *et al.* (1982) and Ahmed and Young (1982).

The existence of free reducing sugars and the production of reducing sugars by fermentation and roasting has been documented (Newell and Mason, 1967). Newell *et al.*

(1967) reported that glucose and fructose were the main reducing sugars, which react with amino acids when peanuts are roasted. Previously, Hodge (1953) showed sucrose as a source of reducing sugars since glucose and fructose are present in very small quantities in peanuts. Mason *et al.* (1969) confirmed that sucrose was inverted to fructose and glucose during roasting. Mason *et al.* (1967) suggested other carbonyl compounds as precursors to roasted peanut flavor.

How (1984) and Oupadissakoon and Young (1984) used descriptive analysis terminology to define flavor attributes associated with peanut variety, handling, roasting and storage. Johnsen *et al.* (1988) created a descriptive flavor lexicon to describe the desirable and undesirable flavors in peanuts. This lexicon was further expanded by Sanders *et al.* (1989) to include the term fruity fermented. The peanut lexicon mainly consists of three categories: aromatics, tastes and chemical feeling factors (Johnsen *et al.*, 1988) (Table 1). The various descriptors for aromatic attributes include roasted peanutty, raw/beany, dark roast, sweet aromatic and woody/hulls/skins and the off-flavors such as cardboard, painty, earthy/musty, plastic chemical and fruity-fermented. The tastes attributes include the four basic tastes: sweet, sour, salty and bitter and the chemical feeling factors are astringent and metallic. The intensity of all flavor descriptors is evaluated on a 0-15 point universal reference scale (Meilgaard *et al.*, 1987). The universal scale is an absolute scale, which is constant across all products and attributes.

### **1.7.1 Fruity Fermented off-flavor**

Certain undesirable flavors in peanuts are a function of curing temperature, exposure time to excessive temperatures, moisture content and maturity stage of the peanut kernels (Pattee *et al.*, 1965). Thomas *et al.* (1968) performed acceptance tests on peanuts with



various defects and found that drying temperatures of 120° F caused inferior flavored peanuts. Sanders et al. (1989) compared the effect of three wagon-drying temperatures (ambient, ambient + 8.4 °C and ambient + 16.8 °C) on the various maturity stages of peanuts. The more mature peanuts were relatively unaffected by high temperature curing. However, immature peanuts exhibited lower intensities of roasted peanutty and sweet aromatic and higher intensities of fruity fermented, sour and dark roast at higher curing temperatures.

The fruity fermented flavor defect originally described as high-temperature curing off-flavor can therefore be defined as the flavor associated with immature and improperly cured peanuts or fermented peanut vegetation flavor which is reminiscent of over ripe / rotten fruits, vegetables or grain (Ory *et al.*, 1992; Pattee *et al.*, 1999). Schenk (1961) found that curing temperatures of 42°C and above caused maximum respiration rates in peanuts. Studies have shown that the process of curing has a significant effect on seed respiration (Whitaker and Dickens, 1964; Whitaker *et al.*, 1974). Rapid respiration was found to reduce oxygen levels inside the peanuts and induce anaerobic respiration. As a result certain volatile compounds were formed which were assumed responsible for the off-notes. The presence of more volatiles in immature peanuts correlated positively with increased intensity of off-flavor (Whitaker and Dickens, 1964). Young *et al.*, (1982) recommended that curing temperature should not increase beyond 5 -10 °C above ambient temperature or exceed more than 35°C.

Pattee *et al.*, (1965) and Singleton *et al.*, (1971) reported that acetaldehyde, ethanol, ethyl acetate, formaldehyde, acetone, 3- methylpropanal, butanal, 3-methylbutanal, 2-methylpentanal and hexanal were among the volatile compounds detected in high-temperature-cured peanuts that indicated flavor deterioration. Didzbalis *et al.*, (2004) found

that immature peanuts with fruity-fermented off-flavor contained fruit like esters (ethyl 2-methylpropanoate, ethyl 2-methylbutanoate and ethyl 3-methylbutanoate) in addition to higher levels of short chain organic acids (butanoic, 3-methylbutanoic and hexanoic). Sanders *et al.*, (1989 c) and Pattee *et al.*, (1990) showed that fruity fermented intensity was inversely proportional to the roasted peanut attribute in immature virginia and runner type peanuts.

### **1.8 Shelf-life**

Peanut shelf life or stability is generally associated with lipid oxidation. Oxidation may occur via enzymatic or auto-oxidation mechanisms, respectively during storage of raw and roasted peanuts. Fatty acid composition, presence of antioxidants and metals and lipoxygenase activity also influence stability. In raw peanuts the lipoxygenase-catalyzed oxidation reaction is the major cause of off-flavors. However, heat treatments such as roasting effectively inactivate lipoxygenase activity. Therefore auto-oxidation is the primary concern for the shelf life of roasted peanuts. The initiation of auto-oxidation is by the abstraction of a hydrogen atom adjacent to a double bond in a fatty acid molecule to form alkyl and hydrogen free radicals (Shahidi and Wanasundara, 1998). UV light, metal ions or heat can catalyze the initiation process. In the propagation step, atmospheric oxygen reacts with an alkyl radical to form an unstable peroxy radical. The peroxy free radical can slowly abstract a hydrogen atom from another unsaturated fatty acid molecule to produce hydroperoxide and a new alkyl free radical. A chain reaction occurs until two radicals combine at termination.

Oils with more polyunsaturated fatty acids are generally less stable because they have a relatively increased rate of auto-oxidation. In peanuts, the oleic: linoleic (O/L) ratio has

been studied in relation to stability. Manning (2000) studied the effect of O/L ratio on the flavor quality of roasted peanuts during shelf life. It has also been observed that Maillard reaction products produced during peanut roasting have antioxidant activity and decrease lipid oxidation (Franzke and Iwainsky, 1954; Griffith and Johnson, 1957; Alaiz et al., 1995).

### **1.9 Roast Color**

Roast color significantly affects the quality of peanuts, as it is associated with the development of flavor and aroma during roasting (Morris *et al.*, 1953). The characteristic color results from amino acid-sugar reactions (Hodge, 1953) that intensify with higher roast temperature and prolonged roast time. Caramelization or thermal degradation of sugars also causes browning in roasted peanuts (Mason *et al.*, 1966).

Ferreira *et al.*, (1994) suggested that the Hunter L, a, b and  $L^* a^* b^*$  systems correlate best to sensory, visual and objective assessments of color. Hunter L values are the primary parameter for peanut butter color in the peanut industry (Pattee *et al.*, 1991). Hunter L color measurement is based on the Opponent-Colors theory, which assumes that the receptors in the human eye perceive color as the following pairs of opposites: light-dark, red-green and yellow-blue (Hunter Lab, 2001). The L value indicates the level of light or dark on a 0-100 scale. The a value is a measure of red or green and the b value is a measure of yellow or blue respectively (Figure 1). All three values are required to completely describe the color of an object. Peanut roasting studies usually apply a time-temperature protocol or refer to degree of roast as 'light', 'medium' or 'dark' (Buckholz *et al.*, 1980; Oupadissakoon and Young, 1984). Pattee and co-workers (Pattee *et al.*, 1982 a, b) used Hunter L value of 49 as equivalent to a medium roast color. Sanders *et al.*, (1989 a, b) and Landsen *et al.*, (1988)

used Hunter *L* values as a definitive measure of degree of roast and found that immature peanuts in any sized lot acquired a darker roast color than mature peanuts.

### **1.10 Machine Vision**

Computer vision helps to capture, process and analyze images and facilitate an objective, non-destructive assessment of visual quality characteristics in food products (Timmermans, 1998). The potential of computer vision in the food industry has long been recognized (Tillett, 1990) and currently the food industry is ranked among the top 10 industries using this technology (Gunasekaran, 1996). Rapid advances in hardware and software have provided low cost effective solutions and have motivated numerous studies on the application of computer vision systems in the evaluation of the quality of many raw and processed foods (Locht *et al.*, 1997; Sun, 2000). Automated machine vision technology is of substantial benefit in the food industry because it is cost effective, consistent, fast and accurate.

As a consequence of increasing consumer awareness it is a basic prerequisite for optical sorting machines to identify and remove all gross contaminants (glass, stones, insects, extraneous matter etc.) from food ingredients and /or products. In addition, optical sorting provides an aesthetic enhancement to the product by removal of blemished, discolored and misshapen products. The size, cost and complexity of sorting machines vary, depending on the size of the product to be color sorted, the throughput requirement and the complexity of optical measurement. Rice and mustard seeds are among the smallest food products that are color sorted on a commercial basis. Seeds and nuts are usually sorted on a single or double chute machine with a throughput of 60-600 kg/hour (Bee and Honeywood, 2002).

### **1.10.1 High-Speed Color Sorter**

The demand for automatic color sorting machines has increased over the years due to escalating costs of hand sorting and higher quality requirements imposed on food producers. The optical sorting of peanuts is a complex process and in some cases pushes even current technology to its limits. Difficulties arise when the material to be rejected is of similar color or texture to the acceptable product or when defects (such as insect damage) are very small (Bee and Honeywood, 2002). In current color-sorting machines, spectral reflectivity at particular wavelengths rather than color as a whole is used. The relative reflectance signal varies from black (zero and hence no reflectance) to white (100 % reflectance). The wavelengths cover the visible spectrum (400-700 nm) and extend into the near infra-red (700-1100 nm). Optical sorting exploits the region of the spectrum where the reflectance values for all acceptable products are either higher or lower than values for unacceptable products. With the use of suitable optical filters, this part of the spectrum is used as a basis for color sorting the particular product. Diffuse spherical broadband lighting uniformly illuminates the product during color sorting. The reflected light is split into constituent wavelengths. The output is measured using a suitable detector. Hence, for effective optical sorting there must be a distinct difference in reflectance within the selected wavebands between the acceptable product and the reject product (Bee and Honeywood, 2002). Bichromatic sorting techniques analyze the reflected light in two separate wavebands simultaneously and utilize the ratio of light intensity in these wavebands to build up a two-dimensional color map. If the wavebands are, for example, red and green, the combination of these colors allows the image processor to discriminate all the shades of red, green, orange, yellow and brown that can be created by mixing them, allowing a very sensitive color sort to

be carried out. Two spectral reflectance curves are obtained where one set of data represents the lightest and darkest of acceptable product and the other represents the lightest and darkest of the reject product (Figure 2). Bichromatic sorting involves twice as many optical components as monochromatic sorting, additional lighting devices and more complex signal processing. Color sorters with this technology can effectively sort a wide variety of colors making it possible to remove darker roasted peanuts within a peanut lot. (Sortex Ltd., 2002).

Equally important to the accuracy of a color sorter is the precision of the ejection system. The ejectors remove the reject product from an incoming stream of product without removing acceptable product. In reality, some acceptable product is always ejected along with the defects so the measure of a good sorter is the concentration of the reject product. The reject product can be re-sorted to retrieve as much good product as possible. (Sortex Ltd., 2002).

### **1.10.2 Components of the Color Sorter**

Color Sorters generally have four principal systems: Feed System, Optical system, Ejection system and Image processing algorithms (Bee and Honeywood, 2002) (Figure 3).

The feed system consists of a vibrating hopper into which dry food products are introduced (rice, coffee, peanuts etc.) onto a flat or channeled gravity chute or an inclined belt. The feeding system functions to meter, accelerate to a constant velocity and align the product. It ensures that the optimum number of particles per unit time is fed through the optical inspection area. The system ascertains that the time taken for the product to travel from the optical inspection point to the ejection point is constant so that activation of the ejector can be accurately synchronized with the position of the product. The feed system

further ensures a controlled trajectory through the inspection and ejection points (Bee and Honeywood, 2002).

The optical inspection system measures the reflectivity of the product. The inspection components are housed within an optical box and the objects under inspection travel either through or past the optical box. Product does not come into direct contact with any part of the optical box and are separated from it by toughened glass windows. The optical system has one or more lenses and detection units depending on the number of directions from which the incoming product is viewed. Most color sorters have two or three cameras, which view the incoming product from different angles. This feature increases the efficiency of the system to identify unwanted product. The optical system also contains lamp units designed to provide even, consistent illumination of the product. The range of wavelengths measured by an optical sorting machine is defined by the choice of the light source, the properties of the optical filters and the properties of the detector. A primary objective of selecting filters and lighting is to obtain the maximum possible signal-to-noise ratio from the detector at the required wavelengths and the minimum possible signal at all other wavelengths (Bee and Honeywood, 2002).

The simplest inspection system views the incoming product through a small aperture and against an illuminated background. The brightness of the background is adjusted so that the optical system measures the same average value with or without the product. This is known as matched background because it matches the average brightness of the product. Matching the background offers an advantage in that measurement of reflectance is independent of object size. With a matched background, for example when a dark roasted

peanut passes the aperture, there is a decrease in signal amplitude and with a lighter roasted peanut there is an increase in the amplitude (Bee and Honeywood, 2002).

The ejection system is capable of physically removing the reject product from the main stream of incoming product. The ejection typically takes place when the product is in free fall. The accept products (desirable end product) continue along their normal trajectory and collect in a receptacle while the reject products (unwanted product) are deflected into another receptacle. The usual method of removing reject products from the main stream is with a blast of compressed air from a high-speed solenoid or piezoelectric valve connected to a strategically positioned nozzle. Pneumatic ejector valves have a rapid, reliable action capability. Ejectors operate at input pressures between 200 to 550 kPa (30 –80 psi) depending on the size of the product to be removed. Typically the ejection point is located outside the optical inspection area. The accurate timing which is required to coincide the ejector air blast with that of the object to be ejected relies on the fact that the objects have constant velocity as they fall in front of the ejector nozzle (Bee and Honeywood, 2002).

The image processing system classifies the incoming product as either accept or reject on the basis of color. The electronic processing systems in sorting machines are currently equipped with advanced digital microprocessor-based circuits. A sophisticated optical sorter tracks the average color of the product so that even though the average product color may change with time, the machine continues to remove only the pre-defined reject product. Optical sorters are provided with a white calibration plate, which may be manually or automatically placed in the optical view at user-defined intervals. The machine is then able to correct for any measurement drift that may occur (Bee and Honeywood, 2002).



Once a machine is set up for a particular food product all the machine settings can be stored in memory. This way the machine can be made ready to sort anytime simply by recalling the appropriate settings from the memory. Alternatively, the settings can be used as a coarse starting point from which to fine tune the machine towards an optimum setting for a particular set of products (Bee and Honeywood, 2002).

### **1.10.3 Mapping Techniques**

A bichromatic sorting machine such as the Sortex 3000 uses two band –pass filters for example green and red and processes to a decision point based on the ratio of the two signals in conjunction with the intensity of the individual signals. This can be represented as a two-dimensional color map by plotting the reflectivity of color 1 versus that of color 2 (Figure 4). The bottom left-hand corner of this map represents the reflectivity from a black particle (0% reflectivity) and the top right-hand corner represents the reflectivity from a white particle (100% reflectivity). The boundary curve in Figure 4 is the reflectivity map contour outlining the acceptable product as visualized by the color-sorting machine. The contour line represents the chosen accept /reject threshold. The ‘+’ within the map contour is the background ‘balance point’ that represents the average color of the product. A major part of setting up a color-sorting machine is to achieve the best overall accept/reject ratio for the product being sorted. The operator can adjust the size and shape of the map contour to match as accurately the map contour of the product. The sorting sensitivity increases as the machine map contour is decreased in area. The product within the area bounded by the threshold levels is the accept product and outside the boundary are the rejects. This allows an optical sorting machine to remove a greater range of unwanted products without removing large amounts of acceptable product. Once the machine is calibrated, sensitivity as defined above

is the principal parameter that can be changed to increase or decrease the amount of reject products (Figure 4) (Bee and Honeywood, 2002).

#### **1.10.4 Limitations of Color Sorting**

There is often a misunderstanding that a color sorter can remove 100% of the unwanted product from a given batch of product. A color sorter reduces the concentration of unwanted product but not with 100% effectiveness. All color sorters remove some acceptable product and fail to remove some of the reject product. This may occur because the color difference of the defect from the streaming incoming product is too small for accurate detection. Occasionally, the machine may detect a defect and remove the unwanted product but it may re-enter the accept stream after it has been ejected as a consequence of random collision. The performance and position of the ejectors can also become a limiting factor for accurate ejection of the unwanted product. Increasing the sensitivity of the color sorter results in rejection of more undesirable product; however, a greater proportion of good product will also be rejected as the sensitivity threshold approaches the average product color. Also, if the incoming product is not in a monolayer, the food product can overlap and sorting performance can deteriorate causing rejects to pass undetected by the optical system. Increasing the flow of the product through the machine can also result in increased loss of the good product because of overlapping and collision of product (Bee and Honeywood, 2002).

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Table 1. Lexicon of peanut flavor descriptors

<b>Attribute</b>	<b>Definition</b>
Roast Peanuty	The aromatic associated with medium roast peanuts and having fragrant characteristic of methyl pyrazine
Raw Beany	The aromatic with legume-like character
Dark Roast	The aromatic with very browned, toasted character
Sweet Aromatic	The aromatics associated with caramel, vanilla, molasses and fruit
Woody/Hulls/Skin	The aromatics associated with base peanut character (absence of fragrant top notes) and related to dry wood, peanut hulls and skin
Cardboard	The aromatics associated with oxidized fats and oils and reminiscent of cardboard
Painty	The aromatic associated with linseed oil and oil based paint
Earthy/Musty/Wet Dirt	The aromatic associated with wet dirt and mulch
Plastic Chemical	The aromatic associated with plastic and burnt plastics

<b>Attribute</b>	<b>Definition</b>
Metallic	The chemical feeling factor on the tongue described as flat, metallic and associated with iron and copper
Fruity Fermented	The aromatic associated with over ripe fruit or fermented vegetation
Sweet	The taste associated with sugars
Sour	The taste associated with acids
Salty	The taste associated with sodium ions
Bitter	The taste associated with bitter agents as caffeine or quinine
Astringent	The chemical feeling factor described as puckering/dry and associated with tannins or alum

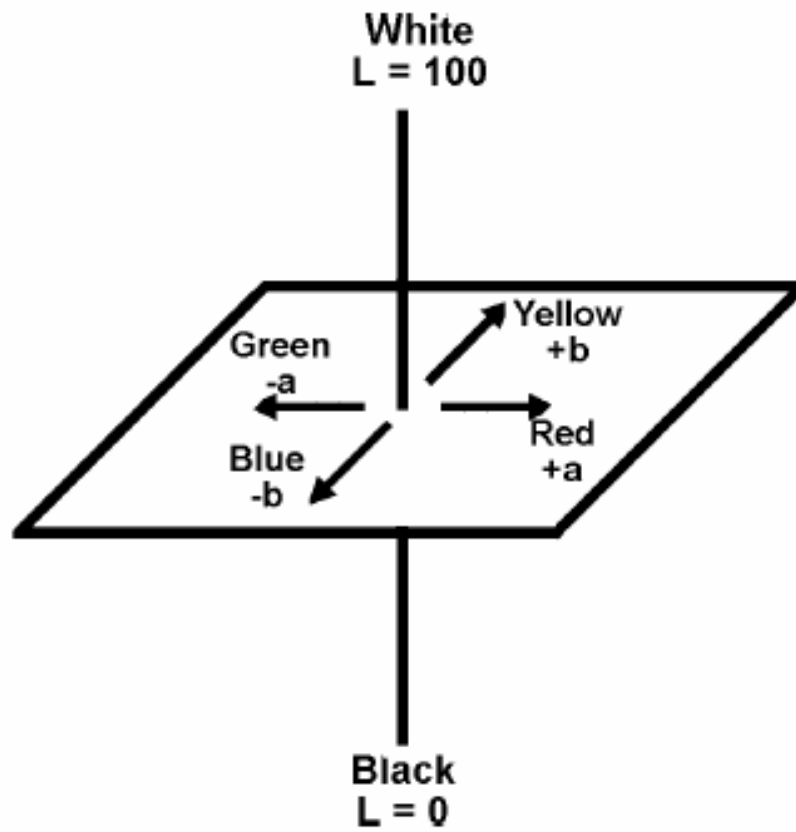


Figure 1. Hunter lab color system

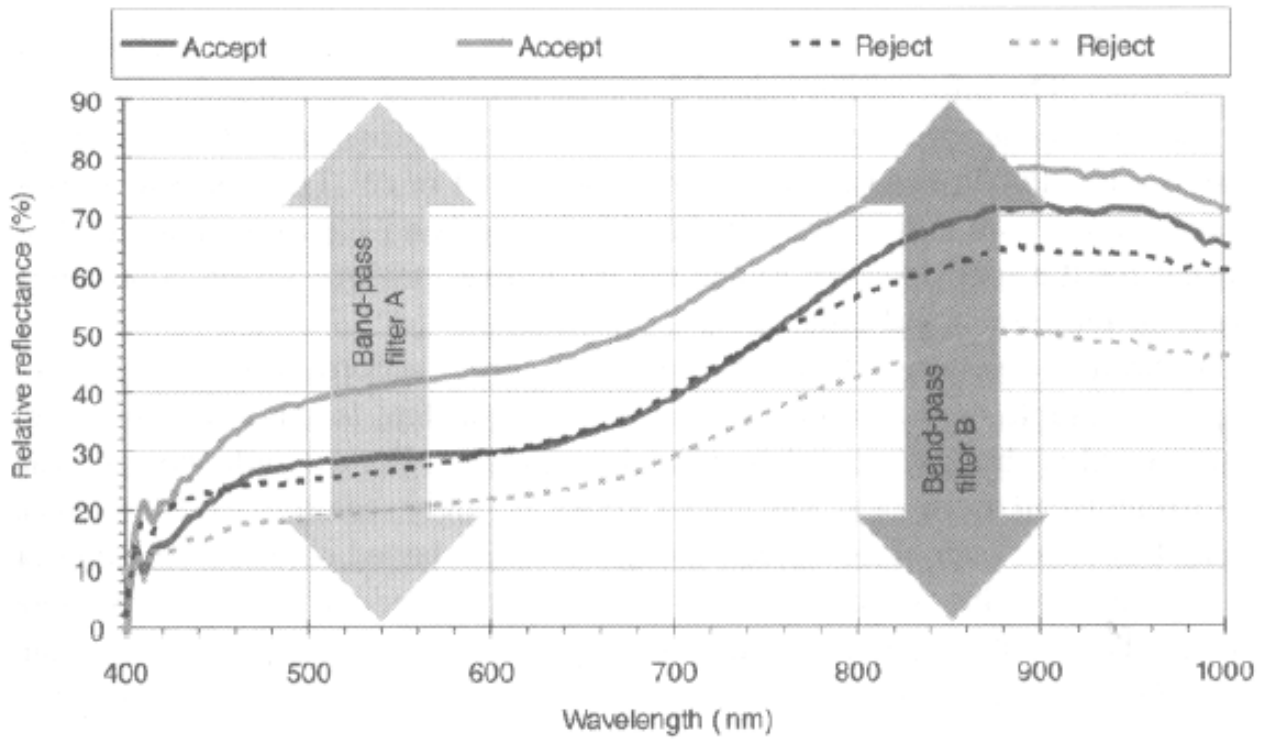


Figure 2. Spectral curves in bichromatic sorting. (Bee and Honeywood, 2002).

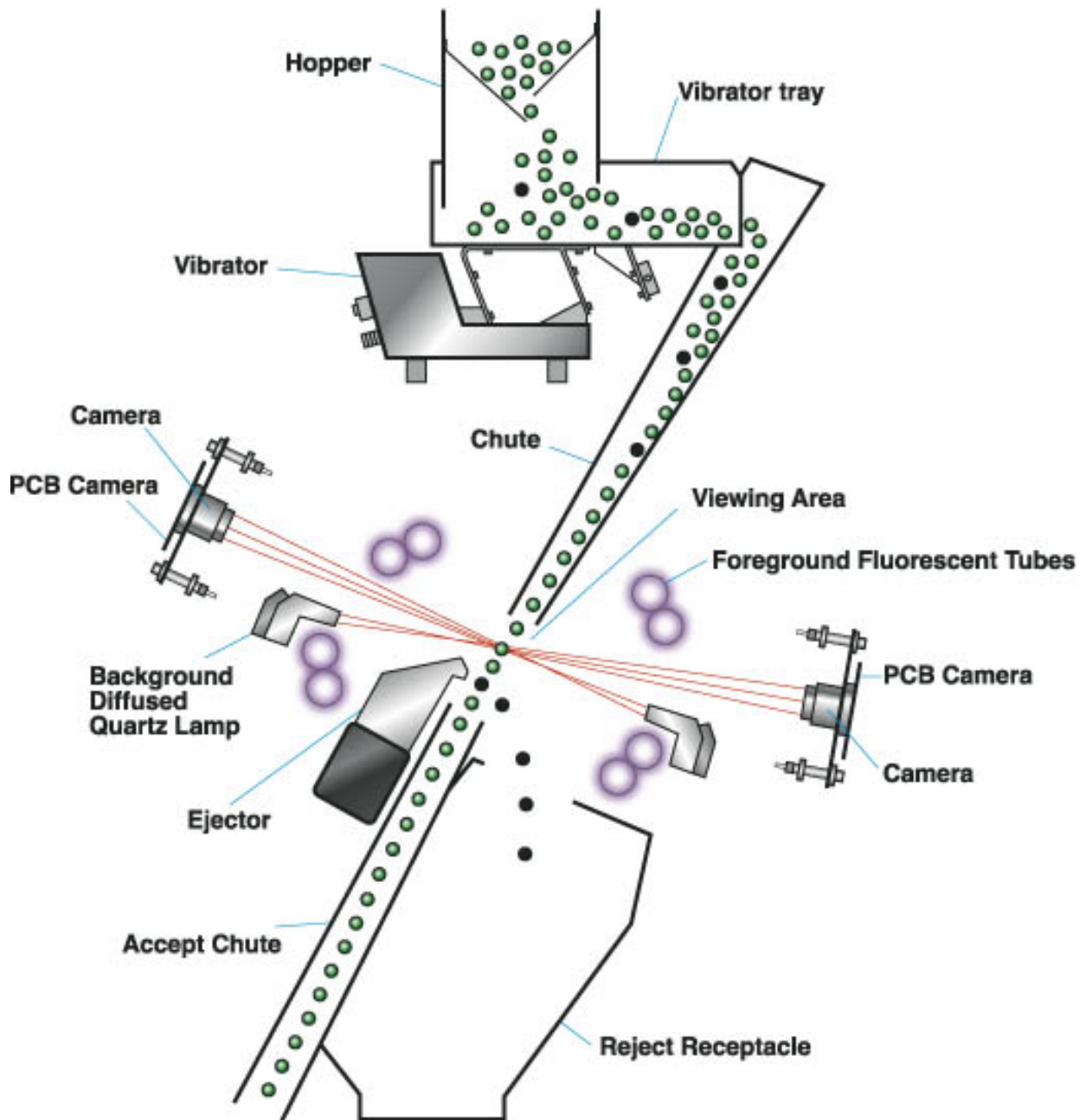


Figure 3. Schematic layout of a typical color-sorting machine (Sortex, 2003)



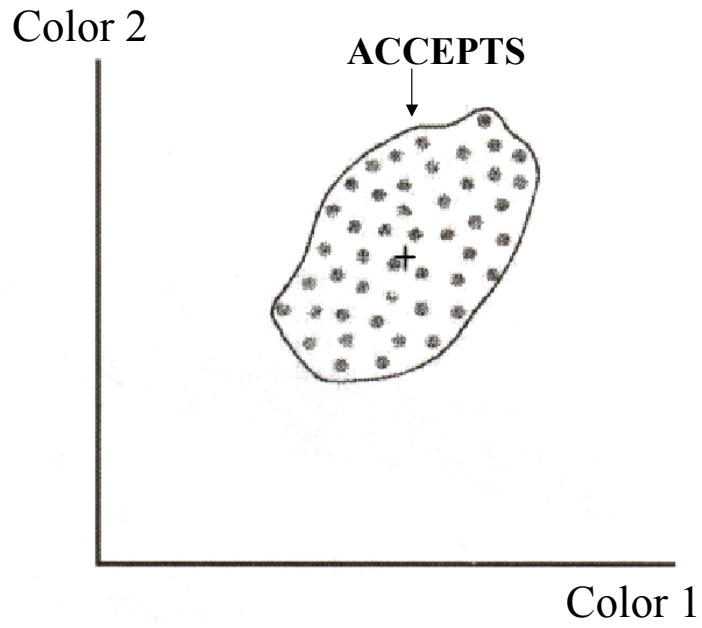


Figure 4. A bichromatic color map representing the distribution of color 1 versus color 2 (Bee and Honeywood, 2002).

CHAPTER 2

**REDUCTION OF FRUITY FERMENTED OFF-FLAVOR BY COLOR SORTING OF  
ROASTED PEANUTS**

## 2.1 Abstract

All big peanuts are not mature and all small peanuts are not immature because of the indeterminate flowering habit of the peanut plant. The relative percentages of peanuts from each maturity class influence lot characteristics such as flavor/off-flavor potential, roast color variation and storability. Peanuts from immature classes roast darker and have potential for more fruity fermented off-flavor and less roast peanutty flavor than mature peanuts of the same size. In 2003, peanuts from many West Texas locations were found to contain unusually high fruity fermented off-flavor characteristic presumably because of drought conditions during maturation (June –August), which delayed maturation and high temperatures ( $>35^{\circ}\text{C}$ ) during harvest (October).

The objective of this study was to determine the effectiveness of high-speed color sorting for reduction of fruity fermented off-flavor in roasted peanuts.

Peanuts of Flavor Runner-458 var. from 2002 and 2003 crop years identified to have fruity fermented off-flavor were roasted to a Hunter L of  $50 \pm 1$  and color sorted to remove successively higher percentages (5-40 %) of darker peanuts (rejects) from the lighter peanuts (accepts). A highly trained descriptive sensory panel evaluated the unsorted and the color sorted fractions for all peanut flavor attributes. Statistical analysis ( $p < 0.0001$ ) indicated that the highest score (3.1) for fruity fermented off-flavor and lowest score (3.7) for roast peanutty flavor were associated with the first reject fraction (7% of darkest peanuts) from the 2003 crop. The third accept fraction formed by the removal of 20-40% darker peanuts scored highest for roast peanutty flavor. A reduction in the intensity of fruity fermented off flavor

from 2.40 (unsorted) to 0.48 (third accept) in the 2002 crop and from 2.76 (unsorted) to 0.41 (third accept) in the 2003 crop resulted from color sorting.

Analysis of peanuts from the 2002 crop demonstrated that removal of dark peanuts (5-20 %) did not significantly improve the shelf life of the lighter colored peanuts possibly due to the high O/L ratio of this variety. Chemical analysis demonstrated that the first 'reject' with 5-7% of darkest peanuts from both 2002 and 2003 crops had significantly lower oil content (45-46%), higher free fatty acid (0.22-0.26 %) and lower O/L ratio (11.48-11.58). This suggests that peanuts with relative higher immaturity are less mature in their biochemical composition.

The results indicated that fruity fermented off-flavor decreased with successively higher percentage removal of darker-roasted, immature peanuts. High-speed color sorting technology provides a method of remediation of peanuts, which have fruity fermented off-flavor.

## 2.2 Introduction

The unique flavor of roasted peanuts is the basis for the multi-billion dollar peanut industry. Consumers have become more stringent in their demand for high quality peanuts free of chemical residues, toxins and undesirable flavors (American Peanut Council, 2003, Sanders *et al.*, 1989 a). The overall sensory quality of roasted peanuts is described by intensities of desirable flavors such as roasted peanutty and sweet aromatic or undesirable off-flavors such as fruity fermented, painty and bitter (Johnsen *et al.*, 1988). Flavor and quality of roasted peanuts are influenced by a multitude of complex interacting factors. There are uncontrollable factors such as environmental conditions, seed maturity, seed composition and the field-curing process that may cause the flavor quality of the peanuts to vary outside acceptable ranges (Bland and Lax, 2000; Sanders *et al.*, 1982, 1989 a, b; Pattee *et al.*, 1974, 1981).

The peanut plant has an indeterminate flowering habit, which results in pods of various maturities at optimum harvest (Sanders, 1989 b). According to Sanders (1989 b) the peanut size-maturity relationship is not absolute and peanuts of different maturities may be commercially sized together. Total oil, protein and carbohydrate composition change with maturity (Mason *et al.*, 1969; Oupadissakoon and Young, 1984; Sanders, 1980 a; Sanders *et al.* 1982). Maturity differences are perhaps most apparent in large vs. small peanuts (Pattee *et al.*, 1982) but a maturity distribution exists in all commercially sized peanuts (Sanders *et al.*, 1987; Williams *et al.*; 1987). Sanders *et al.*, (1989 b) reported that seeds from mature pods in medium grade size peanuts have greater flavor potential than those from immature pods. Immature peanuts roast darker under similar roasting conditions, have less roast

peanutty flavor and are more likely to develop fruity–fermented off flavor notes (Sanders *et al.*, 1989).

During curing, the moisture level of peanuts is reduced from about 50% in freshly dug peanuts to approximately 10% before storage. Harvested peanuts are subjected to field drying and mechanical drying, or a combination of both. The production of off-flavor due to curing methods has been the focus of research since the development of artificial drying techniques in the early 1950s. Bailey and co-workers (1954) and Beasley and Dickens (1963) showed that the high temperature curing off-flavor produced in immature peanuts was significantly higher at temperatures in excess of 35 °C. The study by Whitaker and Dickens (1964) proved that high-temperature curing caused oxygen depletion and induced anaerobic respiration in peanuts. High temperature curing off-flavor or fruity fermented off-flavor occurred as a result of anaerobic respiration (Beasley and Dickens; 1963, Whitaker and Dickens; 1964, Whitaker *et al.*, 1974). Pattee *et al.*, (1965), Singleton *et al.*, (1971) and Sanders and co-workers (1989) found similar sensory results. Didzbalis *et al.*, (2004) identified compounds that caused the fruity fermented off-flavor as fruity esters and short chain organic acids in addition to others like ethanol, ethyl acetate, formaldehyde, acetone, butanal, hexanal and acetaldehyde.

Since immature peanuts develop a darker roast color, high-speed color-sorting technology should be useful in reduction of the fruity fermented off-flavor in peanut lots. Automatic machine vision systems have been successfully used for objective measurement of various agricultural (He *et al.*, 1998; Li and Wang, 1999) and food products (Sun, 2000). Color sorters are used commercially to remove discolored peanuts (Sortex Ltd., 2002).

The objectives of this study were to remove increasingly higher percentages of darker roasted peanuts from medium grade size peanut lots and evaluate the flavor, shelf life and chemical composition of the color sorted peanuts to provide important information on high speed color sorting technology that can be implemented for the remediation of fruity fermented peanut lots.

## **2.3 Materials and Methods**

### **2.3.1 Preparation**

#### **Peanut Source**

Two fruity fermented lots of Flavor Runner 458 var. (*Arachis hypogaea* L.) were obtained from the 2002 and 2003 crop years, from West Texas. All the peanuts were medium commercial grade size having width less than 8.3 mm but greater than 7.1 mm.

#### **Storage**

Peanuts were stored at a temperature of  $7.0 \pm 0.2$  ° C and relative humidity of  $69.0 \pm 0.2\%$  in tight-lid plastic storage containers.

#### **Peanut Roasting**

Approximately 150 lbs. of each fruity fermented peanut lot were dry roasted on a conveyor belt in a gas fired, thermostat controlled Aeroglide Roaster (Aeroglide Corp, Raleigh NC) at  $348^{\circ} \text{F} \pm 2$  to achieve a target Hunter L value of  $49.0 \pm 1.0$ . Samples were periodically taken during roasting to measure roast color using a Hunter Lab DP 9000 (Hunter Associates Laboratory, Resto, VA). Conveyor belt speed was adjusted as needed to maintain the target Hunter L value throughout the roasting process. The peanuts were cooled with forced room temperature air and each lot was subdivided into three sub lots. A portion of each sub lot was color sorted to form three ‘accepts’ and three ‘reject’ fractions using a Sortex Color Sorter. All color sorted (140 lbs.) and the unsorted roasted peanuts (10 lbs.) were stored in glass jars at  $30^{\circ}\text{C}$  in a Fisher Isotemp Incubator, model 304R (Fisher Laboratory Products, Pittsburgh, PA). Samples were taken from storage after 0, 1, 2, 4, 8, and 12 weeks.



### **Sortex 3000 Color Sorter**

All roasted peanuts were color sorted using a Sortex 3000 color sorter (Figure 3). The Sortex 3000 was particularly suited for sorting low volumes of high-value commodities, since the output and efficiency of the machine is very high (Sortex Ltd., 2002). The feed system had an inclined chute, which aligned the peanuts and ensured that the product passed through the machine at a constant speed. The optical system (CCD camera technology) combined with fast, precise ejectors segregated darker roast colored peanuts from the lighter ones. The sorter had two single channels and three sensors surrounding each channel. 3 cameras set at 120° to each other, providing an all-round view, inspected a single row of roasted peanuts. The Sortex 3000 employed a bi-chromatic sorting method, which compared the intensity of light reflected in 2 of the primary wavebands (red/green or red/blue). This allowed the camera to discriminate by color as well as by intensity (Bee and Honeywood, 2002). The intensity of the light reflected off each peanut was measured allowing those that appeared darker than normal (average Hunter L value = 50) to be identified as a reject product. The ejector used short blasts of compressed air to remove the undesirable peanuts (rejects) from the main stream of peanuts. The accepts and the rejects were collected into separate receptacles. The color sorting capacity of the machine was approximately 600 kg of peanuts per hour (Sortex Ltd, 2002).

### **Color Sorting**

After keeping 10 lbs. aside (unsorted roasted peanuts), 140 lbs. of the remaining roasted peanuts in both fruity fermented lots were divided into three sub lots. Each sub lot

was color sorted to remove progressively higher percentage of dark peanuts. The sensitivity parameter for color sorting the first lot was adjusted to remove 5-7 % by weight of the darkest colored peanuts to form the first reject and a corresponding fraction of lighter peanuts, the first accept. It was essential to have 7-10 lbs. of each reject and accept sample for the purpose of experimental analyses. Sensitivity of the machine was increased by approximately 10-15 % and 25-30 % in color sorting of the next two lots to increase the percentage of dark peanuts rejected. Color difference between the accepts and the corresponding rejects were determined with a Hunter L colorimeter after each sort. Single seed color of randomly selected 400 peanuts from the unsorted roasted peanuts was analyzed. A preliminary sensory test evaluated the intensity of fruity fermented off-flavor in the color distribution of the unsorted peanuts. This helped to ascertain the sensitivity level of color sorting in the three sub lots.

Before color sorting the peanut lots, the color sorter was calibrated with hand sorted roasted peanuts corresponding in color to the desired accept and the reject colors. Adjusting the contour of the bichromatic color map helped to modify the sensitivity of the machine to control the amount of rejects during each color sort. Fine-tuning the map decreased the loss of accept peanuts by preventing their accumulation in the receptacle collecting the reject peanuts.

### **2.3.2 Analysis**

## **Hunter L Color**

The Hunter Lab Color measurement closely matches the degree of perceived color difference by humans. L is the lightness variable on a scale of 0-100; a and b are the chromaticity coordinates. The color was determined of the unsorted and each of the accept and reject fractions using the Hunter Lab DP 9000 (Hunter Associates Laboratory, Resto, VA). Peanuts were placed in a 3-inch diameter petri dish and color measurements were taken in triplicate for each sample after remixing the same peanuts in the petri dish. Hunter L value was also determined for samples after they were made into paste. The Hunter L colorimeter was calibrated with white and black calibration plates and measurements of samples followed immediately after calibration.

## **Moisture Determination**

Moisture content of the raw, unsorted sample and all the color-sorted fractions was determined using the method described by the ASAE Yearbook of Standards S410.1 (Young *et al.*, 1982 b). Approximately 20g of each sample was ground in a Krups household coffee mill (Krups North America, Closter, NJ) for 2-3 minutes. Approximately 5 g of each sample of ground peanut was placed in previously weighed 1-inch diameter aluminum pans and heated for 6 hours at 140 °F. The samples were cooled to ambient temperature and weighed again. Each sample was analyzed in triplicate.

## **Oxidative Stability Index (OSI) and Peroxide Value (PV)**

Approximately 85g of each peanut sample was ground in a Krups household coffee mill (Krups North America, Closter, NJ) and subsequently wrapped in a double layer of cheesecloth. Oil was pressed from the samples for 10 minutes at 20,000 psi using a hydraulic Carver Laboratory Press (Fred S Carver, Inc., Summit, NJ). The oil was filtered through

glass wool and  $5.0 \pm 0.2$  g was weighed into disposable glass tubes for OSI analysis (AOCS, 1992) using an Oil Stability Instrument (Omnion, Inc., Rockland, MA). The tubes were sealed with two hole rubber stoppers and placed in  $110^{\circ}$  C heating blocks on the oil stability instrument. A disposable Pasteur pipette was inserted through the stopper and into the oil through a tube in the rubber stopper. A second pipette inserted into the glass tube was connected via plastic tubing to a second glass tube containing 50 ml of deionized water. Compressed air was purged through the oil at 38 psi and as the oil oxidized volatile compounds were transferred into the water and the change in conductivity in the water was determined with the conductivity sensor connected to a data acquisition system. OSI for each sample was performed in duplicate. OSI was determined by the acquisition software to be the number of hours until the rate of increase in conductivity became exponential.

Peroxide value was determined according to AOAC method 965.3 (AOAC, 1995) using  $5.0 \pm 0.2$  g of filtered oil weighed into an Erlenmeyer flask. The oil was dissolved in 30.0 mL of an acetic acid / chloroform (3:2 v/v) solution and 0.5 mL of a saturated potassium iodide solution was added. The sample was shaken for 1 minute. 30 mL of deionized water and 0.5 mL of 1% starch solution were added into the flask. The solution was then titrated with sodium thiosulfate, at concentrations of 0.001 N, 0.01 N or 0.1N, until a change in color was perceived. PV, performed in duplicate, was reported as milliequivalent of peroxide/kg of oil. Starch was purchased from J.T. Baker chemical Co. (Phillipsburg, NJ) and all other chemicals were purchased from Fisher Scientific, Co. (Pittsburgh, PA).

### **Carbohydrate Analysis**

Samples were first defatted by Soxhlet extraction with 99% hexane/1% ethyl ether according to Oupadissakoon *et al.*, (1980). A 30-50 mg sample of finely ground defatted

peanut meal was placed into a 25 mL screw capped tube. 15 mL of extraction solvent and 1 mL of internal standard mix were added. The extraction solvent was prepared with 600 mL of methanol (Fisher Cat No. A-452-4), 250 mL of chloroform (Fisher cat No. C297-4) and 150 mL of water. The internal standard solution was prepared with 800-ppm lactose (Aldrich Cat No. 25,971-3) and 400 ppm cellobiose (Fluka Chemie, Steinheim, Germany, Cat No.22150) dissolved in water by sonication in a 100 mL volumetric flask. Each sample mixture was vortexed for 1 minute and sonicated for 20 minutes. The contents were then centrifuged in a IEC Model K centrifuge. The solution was decanted into a 50 mL beaker and the solid pellet was discarded. The solution was left in a fume hood to evaporate overnight. 1 mL of water was added to the beaker and swirled / sonicated to dissolve the residue. The solution was stored in a 2 mL screw capped vial. 50  $\mu$ L of solution was withdrawn, diluted to 2 mL with water and passed through a Dionex On Guard-H filter fitted to a syringe. After discarding the first mL, the second mL was collected in an HPLC auto sampler vial. The HPLC standard solution consisted of 5 mg of myo-inositol (Sigma Cat No. I-5125), 10 mg of glucose (Sigma Cat No. G-5250), 15 mg of fructose (Fisher Cat No. L-95), 50 mg of sucrose (Fisher cat No. S-5), 20 mg of raffinose ((Aldrich Cat No. 20,667-9) and 20 mg of stachyose (Sigma Cat No. S-4001) dissolved in 30 mL of water. The HPLC standard was prepared by mixing 9.5 mL of water with 250  $\mu$ L of internal standard solution and 250  $\mu$ L of standard solution and the standard was used at frequent intervals during the experiment.

All the extracts were analyzed by high performance liquid chromatography (HPLC) using a Dionex BioLc (Dionex Corporation, Sunnyvale, CA) at a controlled temperature of 25 °C. The system consisted of a gradient pump, an auto sampler and a pulsed amperometric detector (PAD). The mobile phase was 200 mM NaOH (Fisher Cat No. SS254-1) at an

isocratic flow rate of 1.0 mL/min. The column used was a Dionex PA-1, 250 mm in length and 4mm i.d., fitted with a Dionex PA-1 Guard column. The detector was programmed to run a quadruple waveform as recommended by the manufacturer. A shift in the detector range was programmed from 100 to 500 nC between 4 and 7 minutes to allow sucrose to be quantified along with other sugars. A 10  $\mu$ L sample was injected using a 25  $\mu$ L or smaller sample loop. The lactose internal standard was used to quantify sucrose. Cellobiose was used as the standard for the other known carbohydrate components. A quantitative value for each unknown carbohydrate was obtained by constructing a ratio of the peak height of the unknown to the cellobiose standard peak height. All internal and reference carbohydrates were obtained from Sigma Chemical Corporation (St. Louis, MO) except cellobiose

### **Fatty Acid Profile**

The fatty acid analysis was based on the method developed by Bannon *et al.*, in 1982. 20-30 mg of the oil sample (about 1 drop) was weighed into a 50-ml screw capped tube. One mL of 0.5 M methanolic (Fisher Cat No. A-452-4) potassium hydroxide solution (Fisher Cat No. P-250) was added for the saponification of glycerides. The tube was then heated for 5 minutes in a water bath at 80°C and continued for ten minutes after the addition of 1 mL of boron trifluoride (Sigma, Cat No.B1252) in 14% methanolic solution. 1 mL of water and 1 mL of hexane (Optima grade, Fisher Cat No. H302-4) were added after the tubes cooled slightly. Each solution was vortexed for 30 seconds and then allowed to settle into two phases at room temperature. An aliquot of the hexane layer was transferred into a vial and a small amount of anhydrous sodium sulphate (Sigma cat No. 238597) was added. The prepared hexane solution was used for direct injection into a gas chromatograph (GC). The fatty acid methyl ester standards, Kel-Fim FAME-5 Standard (Matreya Inc., Pleasant Gap,

PA, Cat No.4210) and GLC-21 Standard (Nu-Check Standards) were used for identification and comparison of fatty acids present in the test samples.

The fatty acid methyl esters (FAME) were analyzed with a Perkin Elmer Autosampler XL system (Perkin Elmer Instruments, Norwalk, CN) equipped with a flame ionization detector (FID) and a capillary column containing 70% cyanopropyl polysilphenylene-siloxane as the stationary phase (30 m length, 0.25 mm i.d., 0.25  $\mu\text{m}$  film thickness). Helium at 20 psi (1.85 mL/min) was used as the carrier gas. Hydrogen flow was set to 45 ml  $\text{min}^{-1}$  and the airflow was fixed at 450 ml  $\text{min}^{-1}$ . The split flow ratio was 76.9 mL/minute. The temperature of both the injector and the detector was 265 °C. A temperature program was used with an initial oven temperature of 60° C held for 2 min, which was increased to 180°C at 10°C  $\text{min}^{-1}$ , and then programmed to a final temperature of 235°C at 4°C  $\text{min}^{-1}$ . The amount of sample injected was 1  $\mu\text{l}$ . The total amount of palmitic (16:0), stearic (18:0), oleic (18:1), linoleic (18:2), linolenic (18:3), arachidic (20:0), eicosenoic, (20:1), behenic (22:0) and lignoceric (24:0) acids were calculated by determining the percent area of each FAME. The mean value of three replicates was used to determine the concentration of each fatty acid. Peaks in ascending retention time order were as follows: C16:0, C18:0, C18: 1, C18: 2, C18: 3, C20:0, C20: 1, C22:0, C24:0.).

### **Free Fatty Acid Analysis**

Oil was pressed from the samples using a hydraulic Carver Laboratory Press (Fred S Carver, Inc., Summit, NJ) for 10 minutes at 20,000 psi. The oil was filtered through glass wool and approximately  $7.0 \pm .05$  g of oil was weighed into a 250 mL Erlenmeyer flask to which was added 50 mL of neutralized isopropyl alcohol (99% neutralized with NaOH) and 1 mL of phenolphthalein indicator solution (1% w/v in 95% alcohol). The solution was

titrated with 0.25 to 0.0025 N NaOH and shaken vigorously until a faint and persistent pink color was obtained. The phenolphthalein imparted a pinkish hue to the solution at pH 8-10. The % free fatty acid was equal to the number of mL of 0.25 N NaOH used in the titration. When a different normality of NaOH was used then the number was calculated as follows:

$$\text{FFA} = (\text{normality used} / 0.25) * (\text{mL used in titration})$$

The method of free fatty acid analysis was obtained from A.O.C.S. Official Method Aa 6-38 by Booker (1992).

### **Single Seed Color Distribution**

A Minolta Chroma Meter CR-300 (Minolta Corporation, Mississauga, Ontario, Canada) was used to determine the single seed color of 400 individual peanuts randomly selected from each sample. The colorimeter consisted of a compact tristimulus color analyzer for measuring reflective colors of surfaces. The machine had an 8 mm-diameter measuring area (head) and used a diffuse illumination and a 0° viewing angle. A pulsed xenon arc lamp provided illumination on the sample surface. Six high-sensitivity silicon photocells were used to measure both incident light and reflected light. The instrument displayed absolute measurement of Hunter L value for each peanut. Mostly whole peanuts were selected for color evaluation. In case of split peanuts the color of the curved side was recorded.

### **Total Oil content (Nuclear Magnetic Resonance)**

A Maran Ultra (Resonance Instruments Ltd., Whitney, Oxfordshire, United Kingdom) operating at 11 MHz was used to determine total oil and moisture content of approximately 10 g of each sample by pulsed nuclear magnetic resonance (AOCS Official Method Ak 5-01, 2001). An alternating electromagnetic field applied in the form of an intense 90° radio frequency (RF) pulse was used to excite all the hydrogen nuclei. The free



induction decay (FID) was recorded following the 90° pulse. The maximum amplitude of the signal was proportional to the total number of protons from the water and oil phases of the sample. The application of a second RF pulse produced a spin-echo signal when only the signal from the oil phase contributed to the FID. The difference between the two amplitudes was calculated to be proportional to the moisture content. Once the apparatus was suitably calibrated, the automatic conversion of measured signals estimated the percentages of oil and moisture in each test sample.

### **Descriptive Sensory Analysis**

The unsorted, all ‘accept’ samples and the rejects from the fruity fermented lot of the 2003 crop only were ground into a paste using a Cuisinart Little Pro Plus food processor (Cuisinart Corp., East Windsor, NJ). To maintain paste temperature below 32°C, a grind – cool procedure was utilized (Sanders *et al.*, 1989 b, c) The procedure limited grinding to two, 2 minute grinds with one minute cooling between each one, followed by several 1 minute grinds with 30 seconds cooling between grinds until the desired paste consistency was achieved. Peanut pastes were used for sensory analysis to reduce any variability within the sample (Sanders *et al.*, 1989 a). Paste samples were stored at –22°C prior to and after pasting and removed from the freezer 8-10 hours before descriptive sensory analysis to equilibrate to room temperature. Each peanut paste sample was coded with randomly generated 3-digit numbers. A highly trained descriptive sensory panel consisting of 9-10 panelists evaluated each sample twice which were offered in a random manner. The Spectrum ® method and the peanut lexicon developed by Johnsen *et al.*, (1988) and Sanders *et al.*, (1989 b) were utilized to evaluate all the flavor and off-flavor descriptors. A reference paste with known intensities for the peanut flavor descriptors was provided during each evaluation. Water and salt-less

crackers were provided between samples. The intensity of descriptors such as roasted peanutty, sweet aromatic, dark roast, raw/ beany, woody/hulls/skins, musty, fruity /fermented, painty, plastic chemical, sweet, bitter, and astringency were the attributes evaluated on a 0-15 point Spectrum intensity scale (Meilgaard *et al.*, 1999) (Table 1).

### **2.3.3 Statistics**

All the analytical experiments were conducted in duplicate or triplicate. Means with standard deviation were reported. Analysis of variance (ANOVA) was applied to analyze the variance in the pooled data of various analyses (SAS Institute Inc., Cary, NC).

## 2.4 Results and Discussion

### Color Distribution

The roast color of peanuts has important quality implications. It is associated with roast peanutty flavor and aroma, which develop during roasting (Pattee *et al.*, 1991). There is evidence of variability in roast color, flavor, storability and other quality characteristics of individual seeds within commercial sized peanut lots (Sanders, 1989 a; Sanders and Bett, 1995). This variability is attributed to variable maturity distributions (percentage of each maturity class) that exist in sized lots (Sanders *et al.*, 1989 a).

Hunter L values are the primary color parameter for roasted peanuts. A Hunter L value of  $49 \pm 1$  is considered as a medium roast color and is associated with optimum roasted peanut flavor intensity (Pattee *et al.*, 1991). Sanders *et al.*, (1989 a) reported that for peanuts of the same commercial size, immature peanuts roasted darker (lower Hunter L value) than mature peanuts for a given duration of roasting period. Williams *et al.* (1987) and Sanders (1989 b) reported that higher percentage of immature peanuts increased the potential for a negative effect in any peanut lot.

The roasted peanuts of fruity fermented lots from 2002 and 2003 crops had a color distribution (Hunter L) that ranged from 34 to 70 (Figure 2.1). Roasted peanuts from both lots were sorted at three color sorter sensitivity levels and successively higher percentages of rejects were removed in each sort (Figure 2.2). Figure 2.3 is a visual demonstration of the unsorted and all color sorted accepts (lighter fractions) and rejects (corresponding darker fractions) produced by color sorting the 2003 fruity fermented roasted peanut lot at three successively higher color sorter sensitivities. In the first color sort, 5-7 % (by weight) of the

darkest peanuts were removed as rejects at a preset sensitivity level of 50-65. The mean Hunter L value of the first reject from both fruity fermented lots was  $42 \pm 1$  (Table 2.1).

The first accept fraction consisted of 93-95 % of the remaining peanuts and had a mean Hunter L value of  $51 \pm 0.5$ . At a higher sensitivity level (65-80), 12-24% of the darker peanuts were removed and the reject and accept fractions had Hunter L values of  $45 \pm 1$  and  $51 \pm 1$  respectively. In the third color sort, 20-40 % of dark peanuts in the two fruity fermented lots using a color sorter sensitivity level of 80-95. The mean Hunter L values of the third reject was  $46 \pm 1$  and of the third accept was  $53 \pm 1$  (Table 2.1). In each color sort, the color of the accept peanuts had a higher Hunter L reading than the corresponding reject peanuts by 6-8 units. The results confirm the observation made by Sanders *et al.*, (1989 a, b) that when similar peanut color ( $49 \pm 1$ ) was used as roast objective, mature peanuts roasted lighter (higher Hunter L value) than immature peanuts. An examination of commercially roasted whole peanuts will show a distribution of roast colors associated with the maturity distribution of the lot (Sanders *et al.*, 1989 a).

The weight percentages of accept and reject fractions produced by color sorting roasted peanuts depended upon the sensitivity level of the color sorter and the color distribution (percentage of each color) within the roasted peanut lots. The frequency distribution of roast colors of 400 peanuts picked in a random manner from each accept and reject fraction was determined for both fruity fermented lots (Figures 2.4 and 2.5). All rejects contained a higher percentage of dark peanuts. Color sorting at increased sensitivity levels produced larger fractions of rejects. The rejects had a narrow distribution of roast colors compared to the accepts. All accept samples were made up of lighter colored peanuts because with each color sort, peanuts with lower Hunter L values were removed. However, some

darker peanuts in the accepts and some lighter peanuts in the rejects were observed which could be attributed to error in machine performance or less rigid calibration. Although color sorting at increased sensitivity resulted in larger reject fractions, there was also an increase in the loss of desirable product (accept peanuts).

### **Compositional Analyses**

Young *et al.*, (1972, 1974), Pattee *et al.*, (1974) and Sanders *et al.*, (1982, 1989 b) have reported the influence of maturity on peanut chemical composition, oil stability and other quality factors. The relative weight percent of moisture and lipid content in the accepts and rejects produced by color sorting roasted peanuts from lots of 2002 and 2003 are presented in Tables 2.2 and 2.3.

In the 2003 crop, moisture content of the rejects (1.36-1.38 %) was slightly higher than that of the accepts (1.23-1.24). The results are in agreement with the observation made by Kim and Hung (1991) who reported lower moisture content in mature peanuts at harvest than in immature ones. However, the second and third rejects from 2002 lot had lower moisture content than the second and third accepts respectively. Overall, very small differences were observed in the moisture content for all the color sorted fractions in both lots.

Pattee *et al.*, (1974) and Sanders *et al.*, (1982) observed that oil content increased from immature peanuts to nearly mature peanuts and then decreased slightly in the most mature peanuts. The oil content of the accept fractions in both fruity fermented lots was between 48.45-49.4 % and was significantly higher than the oil content of all rejects (Tables 2.2 and 2.3). The first reject with maximum percent of darkest peanuts had the lowest oil

content in both lots from 2002 (46.24 %) and 2003 (45.94%). The difference in the oil content between the accepts and rejects suggested that mature peanuts were more prevalent in the accepts. Sanders *et al.*, (1980 a) reported that the dry weight of the peanut increased rapidly during maturity stages and these increases corresponded to an increase in oil content per seed. Sanders *et al.*, (1982) who determined progressive changes in oil content and composition in the Pod Maturity Profile (PMP) stages, further supported the data in this study.

Sanders *et al.*, (1980 b) reported that fractionation of the total oils from seeds at eight maturity stages (PMP stages) revealed that all lipid classes changed somewhat with maturity. The free fatty acid (FFA) content ranged between 0.14 % - 0.26 % in the unsorted and all color sorted samples of both fruity fermented lots (Tables 2.2 and 2.3). FFA was significantly higher (0.22 % and 0.26%) in the first reject than in the first accept (0.16% and 0.14%) in 2002 and 2003 respectively. However, in both fruity fermented lots, the accepts and rejects of the second and third color sort were not significantly different in FFA content. Overall, the accept samples had lower values of free fatty acids and this data is in agreement with the result reported by Sanders *et al.*, (1982) of a decreasing trend of FFA with increasing maturity. The second and third rejects produced at higher color sorter sensitivity levels were larger fractions by weight and were diluted with mature peanuts.

The 2002 and 2003 fruity fermented lots were a high oleic genotype and the oleic/linoleic ratio (O/L) ranged between 11.48 -12.99 for all samples (Tables 2.2 and 2.3). Linoleic acid is polyunsaturated and an inverse relationship exists between linoleic acid and oil stability (Brown *et al.*, 1975; Fore *et al.*, 1953; Braddock *et al.*, 1995; Holley and Hammons, 1968; O'Keefe *et al.*, 1993). According to Sanders *et al.*, (1982) peanuts with

high O/L ratios have slower lipid degradation and therefore better peanut oil stability than peanuts of normal genotype. The O/L ratios of the first reject in the 2002 crop (11.58) and 2003 crop (11.48) were the lowest among all the color-sorted fractions. The O/L ratio was not significantly different among the accepts and rejects of the 2003 lot. However, there was conflicting data between the accept and reject in the first and third color sort of the 2002 crop. Worthington (1969), Young *et al.*, (1972), Sanders (1980) and Kim and Hung (1991) examined peanuts from normal O/L ratio genotypes and reported that the O/L ratio increased with maturity of the seeds. Overall, the first reject fraction showed lower oil content, lower O/L ratio and higher free fatty acid (2002 and 2003 crops) and higher moisture content (2003 crop only) indicating the presence of a higher percentage of immature peanuts. These results were supported by previous studies (Sanders *et al.*, 1980 and 1982) Peanut maturity is significantly related to biochemical composition and therefore overall quality (Sanders *et al.*, 1989 b; Sanders and Bett, 1995; Bett and Boylston, 1992). The application of color sorting to reduce the percentage of immature peanuts in any peanut lot may improve lot characteristics.

Many researchers have reported conflicting trends for changes in fatty acid profiles as seeds mature. Increase in oleic (18:1) and decreases in palmitic (16:1), linoleic (18:2), arachidic (20:0), eicosenoic (20:1) behenic (22:0) and lignoceric (24:0) acids with seed maturity have been observed by Worthington (1969), Young *et al.*, (1972), Cobb and Johnson (1974) and Sanders *et al.*, (1982). However, a decrease in oleic and an increase in linoleic acid were reported by Lynd and Ansman (1989) and Hashim *et al.*, (1993). In two studies by Mozingo *et al.*, (1985, 1988a) stearic (18:0), oleic and arachidic increased while

the other fatty acids decreased with maturity. Kim and Hung (1991) noted an increase in stearic and oleic acids and no change in palmitic acid.

Palmitic, stearic, oleic and linoleic acids made up more than 90% of fatty acids in both peanut lots (Tables 2.4 and 2.5). In the 2002 crop, palmitic acid was significantly higher in the unsorted and accepts (5.87-5.98%) than in the rejects (5.43- 5.47%). A similar trend was observed in the 2003 crop, where the second and third accepts had significantly higher content of palmitic acid (5.83 and 5.91 %) than the rejects (5.54 and 5.44%). Although significant differences were found, the differences were within experimental error of methodology. There were no significant differences in stearic acid among the samples except for the first accept which had the lowest amount (1.45%) in the lot of 2003. The weight percent of oleic acid ranged between 75 and 80 % in both lots. First and second rejects (2002 and 2003 lots) had significantly lower oleic acid (75-78 %) than their corresponding first and second accepts (77.3-79.5 %). However, no significant difference was observed between the third accept and third reject in both peanut lots. This data is in agreement with previous studies which have shown that mature peanuts have higher oleic acid than immature peanuts (Worthington (1969), Young *et al.*, (1972), Cobb and Johnson (1974) and Sanders *et al.*, (1982). Since both lots were of high oleic genotype, linoleic acid was present in much lower quantities (5.9-6.7 %). In the 2002 crop all rejects were consistently higher in eicosenoic (3.18-3.40 %), behenic (2.98-3.09 %) and lignoceric (2.26-2.38 %) fatty acids than those in all accepts. In both peanut lots, the first reject was significantly higher than the first accept in eicosenoic, behenic, and lignoceric fatty acids. The trends observed for these fatty acids were similar to those reported in studies by Worthington (1969), Young *et al.*, (1972), Cobb and Johnson (1974) and Sanders *et al.*, (1982). Overall, the results indicated that color sorting



resulted in relatively small changes in the concentration of various fatty acids in the color-sorted fractions especially in fractions (accepts and rejects) produced at higher color sorter sensitivity. In general, the accept fractions contained more stearic acid and oleic acid and less linoleic, eicosenoic, behenic and lignoceric acids. The results agree with those by Sanders *et al.*, (1982) that peanut oil content and composition are related to maturity.

According to Oupadissakoon *et al.*, (1980) climate, maturity, curing and storage among other factors affect the precursor levels of various chemical components. Basha *et al.*, (1976) reported that the carbohydrate content in immature peanuts of all cultivars declined as they approached maturity. Pattee *et al.*, (1974) observed similar changes and hypothesized that maturing seeds used stored, non-structural carbohydrates as a source of energy for the synthesis of lipids and proteins.

The total sugar content (Tables 2.7 and 2.8) was approximately 120-140 mg/g (2002 lot) and 75.5-101.0 mg/g (2003 lot). All rejects in both lots had significantly higher amounts of inositol and raffinose. In the 2002 lot, glucose and fructose were present in significantly higher amounts in the rejects than in the accepts. Sucrose, the major carbohydrate, was not significantly different in any of the accept vs. reject samples in both lots except it was significantly higher in the second accept (75.9%) than in second reject (2003 lot). Stachyose was significantly higher in the second reject (26.6 %) in 2002 and third reject (18.86 %) in 2003 in comparison to the second and third accepts.

Color sorting of the roasted peanuts did not produce accepts and rejects with significant differences in sucrose or total sugar content. However, the rejects, which had higher percentages of dark peanuts, had higher amounts of fructose, raffinose and inositol. The data agreed with the findings of Newell (1967) who reported that immature peanuts

roasted darker because they had higher amounts of reducing sugars, glucose and fructose, which participate in the browning process (Maillard reaction) during roasting. Although the accepts were lighter peanuts and the rejects had successively higher percentages of dark peanuts in them, the data did not indicate a strong trend of a decrease in carbohydrate content with peanut maturity as reported by Pattee *et al.*, (1974) and Kim and Hung, (1991).

However, the carbohydrate data supported the report by Kim and Hung (1991) that less difference was observed in the chemical composition after the peanuts matured to a certain degree (orange mesocarp color).

### **Sensory evaluation**

According to Sanders (1989 a), maturity distribution influences flavor characteristics based on the percentages of the various maturity classes in a screen-sized lot. Immature peanuts have been shown to have more reactive and less stable components (oil and protein composition, moisture, enzymes) and to possess more potential for off-flavor (Sanders 1989 a, b). Sanders *et al.*, (1989 b) analyzed intensities for flavor descriptors, which were significantly affected by the interaction of curing temperature and maturity. They reported that intensity of roasted peanutty was progressively lower in medium grade size immature peanuts cured with increasingly high temperature air (8.4-16.8°C higher than the ambient temperature). They also reported higher intensities for fruity fermented and bitter in immature peanuts. Pattee *et al.*, (1989) used sized peanuts with increasing headspace volatile concentrations to demonstrate the role of high temperature curing in the inverse relationship of roasted peanutty and fruity fermented flavor attributes.

Descriptive sensory analysis for all flavor descriptors (Tables 2.8 and 2.9) indicated that all accept samples had significantly higher intensities of roasted peanutty; 4.69-4.82

(2002 lot) and 4.26-4.63 (2003 lot). The reject fractions from 2002 lot were not subjected to descriptive sensory analysis. The rejects (2003 lot) had low roasted peanutty scores between 3.77 and 4.02 (Table 2.9). Roasted peanutty flavor was inversely related to the fruity fermented off flavor (Figures 2.6 and 2.7). In the 2003 crop all rejects had significantly higher fruity fermented intensities (2.26-3.11) than all accepts (2.01-0.41) (Table 2.9 and Figure 2.7). Similarly, the accepts in 2002 lot had low fruity fermented intensities (1.40 and 0.48) (Table 2.8 and Figure 2.6). In comparison to the fruity fermented off-flavor intensity (2.76) in unsorted peanuts (2003 lot), the off-flavor was reduced by 25 % (2.07) when 7 % of the darkest peanuts were removed in the first color sort. The off-flavor intensity was further decreased by 70 % in the second color sort (0.83) and by 85 % in the third color sort (0.41), which were produced when 20 and 40 % of dark peanuts were removed (Figure 2.7). The sensory analysis for both peanut lots proved that color sorting of roasted peanuts helped in the remediation of fruity fermented peanuts. The intensity of fruity fermented off-flavor was reduced below the detection threshold (1.0) in the second and third accepts in both peanut lots (Figures 2.6 and 2.7). However, a higher percentage of dark peanuts (20-40 %) had to be removed in the reject fractions to reduce the off-flavor in the 2003 lot. In West Texas, there were unusually high temperatures during harvest (October, 2003) and longer duration of high temperature during the period of growth (June – October) in 2003. As a result, more peanuts acquired the fruity fermented off-flavor because of decreased physiological maturity. Hence, larger fractions of dark peanuts were removed by color sorting to reduce the fruity fermented off-flavor below the detection threshold.

According to Sanders and Bett (1995), the descriptor dark roast is mostly related to roast color. In this study, the darker rejects (2003 lot) showed significantly higher scores for

dark roasted flavor (3.86-4.27) and bitter (3.34-3.57) attributes (Figure 2.8). It was also observed that dark roast was inversely related to raw beany (Table 2.10). The rejects had significantly lower raw beany attribute (0.43-0.89) while the accepts had low scores for dark roast (2.70-2.94) and high scores for raw beany (2.13- 2.35). Intensities for sweet aromatic, sweet taste and woody/hulls descriptors were not significantly different among all color-sorted fractions (Tables 2.9 and 2.10). The first reject fraction (2003 lot), which had the highest concentration of dark peanuts, had the highest intensity of fruity fermented, (3.11), bitter (3.57) and dark roast (4.27) and the lowest intensity of roast peanutty (3.77) and sweet aromatic (3.08) (Table 2.9). The third accept sample (2003 lot), from which the maximum number of dark peanuts were removed, exhibited the highest intensity for roast peanutty (4.63), sweet aromatic (3.23), raw beany (2.35), sweet taste (2.62) and the lowest intensity for fruity fermented (0.41), dark roast (2.70) and bitter taste (2.61) (Table 2.9). No significant differences were observed among the accepts and unsorted peanuts (2002 lot) for all flavor descriptors except for fruity fermented off-flavor. The off-flavor reduced from 1.40 to 0.48 with the removal of 5 to 20 % of darkest peanuts (Table 2.8). Roast peanutty and fruity fermented off-flavor of the unsorted peanuts and the accepts (2002 lot) did not significantly change in 12 weeks of storage (Figure 2.9). However, all samples were scored at about threshold levels for lipid degradation off-flavors such as cardboardy (0.93-1.79) and painty (0.25-1.83) (Table 2.10). During lipid oxidation, volatiles such as hexanal and pentanal are formed from hydroperoxides (How, 1984; Bett *et al.*, 1992). Since both lots were of high oleic genotype, the peanuts had high oil stability and high intensities of painty and cardboardy were not observed in the samples in storage. Sensory evaluation of both peanut

lots from 2002 and 2003 indicated that high-speed color sorting technology could be implemented for the reduction of fruity fermented off-flavor.

The generally small difference in the Hunter L values among the three accepts and among the three rejects should not be considered as a contributor to noted flavor differences. However differences of  $8 \pm 2$  Hunter L units between each accept and the corresponding reject (Table 2.1) was a major contributor to noted flavor differences especially in roasted peanutty, dark roast and fruity fermented intensities.

### **Shelf-life characteristics**

Oil stability strongly influences peanut flavor and aroma quality. Peanut oil contains more than 80 % unsaturated fatty acids making the oil susceptible to lipid oxidation. (Mercer *et al.*, 1990; Braddock *et al.*, 1995; Moore and Knauff, 1989; O'Keefe *et al.*, 1993). The Peroxide Value (0.25-0.40) and OSI values (59-67) for all accepts and rejects indicated high oxidative stability (Figure 2.11) for the 2003 lot. For the 2002 lot, Peroxide Value increased from 0.80 to 10.3 and OSI value decreased from 45 to 27 over 12 weeks in storage among the unsorted peanuts and the accept fractions (Figure 2.10). Since both peanut lots were of high oleic genotype, all color-sorted fractions exhibited high oil stability. Color sorting did not result in significant variation of shelf-life characteristics among the accepts and the unsorted peanuts.

## **2.5 Conclusion**

Color sorting of the fruity fermented lots at increased sensitivity resulted in the separation of increasingly higher percentages of rejects (5 - 40%) and formation of accepts of lighter colored peanuts. The fact that immature peanuts were removed as the darker roasted reject fraction was confirmed by oil and sugar composition evaluation. Sensory evaluation proved that all rejects had significantly higher intensities of fruity fermented off-flavor, dark roast and bitter flavor and significantly lower intensities of roasted peanutty flavor. Color sorting technology did not result in a measurable improvement in shelf life but was effective in the reduction of maturity related off-flavor (fruity fermented). Color sorting can help reclaim a high percentage of the fruity fermented lot for normal manufacturing processes.

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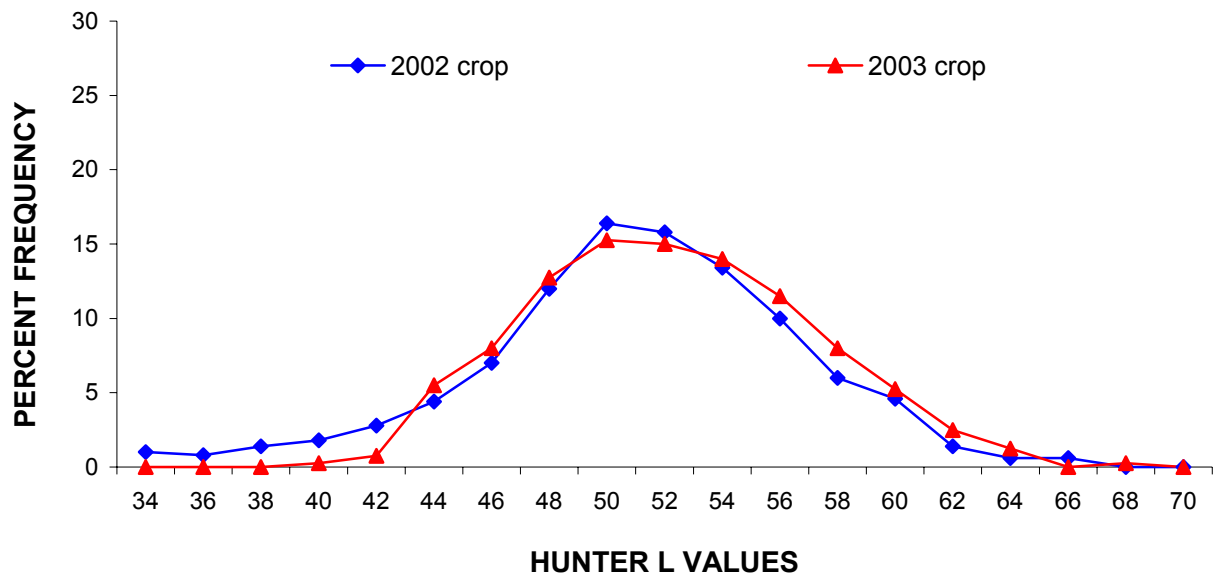


Figure 2.1. Single seed color distribution of 400 randomly picked roasted peanuts of 2002 and 2003 fruity fermented lots

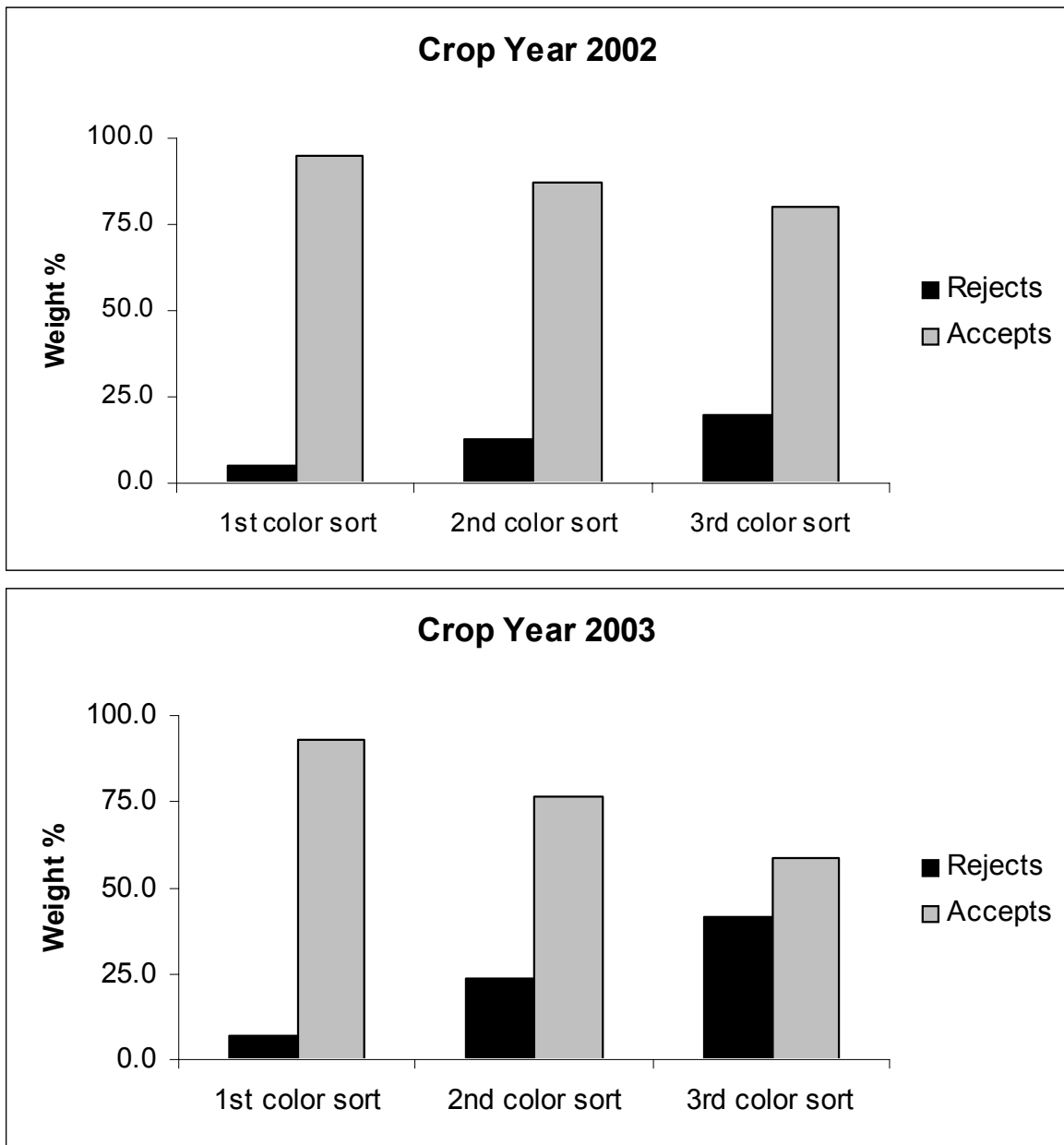


Figure 2.2. Weight % of color sorted accepts and rejects of 2002 and 2003 fruity fermented lots at three color sorter sensitivity levels



Table 2.1. Mean Hunter L values of roasted peanuts of unsorted and color sorted accept and reject fractions of 2002 and 2003 fruity fermented lots

Roasted Peanut Hunter L values							
	Unsorted	Accept 1	Accept 2	Accept 3	Reject 1	Reject 2	Reject 3
	Color Sorted Fractions						
2002 crop	49.88	49.91	51.21	52.32	41.61	44.35	45.69
2003 crop	49.47	50.42	51.45	53.51	42.42	45.61	47.42

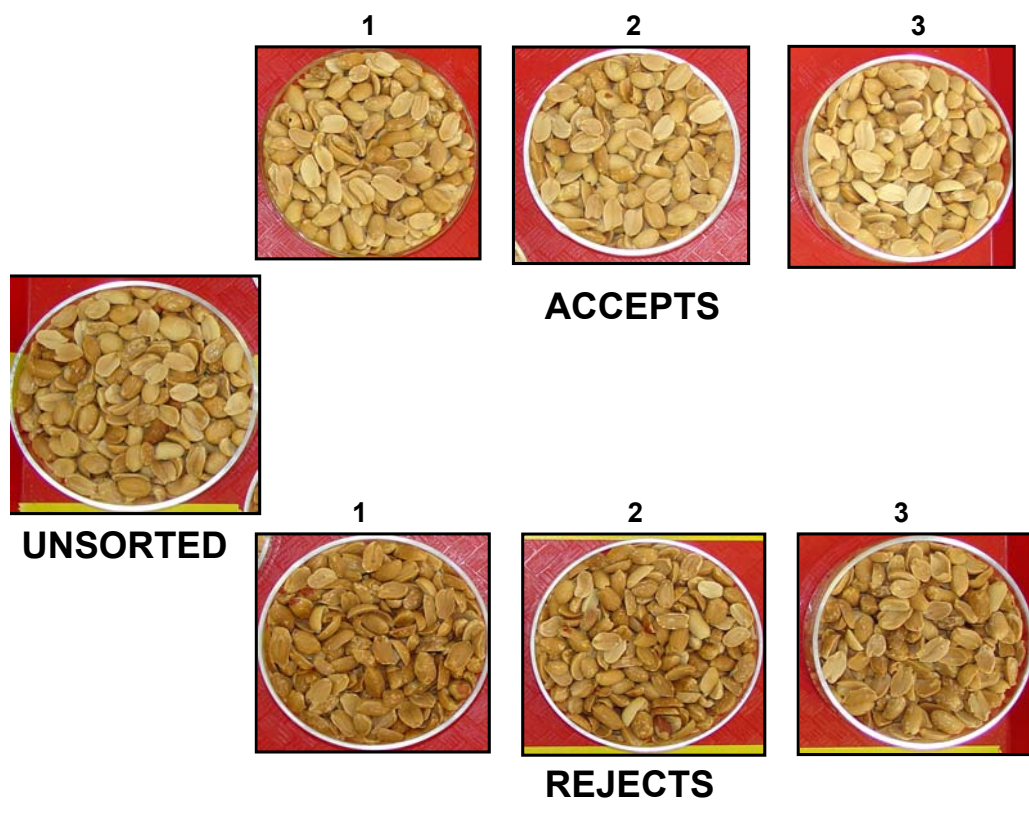


Figure 2.3. A visual representation of the unsorted and color sorted accepts and rejects produced after color sorting of 2003 fruity fermented peanut lot.

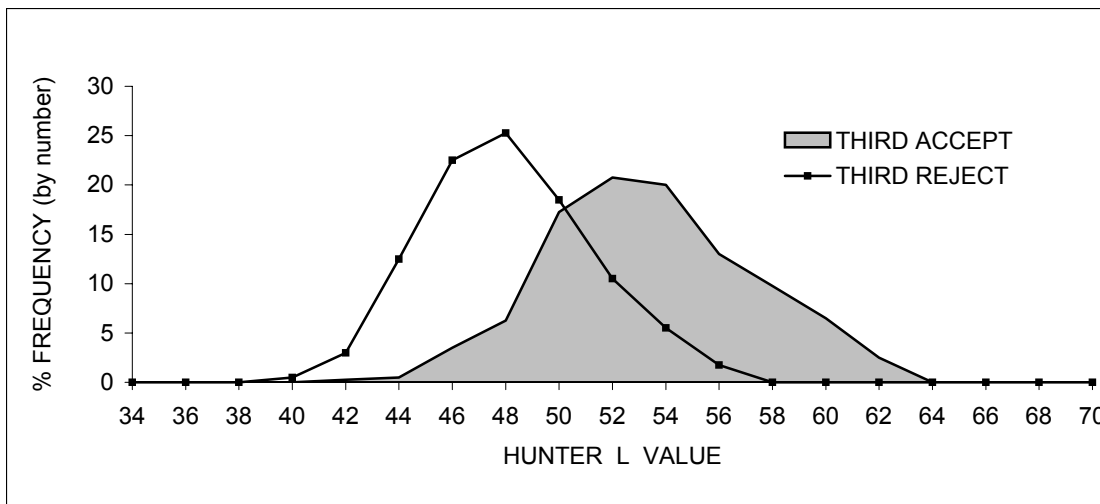
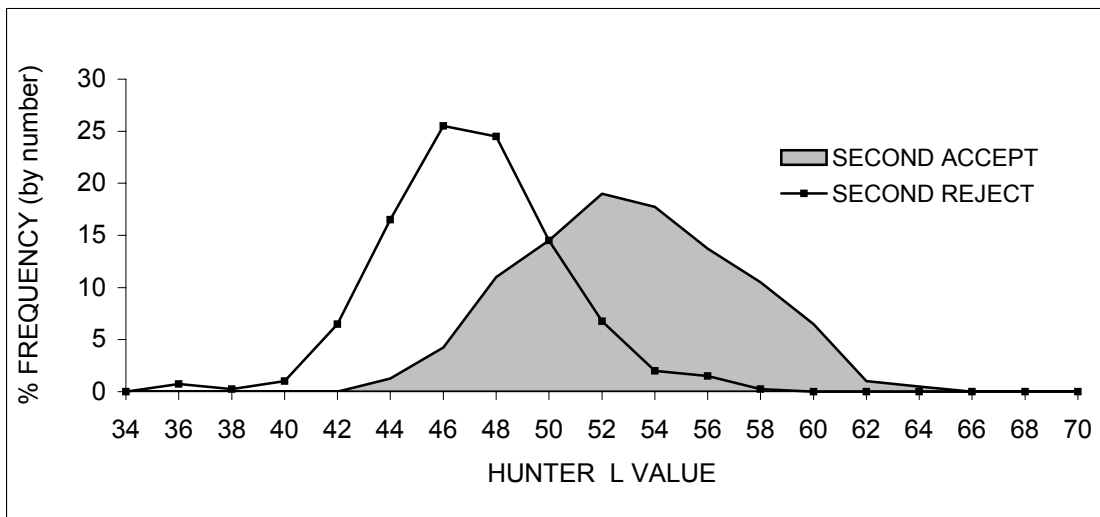
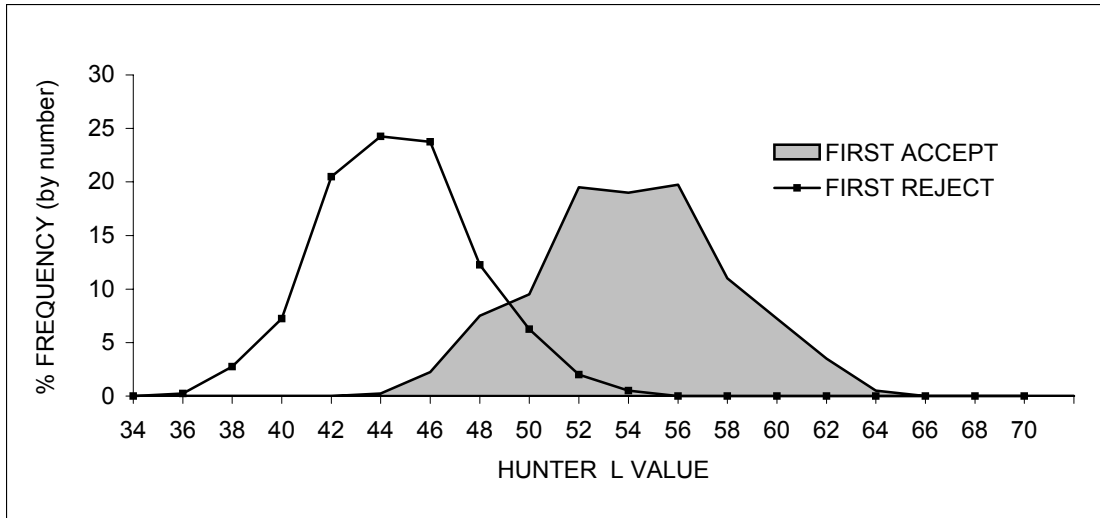


Figure 2.4. Single seed color distribution of 400 randomly picked seeds from the first, second and third accepts and rejects of the 2002 fruity fermented lot

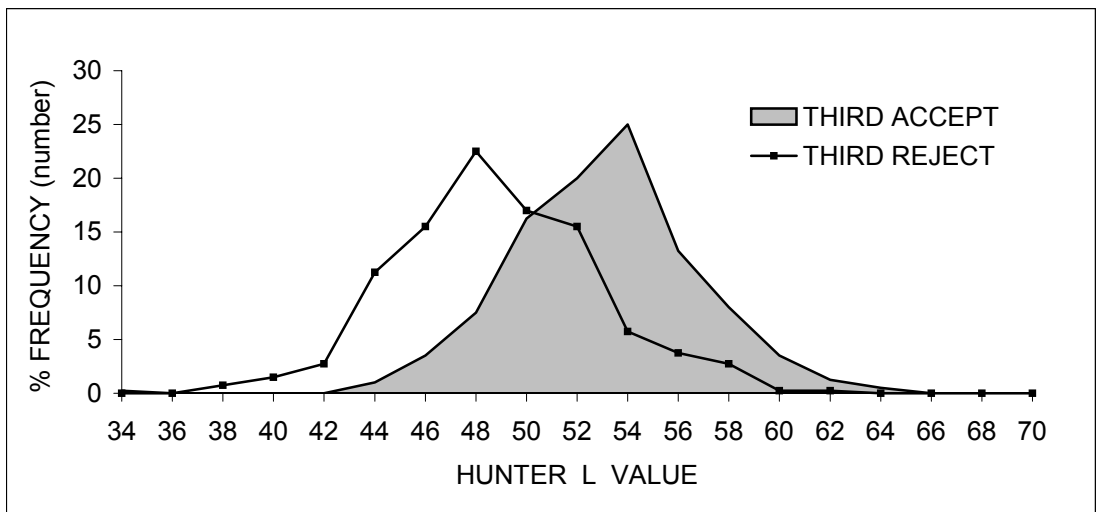
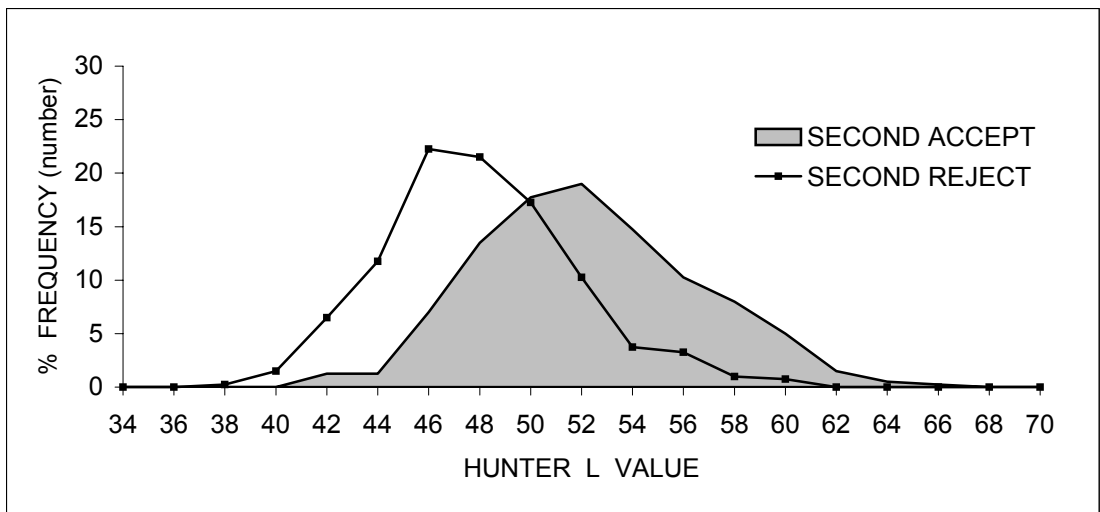
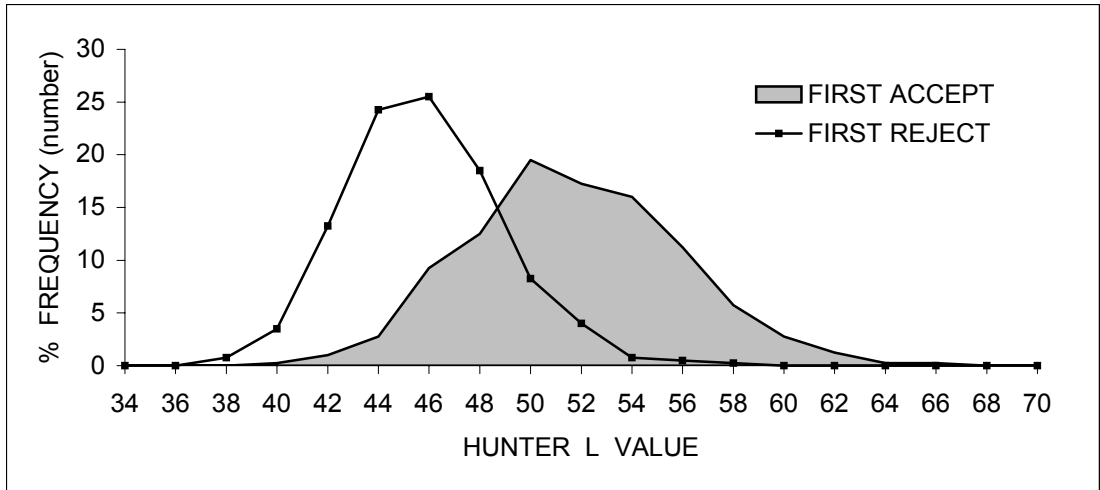


Figure 2.5. Single seed color distribution of 400 randomly picked seeds from the first, second and third accepts and rejects of 2003 fruity fermented lot

Table 2.2. Moisture and oil characteristics of 2002 fruity fermented lot

Sample		Moisture %	Oil %	Free Fatty Acid	O/L ratio
Raw	NA	6.09 <sup>a</sup>	45.93 <sup>d</sup>	0.15 <sup>cd</sup>	13.25 <sup>a</sup>
Roasted Peanuts					
Unsorted	NA	1.03 <sup>b</sup>	47.69 <sup>c</sup>	0.19 <sup>b</sup>	12.56 <sup>bcd</sup>
Accept	1	0.97 <sup>bc</sup>	48.71 <sup>ab</sup>	0.14 <sup>d</sup>	12.06 <sup>e</sup>
Reject	1	1.01 <sup>b</sup>	45.94 <sup>d</sup>	0.26 <sup>a</sup>	11.58 <sup>f</sup>
Accept	2	1.02 <sup>b</sup>	48.94 <sup>ab</sup>	0.19 <sup>b</sup>	12.45 <sup>cde</sup>
Reject	2	0.93 <sup>cd</sup>	47.77 <sup>c</sup>	0.18 <sup>bc</sup>	12.83 <sup>abc</sup>
Accept	3	1.00 <sup>b</sup>	49.41 <sup>a</sup>	0.19 <sup>b</sup>	12.34 <sup>de</sup>
Reject	3	0.91 <sup>d</sup>	48.19 <sup>bc</sup>	0.18 <sup>bc</sup>	12.99 <sup>ab</sup>

Means in column followed by common superscript letter are not significantly different (P>0.05)

Table 2.3. Moisture and oil characteristics of 2003 fruity fermented lot

Sample		Moisture %	Oil %	Free Fatty Acid	O/L ratio
Raw	NA	6.28 <sup>a</sup>	45.49 <sup>cd</sup>	0.16 <sup>c</sup>	12.29 <sup>a</sup>
Roasted Peanuts					
Unsorted	NA	1.36 <sup>b</sup>	48.92 <sup>ab</sup>	0.15 <sup>bc</sup>	12.78 <sup>a</sup>
Accept	1	1.23 <sup>c</sup>	48.45 <sup>ab</sup>	0.16 <sup>c</sup>	12.0 <sup>bc</sup>
Reject	1	1.38 <sup>b</sup>	46.24 <sup>cd</sup>	0.22 <sup>ab</sup>	11.48 <sup>c</sup>
Accept	2	1.24 <sup>c</sup>	48.99 <sup>ab</sup>	0.17 <sup>bac</sup>	12.89 <sup>a</sup>
Reject	2	1.37 <sup>b</sup>	47.11 <sup>c</sup>	0.23 <sup>a</sup>	12.49 <sup>ab</sup>
Accept	3	1.24 <sup>c</sup>	49.10 <sup>a</sup>	0.15 <sup>c</sup>	12.49 <sup>ab</sup>
Reject	3	1.36 <sup>b</sup>	48.14 <sup>b</sup>	0.20 <sup>bac</sup>	12.6 <sup>ab</sup>

Means in column followed by common superscript letter are not significantly different (P>0.05)

Table 2.4. Fatty acid composition of 2002 fruity fermented lot (Weight %)

		C 16:0	C18:0	C 18:1	C 18:2	C 20:0	C 20:1	C 22:0	C 24:0
Raw	NA	5.69 <sup>b</sup>	1.69 <sup>a</sup>	77.0 <sup>bc</sup>	5.81 <sup>d</sup>	0.98 <sup>ab</sup>	2.85 <sup>c</sup>	2.83 <sup>bcd</sup>	2.12 <sup>cd</sup>
Roasted Peanuts									
Unsorted	NA	5.87 <sup>ab</sup>	1.51 <sup>bc</sup>	77.3 <sup>ab</sup>	6.17 <sup>c</sup>	1.02 <sup>a</sup>	2.73 <sup>d</sup>	2.89 <sup>bc</sup>	2.18 <sup>bc</sup>
Accept	1	5.96 <sup>a</sup>	1.49 <sup>c</sup>	77.3 <sup>ab</sup>	6.41 <sup>ab</sup>	1.01 <sup>a</sup>	2.69 <sup>d</sup>	2.83 <sup>bcd</sup>	2.11 <sup>cd</sup>
Reject	1	5.43 <sup>c</sup>	1.54 <sup>bc</sup>	75.6 <sup>d</sup>	6.53 <sup>a</sup>	0.93 <sup>c</sup>	3.40 <sup>a</sup>	3.09 <sup>a</sup>	2.38 <sup>a</sup>
Accept	2	5.98 <sup>a</sup>	1.55 <sup>bc</sup>	77.7 <sup>a</sup>	6.25 <sup>bc</sup>	1.01 <sup>a</sup>	2.55 <sup>e</sup>	2.75 <sup>cd</sup>	2.06 <sup>cd</sup>
Reject	2	5.47 <sup>c</sup>	1.6 <sup>abc</sup>	76.6 <sup>c</sup>	5.97 <sup>d</sup>	0.95 <sup>bc</sup>	3.24 <sup>b</sup>	2.98 <sup>ab</sup>	2.26 <sup>ab</sup>
Accept	3	5.94 <sup>a</sup>	1.68 <sup>a</sup>	77.1 <sup>bc</sup>	6.25 <sup>bc</sup>	0.98 <sup>ab</sup>	2.52 <sup>e</sup>	2.72 <sup>d</sup>	2.04 <sup>d</sup>
Reject	3	5.45 <sup>c</sup>	1.62 <sup>ab</sup>	76.7 <sup>c</sup>	5.90 <sup>d</sup>	0.98 <sup>ab</sup>	3.18 <sup>b</sup>	3.07 <sup>a</sup>	2.33 <sup>a</sup>

Means in column followed by common superscript letter are not significantly different (P>0.05)

Table 2.5. Fatty acid composition of 2003 fruity fermented lot (Weight %)

		C 16:0	C18:0	C 18:1	C 18:2	C 20:0	C 20:1	C 22:0	C 24:0
Raw	NA	5.68 <sup>bc</sup>	1.64 <sup>a</sup>	77.00 <sup>d</sup>	6.27 <sup>c</sup>	0.94 <sup>a</sup>	2.95 <sup>a</sup>	2.78 <sup>a</sup>	2.15 <sup>a</sup>
Roasted Peanuts									
Unsorted	NA	5.80 <sup>ab</sup>	1.51 <sup>bc</sup>	79.0 <sup>ab</sup>	6.19 <sup>c</sup>	0.79 <sup>b</sup>	2.59 <sup>b</sup>	2.21 <sup>b</sup>	1.72 <sup>b</sup>
Accept	1	6.00 <sup>a</sup>	1.45 <sup>c</sup>	79.50 <sup>a</sup>	6.63 <sup>ab</sup>	0.71 <sup>c</sup>	2.36 <sup>c</sup>	1.83 <sup>c</sup>	1.32 <sup>c</sup>
Reject	1	5.80 <sup>ab</sup>	1.57 <sup>ab</sup>	77.40 <sup>d</sup>	6.75 <sup>a</sup>	0.80 <sup>b</sup>	2.96 <sup>a</sup>	2.39 <sup>b</sup>	1.90 <sup>ab</sup>
Accept	2	5.83 <sup>ab</sup>	1.55 <sup>ab</sup>	79.0 <sup>ab</sup>	6.14 <sup>c</sup>	0.82 <sup>b</sup>	2.52 <sup>bc</sup>	2.26 <sup>b</sup>	1.81 <sup>ab</sup>
Reject	2	5.54 <sup>cd</sup>	1.56 <sup>ab</sup>	78.10 <sup>c</sup>	6.26 <sup>c</sup>	0.83 <sup>b</sup>	2.93 <sup>a</sup>	2.48 <sup>ab</sup>	1.92 <sup>ab</sup>
Accept	3	5.91 <sup>a</sup>	1.59 <sup>ab</sup>	79.0 <sup>ab</sup>	6.33 <sup>bc</sup>	0.82 <sup>b</sup>	2.38 <sup>c</sup>	2.15 <sup>b</sup>	1.65 <sup>bc</sup>
Reject	3	5.44 <sup>d</sup>	1.58 <sup>ab</sup>	78.4 <sup>bc</sup>	6.23 <sup>c</sup>	0.85 <sup>b</sup>	2.86 <sup>a</sup>	2.45 <sup>ab</sup>	1.85 <sup>ab</sup>

Means in column followed by common superscript letter are not significantly different (P>0.05)



Table 2.6. Composition of various sugars in 2002 fruity fermented lot (mg/g of defatted meal)

Sample		Inositol	Glucose	Fructose	Sucrose	Raffinose	Stachyose	Total Sugar
Raw	NA	1.06 <sup>c</sup>	0.13 <sup>bcd</sup>	0.05 <sup>c</sup>	101.8 <sup>ab</sup>	3.51 <sup>b</sup>	22.89 <sup>c</sup>	129.44
Roasted Peanuts								
Unsorted	NA	0.98 <sup>cd</sup>	0.10 <sup>cd</sup>	0.00 <sup>c</sup>	105.60 <sup>ab</sup>	3.38 <sup>b</sup>	24.34 <sup>bc</sup>	134.40
Accept	1	0.92 <sup>cd</sup>	0.11 <sup>bcd</sup>	0.06 <sup>c</sup>	106.12 <sup>ab</sup>	3.36 <sup>b</sup>	23.68 <sup>bc</sup>	134.25
Reject	1	1.66 <sup>a</sup>	0.21 <sup>a</sup>	0.24 <sup>a</sup>	100.67 <sup>ab</sup>	4.06 <sup>a</sup>	25.20 <sup>ab</sup>	132.04
Accept	2	0.84 <sup>cd</sup>	0.10 <sup>cd</sup>	0.03 <sup>c</sup>	92.23 <sup>b</sup>	3.30 <sup>b</sup>	23.82 <sup>bc</sup>	120.32
Reject	2	1.56 <sup>ab</sup>	0.17 <sup>ab</sup>	0.17 <sup>ab</sup>	102.61 <sup>ab</sup>	4.11 <sup>a</sup>	26.60 <sup>a</sup>	135.22
Accept	3	0.82 <sup>d</sup>	0.08 <sup>d</sup>	0.01 <sup>c</sup>	111.55 <sup>a</sup>	3.40 <sup>b</sup>	25.09 <sup>ab</sup>	140.95
Reject	3	1.42 <sup>b</sup>	0.15 <sup>bc</sup>	0.14 <sup>b</sup>	106.45 <sup>ab</sup>	4.06 <sup>a</sup>	26.51 <sup>a</sup>	138.73

Means in column followed by common superscript letter are not significantly different ( $P > 0.05$ )

Table 2.7. Composition of various sugars in 2003 fruity fermented lot (mg/g of defatted meal)

		Inositol	Glucose	Fructose	Sucrose	Raffinose	Stachyose	Total Sugar
Raw	NA	1.18 <sup>b</sup>	0.37 <sup>a</sup>	0.19 <sup>c</sup>	78.84 <sup>a</sup>	3.33 <sup>bc</sup>	17.03 <sup>d</sup>	100.94
Roasted Peanuts								
Unsorted	NA	1.15 <sup>bc</sup>	0.31 <sup>a</sup>	0.45 <sup>abc</sup>	61.41 <sup>bc</sup>	3.72 <sup>a</sup>	20.78 <sup>a</sup>	87.82
Accept	1	0.99 <sup>cd</sup>	0.40 <sup>a</sup>	0.39 <sup>bc</sup>	56.24 <sup>c</sup>	3.11 <sup>c</sup>	18.71 <sup>b</sup>	79.84
Reject	1	1.58 <sup>a</sup>	0.56 <sup>a</sup>	0.57 <sup>ab</sup>	63.26 <sup>abc</sup>	3.68 <sup>a</sup>	18.86 <sup>b</sup>	88.51
Accept	2	1.07 <sup>bc</sup>	0.49 <sup>a</sup>	0.52 <sup>ab</sup>	75.98 <sup>ab</sup>	3.12 <sup>c</sup>	19.05 <sup>b</sup>	100.23
Reject	2	1.49 <sup>a</sup>	0.48 <sup>a</sup>	0.64 <sup>a</sup>	56.49 <sup>c</sup>	3.51 <sup>a</sup>	18.91 <sup>b</sup>	81.52
Accept	3	0.86 <sup>d</sup>	0.31 <sup>a</sup>	0.32 <sup>bc</sup>	62.20 <sup>abc</sup>	2.70 <sup>d</sup>	17.89 <sup>c</sup>	84.28
Reject	3	1.44 <sup>a</sup>	0.41 <sup>a</sup>	0.64 <sup>a</sup>	53.51 <sup>c</sup>	3.60 <sup>ab</sup>	18.86 <sup>b</sup>	78.46

Means in column followed by common superscript letter are not significantly different (P>0.05)

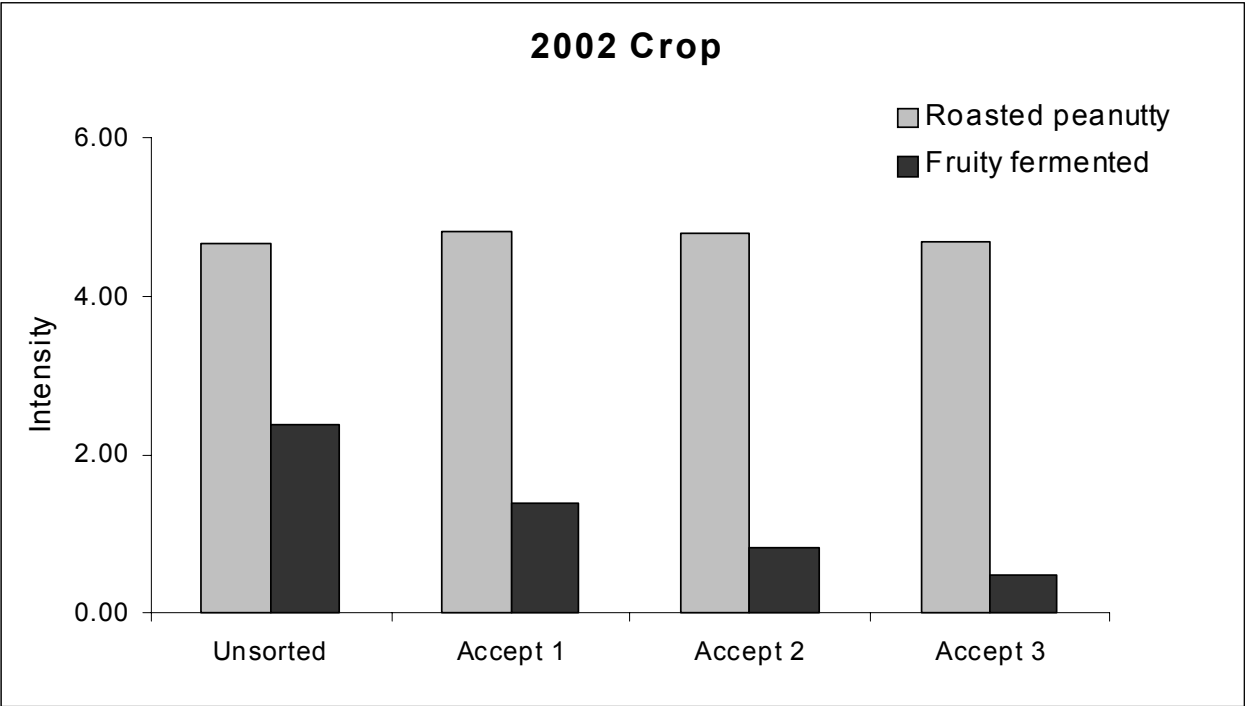


Figure 2.6. Intensity of roast peanutty flavor and fruity fermented off-flavor in the unsorted and accepts of 2002 fruity fermented lot

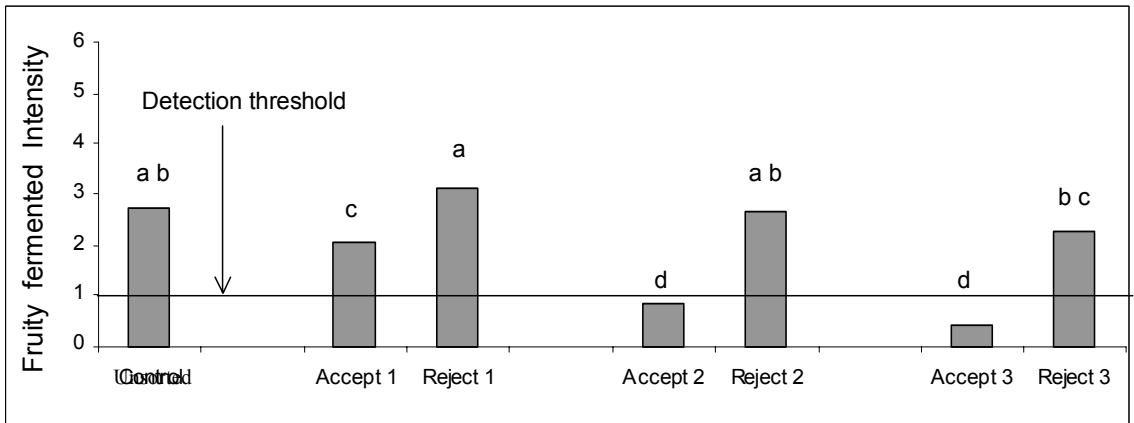
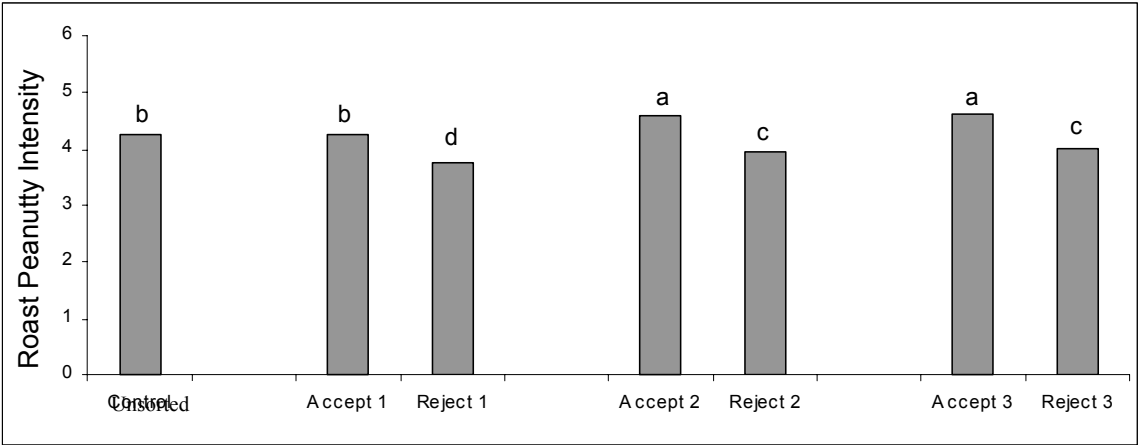


Figure 2.7. Intensity of roast peanuty flavor and fruity fermented off-flavor in the unsorted and color sorted fractions of the 2003 fruity fermented peanut lot

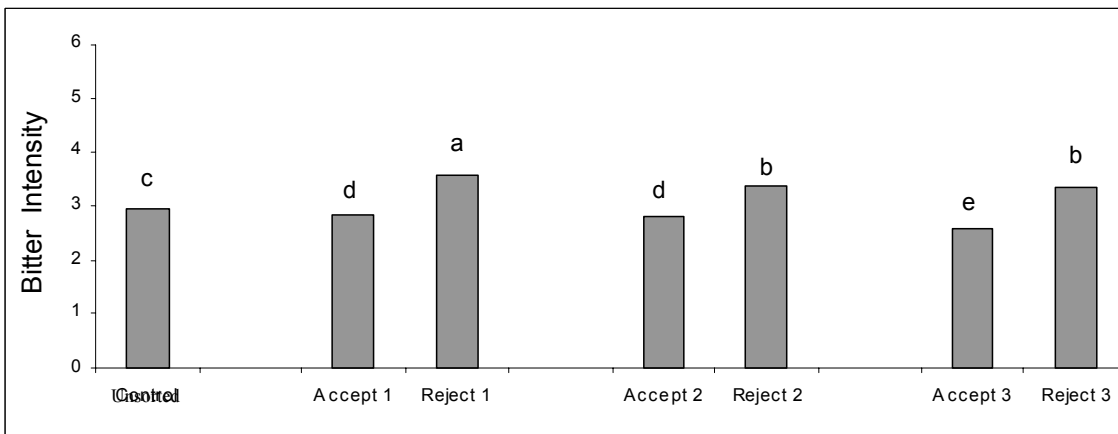
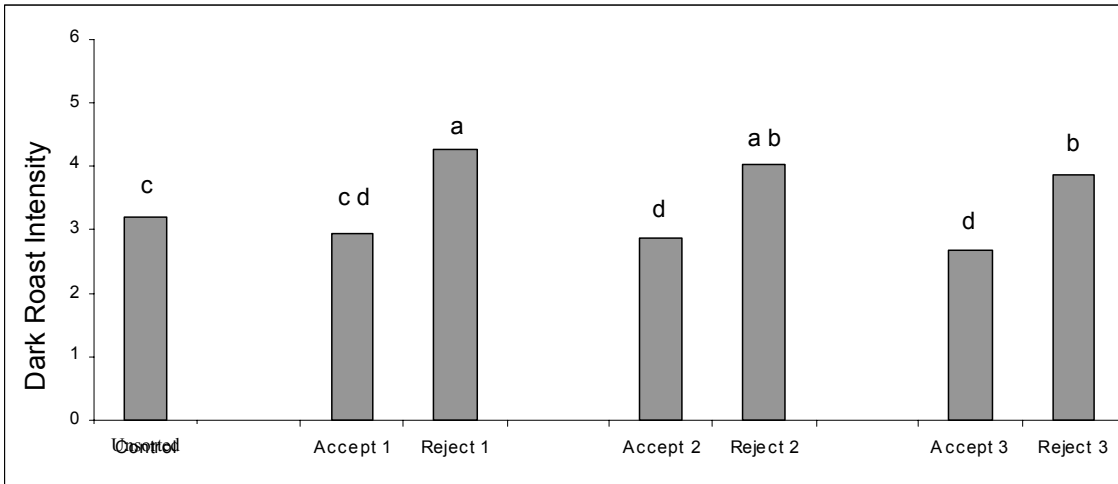


Figure 2.8. Intensity of dark roast and bitter flavors in the unsorted and color sorted fractions of the 2003 fruity fermented peanut lot

Table 2.8. Mean intensity score of flavor descriptors in 2002 fruity fermented lot

Sample		Roast Peanutty	Sweet Aromatic	Dark Roast	Raw Beany	Woody/ Hulls	Fruity Fermented	Sweet	Bitter
		Intensity of flavor descriptors							
Unsorted	NA	4.67 <sup>a</sup>	3.16 <sup>a</sup>	3.02 <sup>ab</sup>	1.97 <sup>a</sup>	2.93 <sup>a</sup>	2.40 <sup>a</sup>	2.33 <sup>a</sup>	2.96 <sup>a</sup>
Accept	1	4.82 <sup>a</sup>	3.10 <sup>a</sup>	3.00 <sup>ab</sup>	2.54 <sup>a</sup>	3.04 <sup>a</sup>	1.40 <sup>b</sup>	2.2 <sup>a</sup>	3.02 <sup>a</sup>
Accept	2	4.80 <sup>a</sup>	3.17 <sup>a</sup>	2.95 <sup>ab</sup>	2.08 <sup>a</sup>	3.03 <sup>a</sup>	0.83 <sup>c</sup>	2.38 <sup>a</sup>	2.90 <sup>a</sup>
Accept	3	4.69 <sup>a</sup>	3.12 <sup>a</sup>	3.04 <sup>a</sup>	2.09 <sup>a</sup>	2.99 <sup>a</sup>	0.48 <sup>d</sup>	2.29 <sup>a</sup>	2.80 <sup>a</sup>

Means in a column followed by common superscript letter are not significantly different (P> 0.05)

Table 2.9. Mean intensity score of flavor descriptors in 2003 fruity fermented peanut lot

Sample		Roast Peanutty	Sweet Aromatic	Dark Roast	Raw Beany	Woody/ Hulls	Fruity Fermented	Sweet	Bitter
		Intensity of flavor descriptors							
Unsorted	NA	4.25 <sup>b</sup>	3.33 <sup>a</sup>	3.19 <sup>c</sup>	1.80 <sup>b</sup>	3.04 <sup>ab</sup>	2.76 <sup>ab</sup>	2.63 <sup>a</sup>	2.97 <sup>c</sup>
Accept	1	4.26 <sup>b</sup>	3.19 <sup>ab</sup>	2.94 <sup>cd</sup>	2.13 <sup>ab</sup>	2.91 <sup>b</sup>	2.07 <sup>c</sup>	2.56 <sup>a</sup>	2.82 <sup>d</sup>
Reject	1	3.77 <sup>d</sup>	3.08 <sup>b</sup>	4.27 <sup>a</sup>	0.43 <sup>d</sup>	3.14 <sup>a</sup>	3.11 <sup>a</sup>	2.53 <sup>a</sup>	3.57 <sup>a</sup>
Accept	2	4.58 <sup>a</sup>	3.13 <sup>b</sup>	2.86 <sup>d</sup>	2.23 <sup>a</sup>	3.03 <sup>ab</sup>	0.83 <sup>d</sup>	2.60 <sup>a</sup>	2.78 <sup>d</sup>
Reject	2	3.96 <sup>c</sup>	3.19 <sup>ab</sup>	4.04 <sup>ab</sup>	0.68 <sup>cd</sup>	3.11 <sup>a</sup>	2.66 <sup>ab</sup>	2.56 <sup>a</sup>	3.38 <sup>b</sup>
Accept	3	4.63 <sup>a</sup>	3.23 <sup>ab</sup>	2.70 <sup>d</sup>	2.35 <sup>a</sup>	3.02 <sup>ab</sup>	0.41 <sup>d</sup>	2.62 <sup>a</sup>	2.61 <sup>e</sup>
Reject	3	4.02 <sup>c</sup>	3.14 <sup>ab</sup>	3.86 <sup>b</sup>	0.89 <sup>c</sup>	3.05 <sup>ab</sup>	2.26 <sup>bc</sup>	2.44 <sup>a</sup>	3.34 <sup>b</sup>

Means in column followed by common superscript letter are not significantly different (P>0.05)

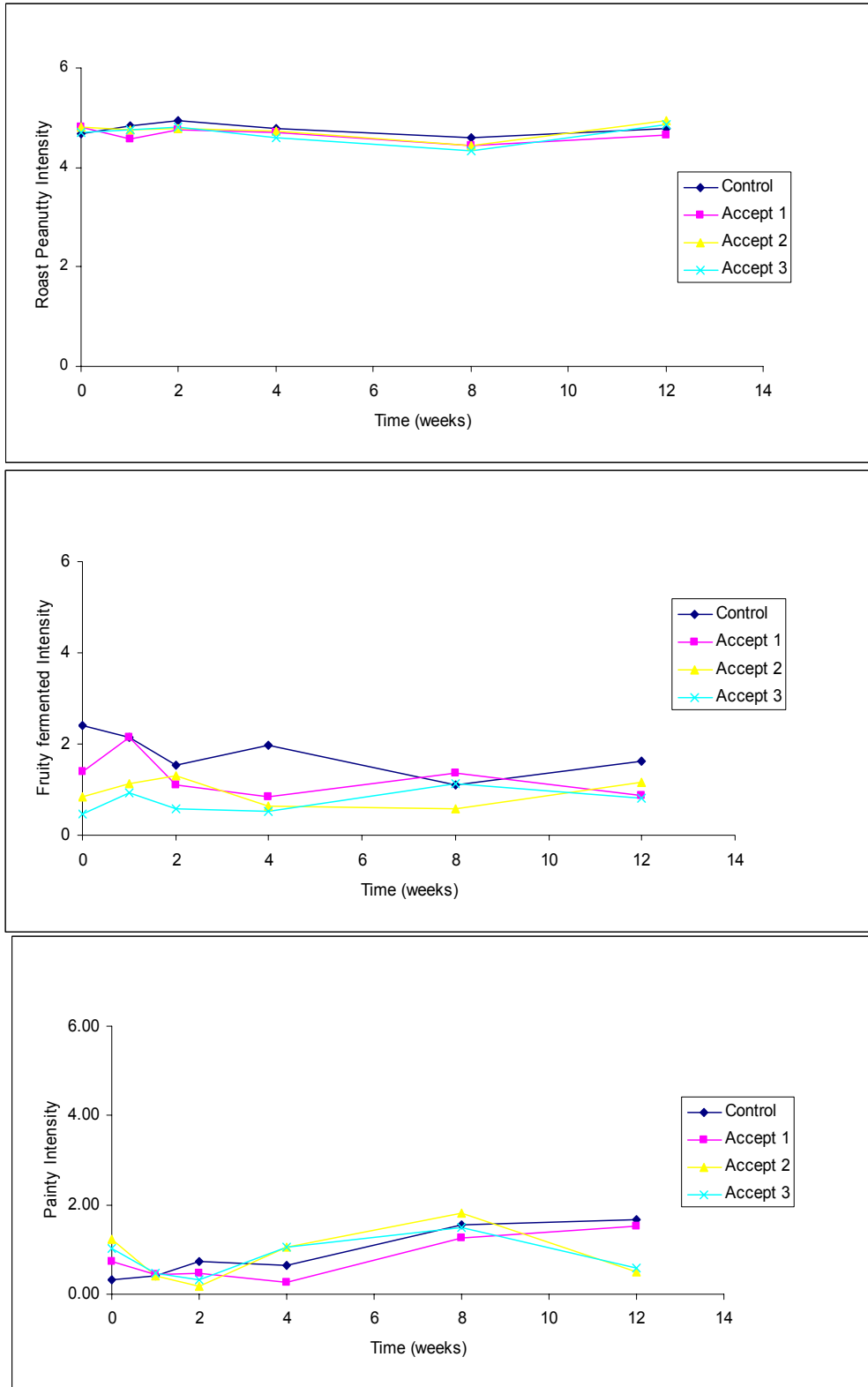


Figure 2.9. Mean intensity scores during storage for roast peanuttiness, fruity fermented and painty flavor attributes of the unsorted and accept fractions of 2002 peanut lot



Table 2.10. Mean intensity score of flavor descriptors of the 2002 unsorted and accepts in storage

Week	Sample	Roast Peanutty	Sweet Aromatic	Dark Roast	Raw Beany	Woody hulls/skins	Cardboardy	Painty	Fruity Fermented	Sweet	Bitter
0	Unsorted	4.67	3.16	3.03	1.97	2.93	1.17	0.33	2.40	2.33	2.96
1	Unsorted	4.83	3.28	3.01	1.97	3.04	1.36	0.40	2.14	2.48	2.97
2	Unsorted	4.93	3.20	3.02	2.05	3.08	0.76	0.74	1.55	2.38	2.92
4	Unsorted	4.80	3.13	3.01	2.00	3.07	1.10	0.65	1.96	2.38	2.89
8	Unsorted	4.60	2.96	2.97	2.09	3.10	1.30	1.56	1.10	2.12	2.90
12	Unsorted	4.78	3.03	3.00	2.11	3.03	1.33	1.67	1.61	2.41	2.95
0	Accept 1	4.82	3.10	3.00	2.54	3.04	1.12	0.72	1.39	2.21	3.02
1	Accept 1	4.56	3.12	3.05	1.94	2.99	1.17	0.43	2.16	2.33	2.93
2	Accept 1	4.77	3.16	3.05	2.00	3.06	1.47	0.48	1.10	2.31	2.88
4	Accept 1	4.71	3.10	3.02	2.04	3.08	1.62	0.25	0.84	2.23	2.89
8	Accept 1	4.44	2.99	3.03	2.08	3.01	0.94	1.27	1.36	2.22	2.93
12	Accept 1	4.66	3.02	3.06	1.98	3.02	1.30	1.53	0.86	2.24	2.89
0	Accept 2	4.80	3.17	2.96	2.08	3.03	1.16	1.22	0.83	2.38	2.90
1	Accept 2	4.76	3.06	2.95	2.07	3.01	1.15	0.40	1.14	2.21	2.83
2	Accept 2	4.77	3.16	2.98	2.13	3.04	1.36	0.17	1.32	2.30	2.84
4	Accept 2	4.74	3.07	2.94	2.06	3.03	0.93	1.05	0.64	2.23	2.97
8	Accept 2	4.44	3.05	3.00	2.00	3.04	1.65	1.83	0.57	2.23	2.98
12	Accept 2	4.95	3.28	2.98	2.01	3.00	1.07	0.50	1.17	2.39	2.96
0	Accept 3	4.69	3.12	3.04	2.09	2.99	1.49	1.03	0.48	2.29	2.80
1	Accept 3	4.75	3.04	2.98	2.08	3.04	1.21	0.46	0.92	2.21	2.83
2	Accept 3	4.82	3.07	2.93	2.13	3.04	1.25	0.33	0.59	2.26	2.83
4	Accept 3	4.61	3.03	2.96	2.10	3.02	1.29	1.04	0.52	2.15	2.91
8	Accept 3	4.34	2.98	2.95	2.09	3.03	1.79	1.49	1.14	2.19	3.03
12	Accept 3	4.86	3.17	2.99	2.09	3.04	1.15	0.59	0.80	2.27	2.90

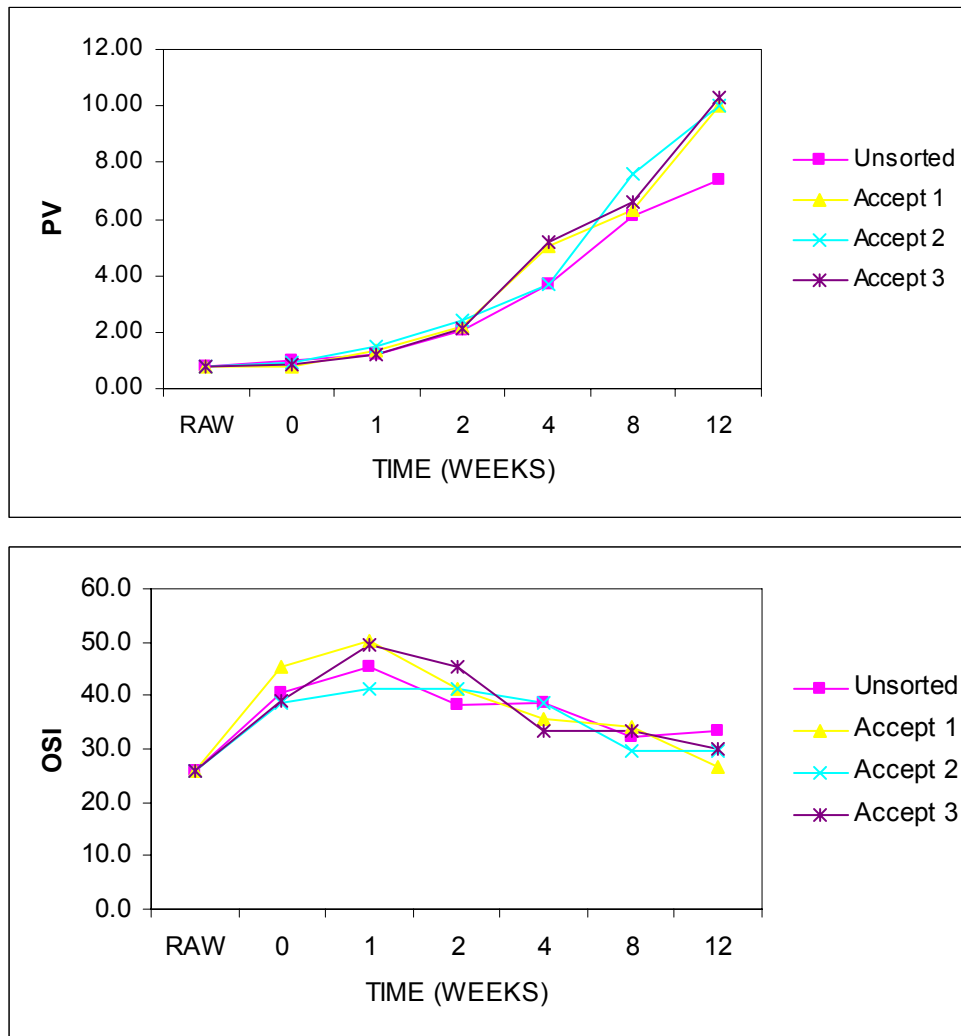


Figure 2.10. PV and OSI values of unsorted and accept fractions of the 2002 fruity fermented peanut lot in 12 weeks of storage

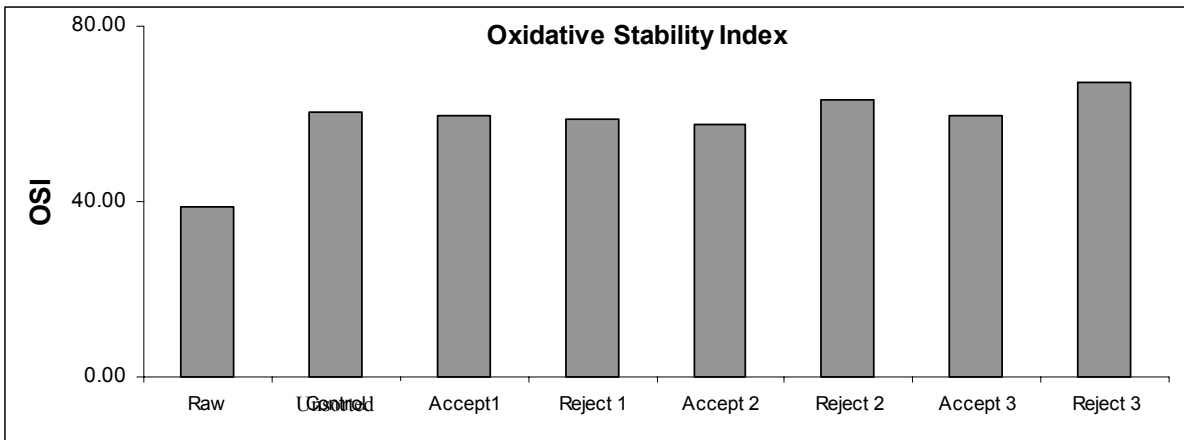
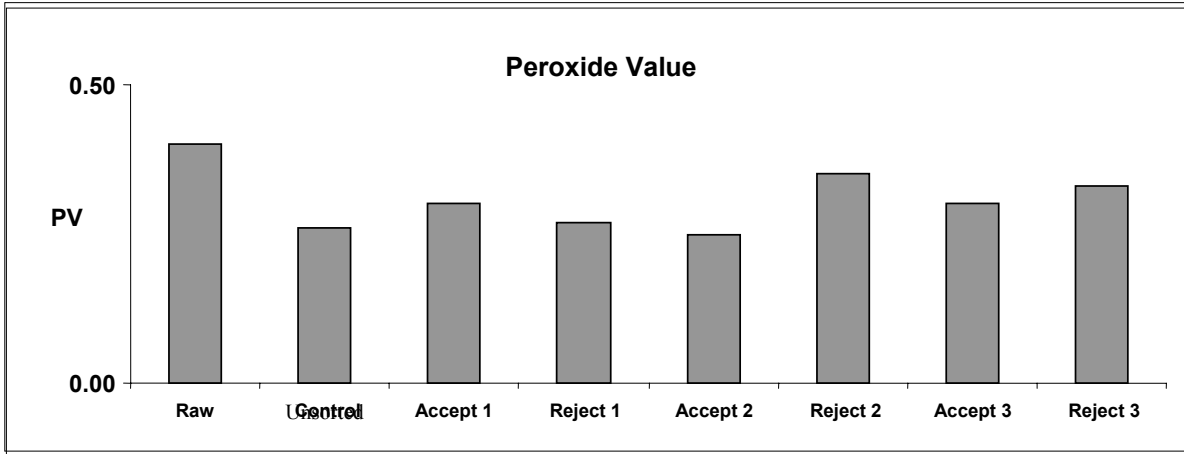


Figure 2.10. PV and OSI of 2003 fruity fermented lot

CHAPTER 3

**APPLICATION OF COLOR SORTING FOR IMPROVEMENT OF FLAVOR AND  
SHELF LIFE OF ROASTED PEANUTS**

### 3.1 Abstract

A maturity distribution exists in commercial screen-sized peanut lots. Chemical composition and oil stability have consistently been shown to change as peanuts mature. Lot characteristics such as flavor/off-flavor potential, roast color variation and storability are influenced by the relative percentage of peanuts of different maturities. Immature peanuts roast darker and have less roast peanutty flavor than mature peanuts of the same size. The objective of this study was to utilize the roast color difference between mature and immature peanuts to determine the effectiveness of high-speed color sorting for improvement of flavor and shelf life of roasted peanuts.

Peanuts (Georgia Green var. 150 lbs.) were roasted to a Hunter L color of  $49 \pm 1$  and color sorted to remove successively higher percentages (4-15 %) of darker roasted peanuts (rejects) from the lighter peanuts (accepts). The Hunter L color difference between each accept and corresponding reject fraction was  $8 \pm 2$ . A highly trained descriptive sensory panel evaluated the unsorted and the accept fractions for all peanut flavor attributes using the Spectrum analysis technique. Statistical analysis ( $p < 0.0001$ ) established no significant difference in the intensity for all flavor attributes among the samples.

All samples had a similar rate of lipid degradation over time which demonstrated that the removal of dark peanuts (5-15 %) did not significantly improve the shelf life of the accept fractions. Chemical analysis demonstrated that the first reject fraction, which consisted of 4% of the darkest peanuts of the roasted lot, had lowest oil content (53.63 %) and O/L ratio (1.54), highest sugar content (82.06 mg/g) and more free fatty acids (2.45) than all other color sorted fractions. All rejects had higher amounts of palmitic, linoleic, eicosenoic,

behenic and lignoceric fatty acids and free fatty acids, lower amounts of oleic acid and lower O/L ratio. Overall, fewer differences in chemical composition were observed between the second and third accepts and rejects respectively.

The results indicated that color sorting removed immature peanuts from the lot but did not result in a measurable improvement in flavor or shelf life of the remaining peanuts in the lot.

### 3.2 Introduction

The unique flavor of roasted peanuts is the basis for the multi-billion dollar peanut industry and consumers have become more stringent in their demand for high quality peanuts (American Peanut Council, 2003; Sanders *et al.*, 1989). The overall sensory quality of roasted peanuts is described by intensities of desirable flavors such as roast peanutty and sweet aromatic or undesirable off-flavors such as fruity fermented, painty, sour and bitter (Johnsen *et al.*, 1988). Flavor and quality of roasted peanuts are influenced by a multitude of complex interacting factors. The use of modern technology in manufacturing operations helps in controlling factors, such as genetics, processing, and storage. However, there are uncontrollable factors such as environmental conditions, seed maturity, seed composition and curing that may cause the flavor quality of peanuts to vary outside acceptable ranges (Bland and Lax, 2000; Sanders *et al.*, 1982, 1989 a, b; Pattee *et al.*, 1974, 1981).

The peanut plant has an indeterminate flowering habit, which results in pods of various maturities at any harvest time (Sanders, 1989 b). According to Sanders (1989 b) the size-maturity relationship is not absolute and peanuts of different maturity occur in screen-sized commercial grades. The total oil, protein and carbohydrate composition change with maturity (Mason *et al.*, 1969; Oupadissakoon and Young, 1984; Sanders, 1980; Sanders *et al.* 1982). Maturity differences are perhaps most apparent in large vs. small peanuts (Pattee and Young, 1982) but a maturity distribution exists in similar size peanuts (Sanders *et al.*, 1987; Williams *et al.*; 1987). Sanders *et al.*, (1989 b) reported that medium grade size peanuts from mature pods have better flavor potential than those from immature pods. Immature peanuts roast darker under similar roasting conditions, have less roast peanutty flavor and are more likely to develop off flavor (Sanders *et al.*, 1989).

The application of high-speed color-sorting technology may be used to reduce the percentage of immature peanuts in a roasted commercial size lot. Automatic machine vision systems have been successfully used for objective measurement of various agricultural (He *et al.*, 1998; Li and Wang, 1999) and food products (Sun, 2000). Color sorters are commonly used to remove discolored peanuts (Sortex Ltd. 2000)

The objective of this study was to evaluate flavor, the shelf life and chemical composition of color sorted fractions of roasted peanuts. The study was conducted to determine if color sorting to remove immature peanuts resulted in a measurable increase in flavor and shelf life.



### **3.3 Materials and Methods**

#### **3.3.1 Preparation**

##### **Peanut Source**

A single lot of 150 lbs. of peanuts of Georgia Green var. (*Arachis hypogaea* L.) was obtained from the USDA-ARS, National Peanut Research Laboratory in Dawson, Georgia. The peanuts were of medium commercial grade size having a width greater than 7.1 mm and less than 8.3 mm.

##### **Storage**

Peanuts were stored in tight-lid plastic storage containers at  $7.0 \pm 0.2$  ° C and relative humidity of  $69.0 \pm 0.2\%$ .

##### **Peanut Roasting**

Approximately 150 lbs. of peanuts were dry roasted on a conveyor belt in a gas fired, thermostat controlled Aeroglide Roaster (Aeroglide Corp, Raleigh NC) at  $347^{\circ}$  F  $\pm$  2 to achieve a target Hunter L value of  $49.0 \pm 1.0$ . Samples were periodically taken during roasting to measure roast color using a Hunter Lab DP 9000 (Hunter Associates Laboratory, Resto, VA). Conveyor belt speed was adjusted as needed to maintain the target Hunter L value throughout the roasting process. The peanuts were cooled with forced air at room temperature and 140 lbs. of the roasted peanut lot was subdivided into three sub lots. Each sub lot was color sorted to form three accepts and three reject fractions using a Sortex Color Sorter. All color sorted and the unsorted control roasted peanuts were stored in glass jars at  $30^{\circ}$ C in a Fisher Isotemp Incubator, model 304R (Fisher Laboratory Products, Pittsburgh, PA). Samples were taken from storage at 0, 1, 2, 4, 8, and 12 weeks for analytical testing.

### **Sortex 3000 Color Sorter**

All roasted peanuts were color sorted using a Sortex 3000 color sorter (Figure 3). The Sortex 3000 was particularly suited for sorting low volumes of high-value commodities, since the output and efficiency of the machine is very high (Sortex Ltd., 2002). The feed system had an inclined chute, which aligned the peanuts and ensured that the product passed through the machine at a constant speed. The optical system (CCD camera technology) combined with fast, precise ejectors segregated darker roast colored peanuts from the lighter ones. The sorter had two single channels and three sensors surrounding each channel. 3 cameras set at 120° to each other, providing an all-round view, inspected a single row of roasted peanuts. The Sortex 3000 employed a bi-chromatic sorting method, which compared the intensity of light reflected in 2 of the primary wavebands (red/green or red/blue). This allowed the camera to discriminate by color as well as by intensity (Bee and Honeywood, 2002). The intensity of the light reflected off each peanut was measured allowing those that appeared darker than normal (average Hunter L value = 50) to be identified as a reject product. The ejector used short blasts of compressed air to remove the undesirable peanuts (rejects) from the main stream of peanuts. The accepts and the rejects were collected into separate receptacles. The color sorting capacity of the machine was approximately 600 kg of peanuts per hour. (Sortex Ltd, 2002).

## **Color Sorting**

After keeping aside approximately 10 lbs. of roasted peanuts, (unsorted sample) 140 lbs. of the remaining roasted peanuts were divided into three sub lots. Single seed color was determined for 400 randomly selected peanuts from the unsorted roasted peanuts. This information was used to determine the sensitivity level of color sorter for color sorting the three sub lots. Each sub lot was color sorted to remove progressively higher percentage of dark roasted peanuts. The sensitivity parameter for color sorting the first lot was adjusted to remove 4 % by weight of the darkest colored peanuts to form the first reject and corresponding fraction of lighter peanuts, the first accept. Sensitivity of the color sorter was increased by 10 % and 20 %, when color sorting the next two lots, in order to increase the weight percentage of dark peanuts in the reject fractions. For the purpose of experimental analyses, each accept and reject fraction produced as a result of color sorting weighed 8-10 lbs. Color of all samples and differences in color between each accept and corresponding reject were determined with a Hunter L colorimeter.

Before color sorting the peanut lots, the color sorter was calibrated with hand sorted roasted peanuts corresponding in color to the desired accept and the reject colors. Adjusting the contour of the bichromatic color map was used to modify the sensitivity of the machine to control the amount of rejects during each color sort. Fine-tuning of the color map decreased the loss of accept peanuts.

### **3.3.2 Analysis**

#### **Hunter L Color**

The Hunter Lab Color measurement closely matches the degree of perceived color difference by humans. L is the lightness variable on a scale of 0-100. The Hunter L colorimeter was calibrated with white and black calibration plates and the colors of the unsorted and all color sorted fractions were determined using the Hunter Lab DP 9000 (Hunter Associates Laboratory, Resto, VA). Peanuts were placed in a 3-inch diameter petri dish and color measurements were taken in triplicate for each sample after remixing the same peanuts. Hunter L value was also determined for the unsorted and the accept samples after they were ground to paste for descriptive sensory analysis.

#### **Moisture Determination**

Moisture content of the raw, unsorted sample and all the color-sorted fractions was determined using the method described by the ASAE Yearbook of Standards S410.1 (Young *et al.*, 1982b). Approximately 20g of each sample was ground in a Krups household coffee mill (Krups North America, Closter, NJ) for 2-3 minutes. Approximately 5 g of each ground peanut sample was placed in previously weighed 1-inch diameter aluminum pans and heated for 6 hours at 140 °F. The samples were cooled to ambient temperature and weighed again. Each sample was analyzed in triplicate.

#### **Oxidative Stability Index (OSI) and Peroxide Value (PV)**

Approximately 85g of each peanut sample was ground in a Krups household coffee mill (Krups North America, Closter, NJ) and subsequently wrapped in a double layer of cheesecloth. The oil was pressed from the samples for 10 minutes at 20,000 psi using a hydraulic Carver Laboratory Press (Fred S Carver, Inc., Summit, NJ). The oil was filtered

through glass wool and  $5.0 \pm 0.2$  g was weighed into disposable glass tubes for OSI analysis (AOCS, 1992) using an Oil Stability Instrument (Omnion, Inc., Rockland, MA). The tubes were sealed with two-hole rubber stoppers and placed in  $110^\circ$  C heating blocks on the oil stability instrument. A disposable Pasteur pipette was inserted through the stopper and into the oil through a tube in the rubber stopper. A second pipette inserted into the glass tube was connected via plastic tubing to a second glass tube containing 50 ml of deionized water and a conductivity sensor. Compressed air was purged through the oil at 38 psi and as the oil oxidized volatile compounds were transferred into the water and the change in conductivity in the water was determined with the conductivity sensor connected to a data acquisition system. OSI for each sample was performed in duplicate. OSI was determined by the acquisition software to be the number of hours until the rate of increase in conductivity became exponential.

Peroxide value was determined according to AOAC method 965.3 (AOAC, 1995) using  $5.0 \pm 0.2$  g of filtered oil weighed into an Erlenmeyer flask. The oil was dissolved in 30.0 mL of an acetic acid / chloroform (3:2 v/v) solution and 0.5 mL of a saturated potassium iodide solution was added. The sample was shaken for 1 minute. 30 mL of deionized water and 0.5 mL of 1% starch solution were added into the flask. The solution was then titrated with sodium thiosulfate, at concentrations of 0.001 N, 0.01 N or 0.1N, until a change in color was perceived. PV, performed in duplicate, was reported as milliequivalent of peroxide/kg of oil. Starch was purchased from J.T. Baker chemical Co. (Phillipsburg, NJ) and all other chemicals were purchased from Fisher Scientific, Co. (Pittsburgh, PA).

## Carbohydrate Analysis

Samples were first defatted by Soxhlet extraction with 99% hexane/1% ethyl ether according to Oupadissakoon *et al.*, (1980). A 30-50 mg sample of finely ground defatted peanut meal was placed into a 25 mL screw capped tube. 15 mL of extraction solvent and 1 mL of internal standard mix were added. The extraction solvent was prepared with 600 mL of methanol (Fisher Cat No. A-452-4), 250 mL of chloroform (Fisher cat No. C297-4) and 150 mL of water. The internal standard solution was prepared with 800-ppm lactose (Aldrich Cat No. 25,971-3) and 400 ppm cellobiose (Fluka Chemie, Steinheim, Germany, Cat No.22150) dissolved in water by sonication in a 100 mL volumetric flask. Each sample mixture was vortexed for 1 minute and sonicated for 20 minutes. The contents were then centrifuged in a IEC Model K centrifuge. The solution was decanted into a 50 mL beaker and the solid pellet was discarded. The solution evaporated overnight. 1 mL of water was added to the beaker and swirled / sonicated to dissolve the residue. The solution was stored in a 2 mL screw capped vial. 50  $\mu$ L of solution was withdrawn, diluted to 2 mL with water and passed through a Dionex On Guard-H filter fitted to a syringe. After discarding the first mL, the second mL was collected in an HPLC auto sampler vial. The HPLC standard solution consisted of 5 mg of myo-inositol (Sigma Cat No. I-5125), 10 mg of glucose (Sigma Cat No. G-5250), 15 mg of fructose (Fisher Cat No. L-95), 50 mg of sucrose (Fisher cat No. S-5), 20 mg of raffinose (Aldrich Cat No. 20,667-9) and 20 mg of stachyose (Sigma Cat No. S-4001) dissolved in 30 mL of water. The HPLC standard was prepared by mixing 9.5 mL of water with 250  $\mu$ L of internal standard solution and 250  $\mu$ L of standard solution and the standard was used at frequent intervals during the experiment.

All the extracts were analyzed by high performance liquid chromatography (HPLC) using a Dionex BioLc (Dionex Corporation, Sunnyvale, CA) at a controlled temperature of 25 °C. The system consisted of a gradient pump, an auto sampler and a pulsed amperometric detector (PAD). The mobile phase was 200 mM NaOH (Fisher Cat No. SS254-1) at an isocratic flow rate of 1.0 mL/min. The column used was a Dionex PA-1, 250 mm in length and 4mm i.d., fitted with a Dionex PA-1 Guard column. The detector was programmed to run a quadruple waveform as recommended by the manufacturer. A shift in the detector range was programmed from 100 to 500 nC between 4 and 7 minutes to allow sucrose to be quantified along with other sugars. A 10 µL sample was injected using a 25 µL or smaller sample loop. The lactose internal standard was used to quantify sucrose. Cellobiose was used as the standard for the other known carbohydrate components. A quantitative value for each unknown carbohydrate was obtained by constructing a ratio of the peak height of the unknown to the cellobiose standard peak height. All internal and reference carbohydrates were obtained from Sigma Chemical Corporation (St. Louis, MO) except cellobiose

### **Fatty Acid Profile**

The fatty acid analysis was based on the method developed by Bannon *et al.*, in 1982. 20-30 mg of the oil sample (about 1 drop) was weighed into a 50-ml screw capped tube. One mL of 0.5 M methanolic (Fisher Cat No. A-452-4) potassium hydroxide solution (Fisher Cat No. P-250) was added for the saponification of glycerides. The tube was then heated for 5 minutes in a water bath at 80°C and continued for ten minutes after the addition of 1 mL of boron trifluoride (Sigma, Cat No.B1252) in 14% methanolic solution. 1 mL of water and 1 mL of hexane (Optima grade, Fisher Cat No. H302-4) were added after the tubes cooled slightly. Each solution was vortexed for 30 seconds and then allowed to settle into two

phases at room temperature. An aliquot of the hexane layer was transferred into a vial and a small amount of anhydrous sodium sulphate (Sigma cat No. 238597) was added. The prepared hexane solution was used for direct injection into a gas chromatograph (GC). The fatty acid methyl ester standards, Kel-Fim FAME-5 Standard (Matreya Inc., Pleasant Gap, PA, Cat No.4210) and GLC-21 Standard (Nu-Check Standards) were used for identification and comparison of fatty acids present in the test samples.

The fatty acid methyl esters (FAME) were analyzed with a Perkin Elmer Autosampler XL system (Perkin Elmer Instruments, Norwalk, CN) equipped with a flame ionization detector (FID) and a capillary column containing 70% cyanopropyl polysilphenylene-siloxane as the stationary phase (30 m length, 0.25 mm i.d., 0.25  $\mu\text{m}$  film thickness). Helium at 20 psi (1.85 mL/min) was used as the carrier gas. Hydrogen flow was set to 45 ml  $\text{min}^{-1}$  and the airflow was fixed at 450 ml  $\text{min}^{-1}$ . The split flow ratio was 76.9 mL/minute. The temperature of both the injector and the detector was 265 °C. A temperature program was used with an initial oven temperature of 60° C held for 2 min, which was increased to 180°C at 10°C  $\text{min}^{-1}$ , and then programmed to a final temperature of 235°C at 4°C  $\text{min}^{-1}$ . The amount of sample injected was 1  $\mu\text{l}$ . The total amount of palmitic (16:0), stearic (18:0), oleic (18:1), linoleic (18:2), linolenic (18:3), arachidic (20:0), eicosenoic, (20:1), behenic (22:0) and lignoceric (24:0) acids were calculated by determining the percent area of each FAME. The mean value of three replicates was used to determine the concentration of each fatty acid. Peaks in ascending retention time order were as follows: C16:0, C18:0, C18: 1, C18: 2, C18: 3, C20:0, C20: 1, C22:0, C24:0.).



### **Free Fatty Acid Analysis**

Oil was pressed from the samples using a hydraulic Carver Laboratory Press (Fred S Carver, Inc., Summit, NJ) for 10 minutes at 20,000 psi. The oil was filtered through glass wool and approximately  $7.0 \pm .05$  g of oil was weighed into a 250 mL Erlenmeyer flask to which was added 50 mL of neutralized isopropyl alcohol (99% neutralized with NaOH) and 1 mL of phenolphthalein indicator solution (1% w/v in 95% alcohol). The solution was titrated with 0.25 to 0.0025 N NaOH and shaken vigorously until a faint and persistent pink color was obtained. The phenolphthalein imparted a pinkish hue to the solution at pH 8-10. The free fatty acid was equal to the number of mL of 0.25 N NaOH used in the titration. When a different normality of NaOH was used then the number was calculated as follows:

$$\text{FFA} = (\text{normality used} / 0.25) * (\text{mL used in titration})$$

The method of free fatty acid analysis was obtained from A.O.C.S. Official Method Aa 6-38 by Booker (1992).

### **Single Seed Color Distribution**

A Minolta Chroma Meter CR-300 (Minolta Corporation, Mississauga, Ontario, Canada) was used to determine the single seed color of 400 individual peanuts randomly selected from each sample. The colorimeter consisted of a compact tristimulus color analyzer for measuring reflective colors of surfaces. The machine had an 8 mm-diameter measuring area (head) and used a diffuse illumination and a  $0^\circ$  viewing angle. A pulsed xenon arc lamp provided illumination on the sample surface. Six high-sensitivity silicon photocells were used to measure both incident light and reflected light. The instrument displayed absolute measurement of Hunter L value for each peanut. Whole peanuts were selected for color evaluation.

### **Total Oil content (Nuclear Magnetic Resonance)**

A Maran Ultra (Resonance Instruments Ltd., Whitney, Oxfordshire, United Kingdom) operating at 11 MHz was used to determine total oil and moisture content of approximately 10 g of each sample by pulsed nuclear magnetic resonance (AOCS Official Method Ak 5-01, 2001). An alternating electromagnetic field applied in the form of an intense 90° radio frequency (RF) pulse was used to excite all the hydrogen nuclei. The free induction decay (FID) was recorded following the 90° pulse. The maximum amplitude of the signal was proportional to the total number of protons from the water and oil phases of the sample. The application of a second RF pulse produced a spin-echo signal when only the signal from the oil phase contributed to the FID. The difference between the two amplitudes was calculated to be proportional to the moisture content. Once the apparatus was suitably calibrated, the automatic conversion of measured signals estimated the percentages of oil and moisture in each test sample.

### **Descriptive Sensory Analysis**

The unsorted and all accept samples were ground into a paste using a Cuisinart Little Pro Plus food processor (Cuisinart Corp., East Windsor, NJ). To maintain paste temperature below 32°C, a grind – cool procedure was utilized (Sanders *et al.*, 1989 b, c) The procedure limited grinding to two, 2 minute grinds with one minute cooling between each one, followed by several 1 minute grinds with 30 seconds cooling between grinds until the desired paste consistency was achieved. Peanut pastes were used for sensory analysis to reduce any variability within the sample (Sanders *et al.*, 1989 a). Paste samples were stored at –22°C prior to and after pasting and removed from the freezer 8-10 hours before descriptive sensory

analysis to equilibrate to room temperature. Each peanut paste sample was coded with randomly generated 3-digit numbers. A highly trained descriptive sensory panel consisting of 9-10 panelists evaluated each sample twice. The Spectrum ® method and the peanut lexicon developed by Johnsen *et al.*, (1988) and Sanders *et al.*, (1989 b) were utilized to evaluate all the flavor and off-flavor descriptors. A reference paste with known intensities for the peanut flavor descriptors was provided during each evaluation. Water and salt-less crackers were provided between samples. Roasted peanutty, sweet aromatic, dark roast, raw/ beany, woody/hulls/skins, musty, fruity /fermented, painty, plastic chemical, sweet, bitter, and astringency were the attributes evaluated on a 0-15 point Spectrum intensity scale (Meilgaard *et al.*, 1999) (Table 1).

### **3.3.3 Statistics**

All the analytical experiments were conducted in duplicate or triplicate. Means with standard deviation were reported. Analysis of variance (ANOVA) was applied to analyze the variance in the pooled data of various analyses (SAS Institute Inc., Cary, NC).

### 3.4 Results and Discussion

#### Color Distribution

The color of roasted peanuts has important quality implications and is associated with roast peanutty flavor and aroma, which develop during roasting (Pattee *et al.*, 1991). There is evidence of variability in roast color, flavor, storability and other quality characteristics of individual seeds within commercial sized peanut lots (Sanders, 1989 a; Sanders and Bett, 1995). This variability is attributed to variable maturity distributions (percentage of each maturity class) that exist in screen-sized lots (Sanders *et al.*, 1989 a).

Hunter L values are the primary color parameter for roasted peanuts. A Hunter L value of  $49 \pm 1$  is considered as a medium roast color and is associated with optimum roast peanut flavor intensity (Pattee *et al.*, 1991). Sanders *et al.*, (1989 a) reported that for peanuts of the same commercial size, immature peanuts roasted darker (lower Hunter L value) than mature peanuts for a given duration of roasting. Williams *et al.* (1987) and Sanders (1989) reported that higher percentage of immature peanuts increased the potential for a negative effect in any peanut lot.

Roasted peanuts in this study had a distribution of color (Hunter L) that ranged from 36 to 64 (Figure 3.1). Roasted peanuts were sorted at three different levels of color sorter sensitivity and successively higher percentages (4, 10 and 15 %) of rejects were removed in each sort (Figure 3.2). In the first color sort, 4 % (by weight) of the darkest roasted peanuts were removed as rejects at a preset sensitivity level of 50. The mean Hunter L value of the first reject was 39.56. The first accept fraction consisted of 96 % of the remaining peanuts and had a mean Hunter L value of 48.98. At a higher color sorter sensitivity level (60), 10 % of the darker peanuts were removed and the reject and accept fractions had Hunter L values

of 41.35 and 49.06 respectively. In the third color sort, 15 % of dark peanuts were removed in the third reject fraction at the highest sensitivity level (70). The mean Hunter L values of the third reject was 42.93 and of the third accept was 50.16. In each color sort, the Hunter L value of the accept was higher than the corresponding reject by  $8 \pm 1$  (Table 3.1). The results confirmed the observation made by Sanders *et al.*, (1989 a, b) that when similar peanut color ( $49 \pm 1$ ) was used as roast objective, mature peanuts roasted lighter (higher Hunter L value) than immature peanuts. An examination of commercially roasted whole peanuts will show a distribution of roast colors associated with the maturity distribution of the lot (Sanders *et al.*, 1989 a).

The weight percentages of accept and reject fractions produced by color sorting depended upon the sensitivity level of the color sorter and the color distribution (percentage of each color) in the roasted peanuts. Color sorting at higher color sorter sensitivity produced larger fractions of rejects by weight. The rejects had a higher concentration of the darker roasted peanuts and the accepts consisted of lighter colored peanuts as seen in the single seed color distribution of 400 randomly picked roasted peanuts from each accept and reject fraction (Figure 3.3). However, the presence of some darker peanuts in the accepts and some lighter peanuts in the rejects could be attributed to errors in machine performance or less rigid calibration. Although color sorting at increased sensitivity resulted in larger reject fractions, there was also an increase in the loss of desirable product (accept peanuts).

### **Compositional Analyses**

Young *et al.*, (1972, 1974), Pattee *et al.*, (1974) and Sanders *et al.*, (1982, 1989 b) have reported the influence of maturity on peanut chemical composition, oil stability and other quality factors. The relative differences in the weight percent of moisture and lipid

content in the color sorted peanuts indicated compositional dissimilarities between the accept and reject fractions (Table 3.2).

Moisture content of the roasted peanuts was determined to be less than 1 % for all the color-sorted fractions and 7.13 % for the raw peanuts. All the reject peanuts had higher moisture percent (0.54-0.17%) than the accept fractions (0.09-0.15%). The results were in agreement with the observation made by Kim and Hung (1991) who reported lower moisture content in mature peanuts at harvest than in immature ones.

Pattee *et al.*, (1974) and Sanders *et al.*, (1982 a) observed that oil content increased from immature peanuts to nearly mature peanuts and then decreased slightly in the mature peanuts. The oil content of the accept fractions was slightly higher (54.03-54.33 %) than the oil content of the rejects (53.63-54.02 %) although the difference was significant only for the first accept and the first reject. Overall, the first reject with maximum concentration of darkest peanuts had the lowest oil content (53.63 %) among all color-sorted fractions. This clearly suggests that immature peanuts were more prevalent in the reject peanuts. Sanders *et al.*, (1980) reported that the dry weight of peanuts increased rapidly during maturation and these increases corresponded to an increase in oil content per seed. The data in this study was in agreement with the work of Sanders *et al.*, (1982) who determined progressive changes in oil content and composition in Pod Maturity Profile (PMP) stages.

Sanders *et al.*, (1980) reported that fractionation of the total oils from seeds at pod maturity profile (PMP) stages revealed that all lipid classes changed somewhat with maturity. The free fatty acid (FFA) content of all samples ranged between 1.95 and 2.58. All the rejects had higher FFA (2.45- 2.58) than the accepts (1.92-1.98) (Table 3.2). The data for the FFA

was consistent with the result reported by Sanders *et al.*, (1982) in which FFA decreased with maturation.

The oleic/linoleic (O/L) ratio ranged between 1.54 and 1.71 for all samples (Table 3.2). Linoleic acid is an unstable fatty acid and an inverse relationship exists between linoleic acid content and oil stability (Braddock *et al.*, 1995; Holly and Hammons, 1968; O'Keefe *et al.*, 1993). According to Sanders *et al.*, (1982 a) peanuts with high O/L ratios have slower lipid degradation and therefore better peanut oil stability. The O/L ratio of the first reject (1.54) was lowest among the color-sorted fractions. All other rejects also had significantly lower O/L ratio than the accepts. Worthington (1969), Young *et al.*, (1972), Sanders (1980) and Kim and Hung (1991) reported that O/L ratio increased with maturity of the peanuts.

Overall, the first reject fraction showed significantly lower oil content and O/L ratio, higher FFA and moisture content indicating the presence of a higher percentage of immature peanuts. The second and third reject fractions were not different in oil content but had higher FFA and moisture content and lower O/L ratio than the corresponding accepts. Peanut maturity is significantly related to biochemical composition and therefore overall quality (Sanders *et al.*, 1989; Sanders and Bett, 1995; Bett and Boylston, 1992). The application of color sorting reduces the percentage of immature peanuts in any peanut lot and may improve lot characteristics.

Many researchers have reported conflicting trends for changes in fatty acid profiles as peanuts mature. Increase in oleic (18:1) and decrease in palmitic (16:0), linoleic (18:2), arachidic (20:0), eicosenoic (20:1) behenic (22:0) and lignoceric (24:0) acids with peanut maturity have been observed by Worthington (1969), Young *et al.*, (1972), Cobb and

Johnson (1974) and Sanders *et al.*, (1982). However, decrease in oleic and increase in linoleic acid was reported by Lynd and Ansman (1989) and Hashim *et al.*, (1993).

Palmitic, stearic, oleic and linoleic acids made up more than 70% of peanut fatty acids (Table 3.3). Palmitic acid was lower in the unsorted and all accepts (9.50-9.55 %) than in the rejects (9.71-9.83 %). These data are in agreement with the result of previous studies (Worthington (1969), Young *et al.*, (1972), Cobb and Johnson (1974) and Sanders *et al.*, (1982) that immature peanuts have higher content of palmitic acid. There were no significant differences in stearic acid among all samples. The weight percent of oleic acid ranged between 48.75 and 51.01 % in all samples. All rejects had significantly lower oleic acid (48.75-49.19 %) than their corresponding accepts (50.75-50.98 %). These data agree with previous studies which have shown that mature peanuts have higher oleic acid than immature peanuts (Worthington (1969), Young *et al.*, (1972), Cobb and Johnson (1974) and Sanders *et al.*, (1982). Linoleic acid was present in higher amounts in all rejects (30.8-31.5 %) than the accepts. All rejects were higher in eicosenoic (1.35-1.37 %), behenic (3.16-3.31 %), and lignoceric (1.76-1.80 %) fatty acids than those in the accepts. The trends observed for these fatty acids were similar to those reported in studies by Worthington (1969), Young *et al.*, (1972), Cobb and Johnson (1974) and Sanders *et al.*, (1982). Overall, the results indicated that color sorting resulted in relatively small changes in the concentration of various fatty acids in the color-sorted fractions especially in those fractions (accepts and rejects) produced at higher color sorter sensitivity. In general, the accept fractions had similar content of stearic acid, more oleic acid and lower amounts of linoleic, eicosenoic, behenic, and lignoceric acids. The results agree with those by Young *et al.*, (1971) and Sanders *et al.*, (1982) that peanut oil content and composition are related to maturity.



According to Oupadissakoon *et al.*, (1980) climate, maturity, curing and storage among other factors affect the precursor levels of various chemical components. Basha *et al.*, (1976) reported that the carbohydrate content in immature peanuts of all cultivars declined as they approached maturity. Pattee *et al.*, (1974) observed similar changes and hypothesized that maturing seeds used stored, non-structural carbohydrates as a source of energy for the synthesis of lipids and proteins.

The total sugar content (Table 3.4) was approximately 61 to 82 mg/g in all samples. The first reject fraction, which had the maximum concentration of the darkest peanuts, had significantly higher levels of inositol (0.76 mg/g), glucose (0.21 mg/g), fructose (0.20 mg/g), sucrose (70.5 mg/g), raffinose (1.53mg/g), stachyose (8.86 mg/g) and total sugars (82.06 mg/g) than the first accept. Both the first and second rejects were higher in glucose, fructose, sucrose and total sugar content than the first and second accept fractions respectively. However, the third reject was not significantly different from the third accept for any of the sugars. The data is in agreement with the findings of Newell (1967), who reported that immature peanuts roasted darker because they had higher amounts of reducing sugars, glucose and fructose, which participate in the browning process (Maillard reaction) during roasting. The data indicated that there was a decrease in sugar content with peanut maturity as reported by Pattee *et al.*, 1974 and Kim and Hung, 1991. The data supported the observation by Kim and Hung (1991) that fewer differences were observed in the chemical composition after the peanuts matured to a certain degree (orange mesocarp color). It can be assumed that the third reject and third accept were similar and therefore did not have significant differences in the content of various sugars.

## **Sensory evaluation**

According to Sanders (1989 a), maturity distribution influences flavor characteristics based on the percentages of the various maturity classes in a screen-sized lot. Immature peanuts have been shown to have more reactive and less stable components (oil and protein composition, moisture, enzymes) and to possess more potential for off-flavor (Sanders 1989 a, b).

Descriptive sensory analysis indicated that all accept samples had similar intensities for all flavor descriptors (Table 3.5) among the unsorted and accept fractions. The unsorted peanuts and the accepts showed a similar rate of decrease in roast peanutty intensity over a period of 12 weeks in storage from ca. 4.8 to ca. 4.0. All samples developed off flavors such as painty (1.4-3.4) and cardboardy (1.1-2.3) in storage (Figure 3.4). These off-flavors are associated with lipid degradation and are indicative of lower oil stability. During lipid oxidation, volatiles such as hexanal and pentanal are formed from hydroperoxides (How, 1984; Bett *et al.*, 1992). These compounds are responsible for the cardboardy and painty off flavor attributes.

Overall, the small differences in Hunter L values among the unsorted and the color sorted accepts did not appear to cause flavor differences. The sensory data indicate that color sorting of roasted peanuts did not significantly improve the flavor of accept fractions when 4, 10 and 20 % of dark peanuts were removed as rejects during color sorting.

## **Shelf-life characteristics**

Oil stability influences peanut flavor and aroma quality during storage. Peanut oil contains more than 80 % unsaturated fatty acids making the oil susceptible to lipid oxidation. (Mercer *et al.*, 1990; Braddock *et al.*, 1995; Moore and Knauff, 1989; O'Keefe *et al.*, 1993).

The PV was between 0.59 and 1.41 and the OSI was between 13.75 and 16.38 for all samples at the beginning of the experiment (time T0) (Table 3.6). The unsorted peanuts and the accept fractions had a similar rate of increase in the peroxide value from ca. 0.59 to 59.0 and a decrease in the OSI values from 13.75 to 2.20 over a period of 12 weeks in storage (Figure 3.5).

Color sorting did not result in significant variations in shelf-life characteristics of the accepts in comparison to the unsorted peanuts. The development of cardboardy and painty off flavors in all samples coincided with an increase in peroxide value and decrease in OSI value over time and indicated a similar rate of lipid degradation for all samples.

### **3.5 Conclusion**

Color sorting at progressively higher sensitivity resulted in rejects with increasingly higher percentage of dark peanuts (4, 10 and 20 %) and accepts consisting of lighter colored peanuts. Chemical analysis of all color-sorted fractions confirmed that the rejects were composed of immature peanuts. Shelf life analysis indicated that there was a similar rate of lipid degradation in the accepts and the unsorted peanuts. Sensory evaluation indicated that color sorting did not improve the flavor quality of roasted peanuts as all accepts and the unsorted peanuts had similar intensities for all flavor attributes initially and in storage. The results indicated that color sorting did remove immature peanuts from the roasted peanut lot but did not result in a measurable improvement in flavor and shelf life of the remaining peanuts in the lot.

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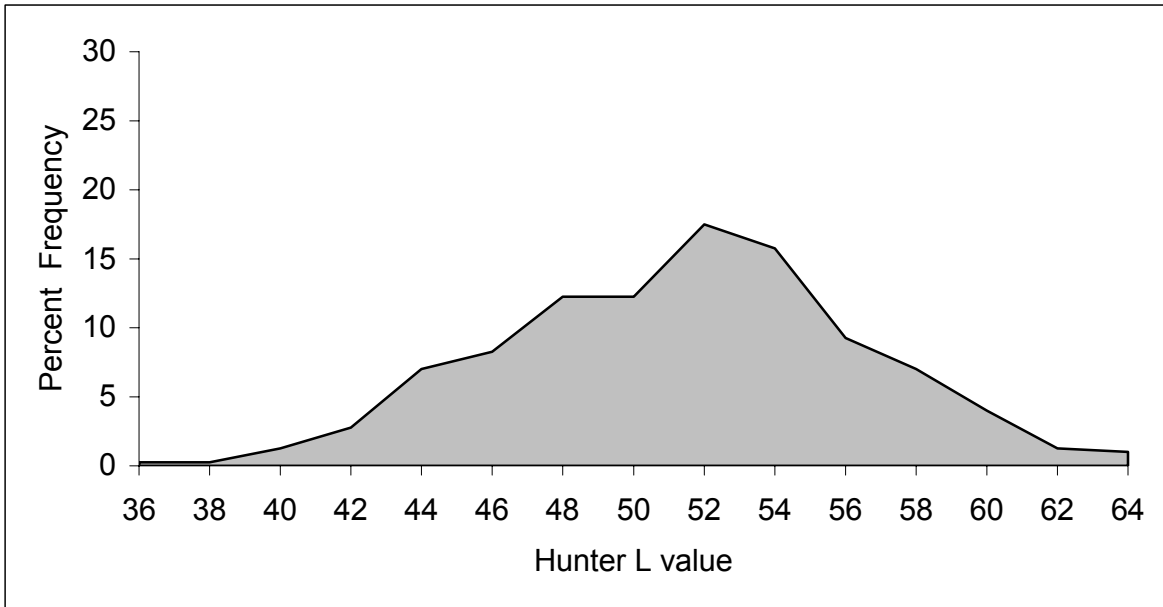


Figure 3.1. Single seed color distribution of 400 randomly picked roasted peanuts

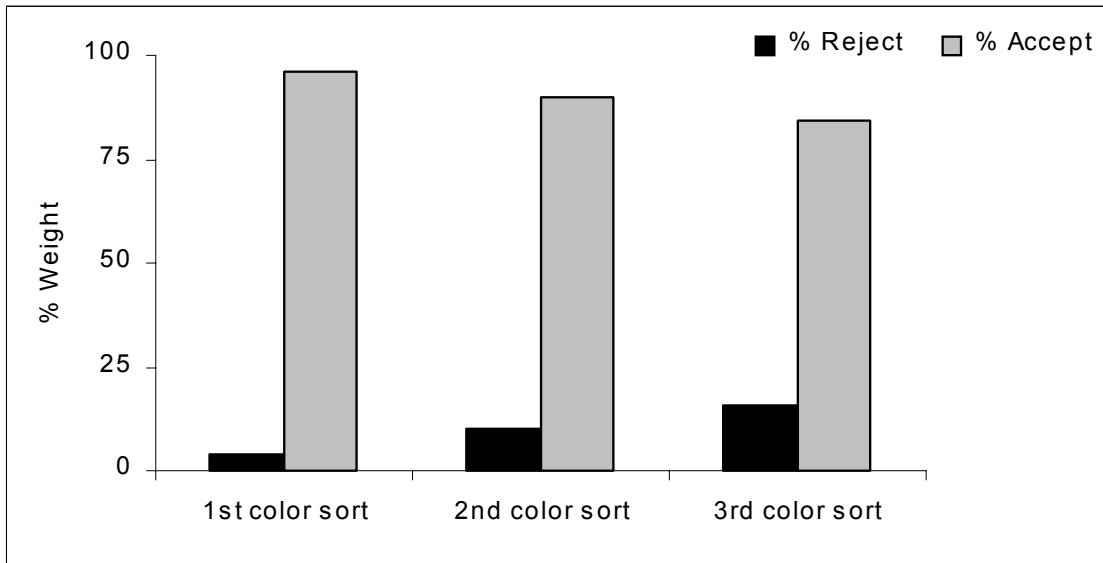


Figure 3.2. Weight of color sorted accepts and rejects produced by color sorting roasted peanuts at three color sorter sensitivity levels

Table 3.1. Mean Hunter L values of roasted peanuts of unsorted and color sorted accepts and rejects

Hunter L values of Roasted Peanuts						
Color Sorted Fractions						
Unsorted	Accept 1	Accept 2	Accept 3	Reject 1	Reject 2	Reject 3
48.34	48.98	49.06	50.16	39.56	41.35	42.93

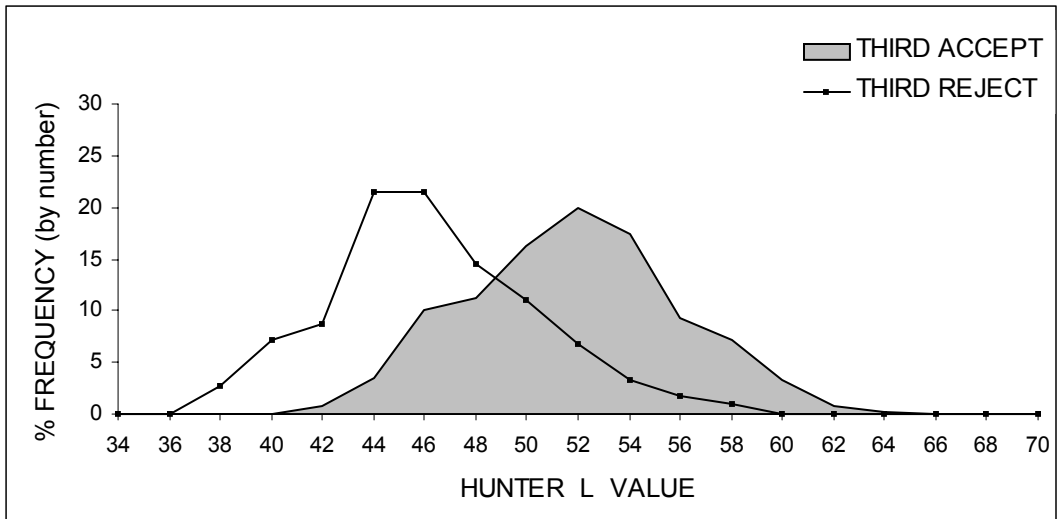
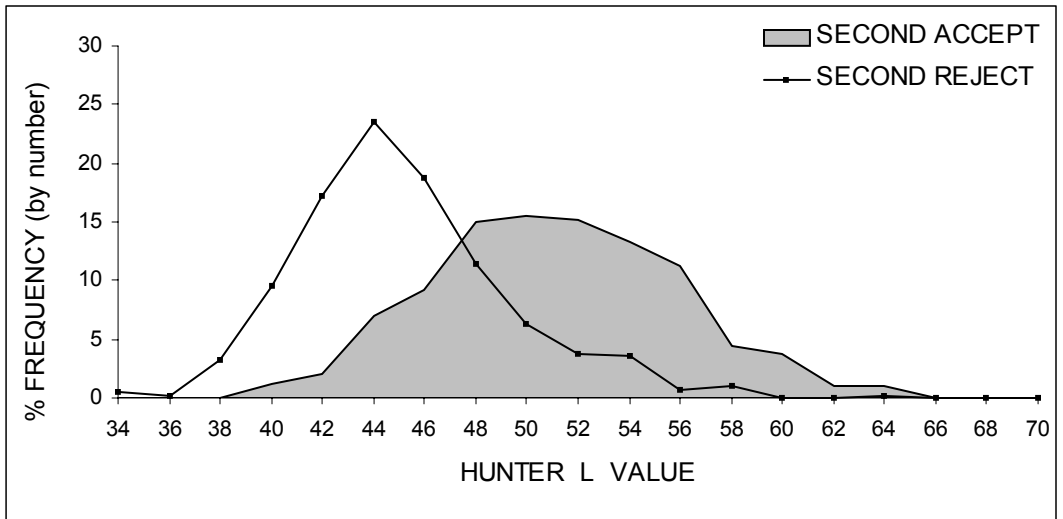
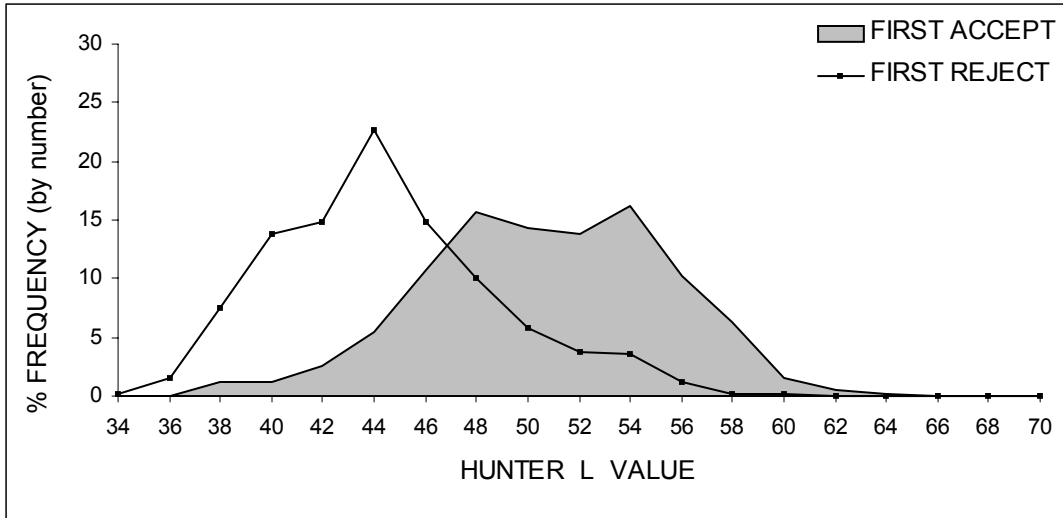


Figure 3.3. Single seed color distribution of 400 randomly picked roasted peanuts from the first, second and third accepts and the corresponding rejects produced by color sorting



Table 3.2. Moisture and oil characteristics of all samples

Sample		Moisture %	Oil %	Free Fatty Acid	O/L ratio
Raw	NA	7.14 <sup>a</sup>	50.26 <sup>c</sup>	2.32 <sup>a</sup>	1.77 <sup>a</sup>
Roasted Peanuts					
Unsorted	NA	0.32 <sup>cd</sup>	54.27 <sup>a</sup>	2.00 <sup>b</sup>	1.67 <sup>b</sup>
Accept	1	0.09 <sup>e</sup>	54.33 <sup>a</sup>	1.93 <sup>b</sup>	1.70 <sup>b</sup>
Reject	1	0.18 <sup>cd</sup>	53.63 <sup>b</sup>	2.45 <sup>a</sup>	1.54 <sup>d</sup>
Accept	2	0.16 <sup>de</sup>	54.08 <sup>ab</sup>	1.95 <sup>b</sup>	1.71 <sup>b</sup>
Reject	2	0.34 <sup>c</sup>	53.84 <sup>ab</sup>	2.58 <sup>a</sup>	1.57 <sup>cd</sup>
Accept	3	0.12 <sup>e</sup>	54.02 <sup>ab</sup>	1.98 <sup>b</sup>	1.68 <sup>b</sup>
Reject	3	0.58 <sup>b</sup>	54.03 <sup>ab</sup>	2.50 <sup>a</sup>	1.60 <sup>c</sup>

Means in a column followed by common superscript letter are not significantly different (P>0.05)

Table 3.3. Fatty acid composition of all samples (Weight %)

		C 16:0	C18:0	C 18:1	C 18:2	C 20:0	C 20:1	C 22:0	C 24:0
Raw	NA	9.74 <sup>a</sup>	2.53 <sup>a</sup>	51.01 <sup>a</sup>	28.84 <sup>e</sup>	1.38 <sup>a</sup>	1.35 <sup>a</sup>	3.09 <sup>bcd</sup>	1.68 <sup>bc</sup>
Roasted Peanuts									
Unsorted	NA	9.50 <sup>b</sup>	2.42 <sup>b</sup>	50.57 <sup>b</sup>	30.2 <sup>cd</sup>	1.32 <sup>bc</sup>	1.29 <sup>b</sup>	3.0 <sup>cde</sup>	1.64 <sup>c</sup>
Accept	1	9.55 <sup>b</sup>	2.43 <sup>b</sup>	50.93 <sup>ab</sup>	29.97 <sup>d</sup>	1.30 <sup>c</sup>	1.27 <sup>bc</sup>	2.9 <sup>e</sup>	1.59 <sup>c</sup>
Reject	1	9.83 <sup>a</sup>	2.39 <sup>b</sup>	48.75 <sup>d</sup>	31.50 <sup>a</sup>	1.31 <sup>bc</sup>	1.35 <sup>a</sup>	3.16 <sup>abc</sup>	1.69 <sup>bc</sup>
Accept	2	9.52 <sup>b</sup>	2.43 <sup>b</sup>	50.98 <sup>a</sup>	29.84 <sup>d</sup>	1.32 <sup>bc</sup>	1.28 <sup>bc</sup>	2.97 <sup>de</sup>	1.62 <sup>c</sup>
Reject	2	9.75 <sup>a</sup>	2.41 <sup>b</sup>	49.00 <sup>cd</sup>	31.1 <sup>ab</sup>	1.35 <sup>abc</sup>	1.35 <sup>a</sup>	3.25 <sup>ab</sup>	1.76 <sup>ab</sup>
Accept	3	9.55 <sup>b</sup>	2.40 <sup>b</sup>	50.75 <sup>ab</sup>	30.14 <sup>d</sup>	1.30 <sup>c</sup>	1.25 <sup>c</sup>	2.90 <sup>e</sup>	1.59 <sup>c</sup>
Reject	3	9.71 <sup>a</sup>	2.44 <sup>b</sup>	49.19 <sup>c</sup>	30.8 <sup>bc</sup>	1.37 <sup>ab</sup>	1.37 <sup>a</sup>	3.31 <sup>a</sup>	1.80 <sup>a</sup>

Means in a column followed by common superscript letter are not significantly different (P>0.05)

Table 3.4. Composition of various sugars for all samples (mg/g of defatted meal)

		Inositol	Glucose	Fructose	Sucrose	Raffinose	Stachyose	Total Sugar
Raw	NA	0.53 <sup>abc</sup>	0.13 <sup>cd</sup>	0.07 <sup>e</sup>	66.65 <sup>ab</sup>	1.46 <sup>ab</sup>	8.12 <sup>abc</sup>	76.96
Roasted Peanuts								
Unsorted	NA	0.41 <sup>bc</sup>	0.09 <sup>d</sup>	0.14 <sup>cd</sup>	55.15 <sup>d</sup>	1.16 <sup>bc</sup>	7.28 <sup>bc</sup>	64.23
Accept	1	0.39 <sup>c</sup>	0.08 <sup>d</sup>	0.12 <sup>d</sup>	53.19 <sup>d</sup>	1.12 <sup>c</sup>	6.83 <sup>c</sup>	61.73
Reject	1	0.76 <sup>a</sup>	0.21 <sup>ab</sup>	0.20 <sup>ab</sup>	70.50 <sup>a</sup>	1.53 <sup>a</sup>	8.86 <sup>a</sup>	82.06
Accept	2	0.57 <sup>abc</sup>	0.13 <sup>bcd</sup>	0.15 <sup>cd</sup>	56.94 <sup>cd</sup>	1.35 <sup>abc</sup>	7.66 <sup>abc</sup>	66.80
Reject	2	0.78 <sup>a</sup>	0.22 <sup>a</sup>	0.21 <sup>a</sup>	68.70 <sup>ab</sup>	1.46 <sup>abc</sup>	9.04 <sup>a</sup>	80.41
Accept	3	0.65 <sup>ab</sup>	0.18 <sup>abc</sup>	0.16 <sup>bcd</sup>	60.75 <sup>bcd</sup>	1.46 <sup>ab</sup>	8.37 <sup>ab</sup>	71.57
Reject	3	0.68 <sup>a</sup>	0.18 <sup>abc</sup>	0.18 <sup>abc</sup>	64.67 <sup>abc</sup>	1.36 <sup>abc</sup>	7.85 <sup>abc</sup>	74.92

Means in a column followed by common superscript letter are not significantly different (P>0.05)

Table 3.5. Mean intensity scores for flavor descriptors of unsorted and accepts in storage

Week	Sample	Roast Peanutty	Sweet Aromatic	Dark Roast	Raw Beany	Woody Hulls /Skins	Cardboardy	Painty	Sweet Taste	Bitter
0	Unsorted	4.8	3.1	3.1	2.0	3.2	1.1	1.7	2.2	3.0
1	Unsorted	5.0	3.1	3.0	2.0	3.0	1.7	1.1	2.3	2.7
2	Unsorted	4.9	3.3	3.1	2.0	3.2	1.6	1.7	2.4	3.2
4	Unsorted	4.5	3.0	3.0	2.1	4.5	1.5	2.3	2.1	3.3
8	Unsorted	4.5	3.0	3.0	2.0	3.2	1.3	3.1	2.2	3.3
12	Unsorted	4.2	2.8	3.1	2.0	3.0	1.6	3.4	1.9	3.4
0	Accept 1	4.9	3.1	3.1	2.1	3.1	1.3	1.4	2.3	3.1
1	Accept 1	4.7	3.1	3.1	1.9	3.1	1.5	1.2	2.2	3.1
2	Accept 1	4.8	3.2	3.1	2.0	3.2	1.6	1.3	2.2	3.1
4	Accept 1	4.7	3.0	3.0	2.1	3.0	1.5	1.3	2.2	3.2
8	Accept 1	4.4	3.0	3.0	2.0	3.1	1.3	2.8	2.1	3.0
12	Accept 1	4.0	2.7	3.0	2.1	3.1	1.6	3.2	2.0	3.2

Week	Sample	Roast Peanutty	Sweet Aromatic	Dark Roast	Raw Beany	Woody Hulls /Skins	Cardboardy	Painty	Sweet Taste	Bitter
0	Accept 2	4.8	3.2	3.1	2.1	3.1	1.1	1.4	2.3	3.1
1	Accept 2	4.9	3.1	3.0	2.0	3.0	1.3	1.3	2.3	2.8
2	Accept 2	5.0	3.3	3.0	2.0	3.2	1.7	1.4	2.4	3.2
4	Accept 2	4.8	3.1	3.0	2.1	3.1	1.9	2.1	2.1	3.0
8	Accept 2	4.5	3.1	3.1	2.1	3.1	1.6	2.6	2.2	3.1
12	Accept 2	4.4	3.0	3.0	2.1	3.1	2.3	3.3	2.1	3.0
0	Accept 3	4.9	3.2	3.0	2.0	3.1	1.2	1.5	2.3	3.0
1	Accept 3	4.9	3.3	3.0	2.1	3.1	1.3	1.5	2.3	3.0
2	Accept 3	4.7	3.2	3.0	2.0	3.1	1.3	1.3	2.3	2.8
4	Accept 3	4.5	3.2	3.0	2.0	2.9	1.2	1.7	2.3	2.9
8	Accept 3	4.5	2.9	3.0	2.0	3.1	2.0	2.8	2.1	3.2
12	Accept 3	4.4	3.0	3.0	2.1	3.1	1.3	3.4	2.0	3.0

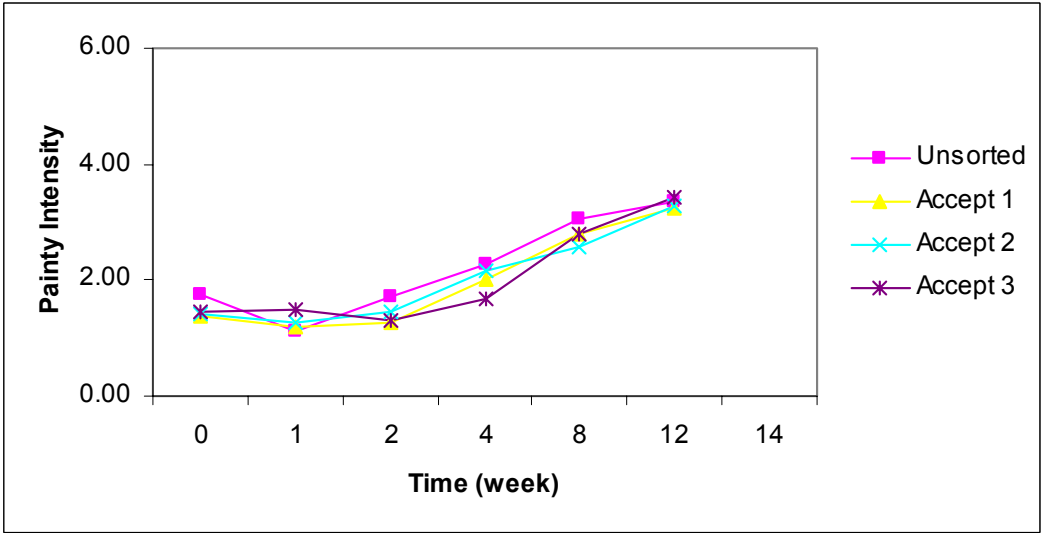
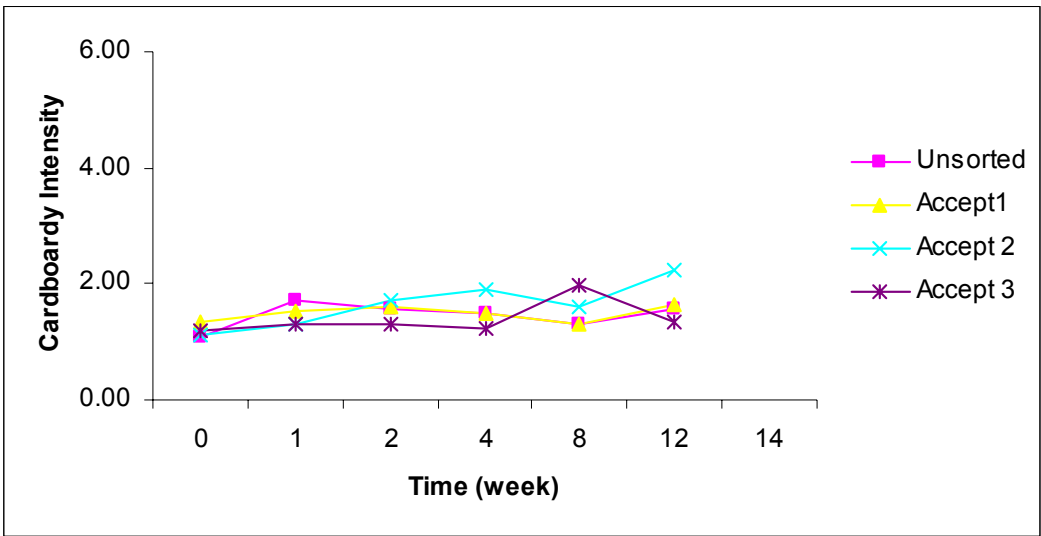
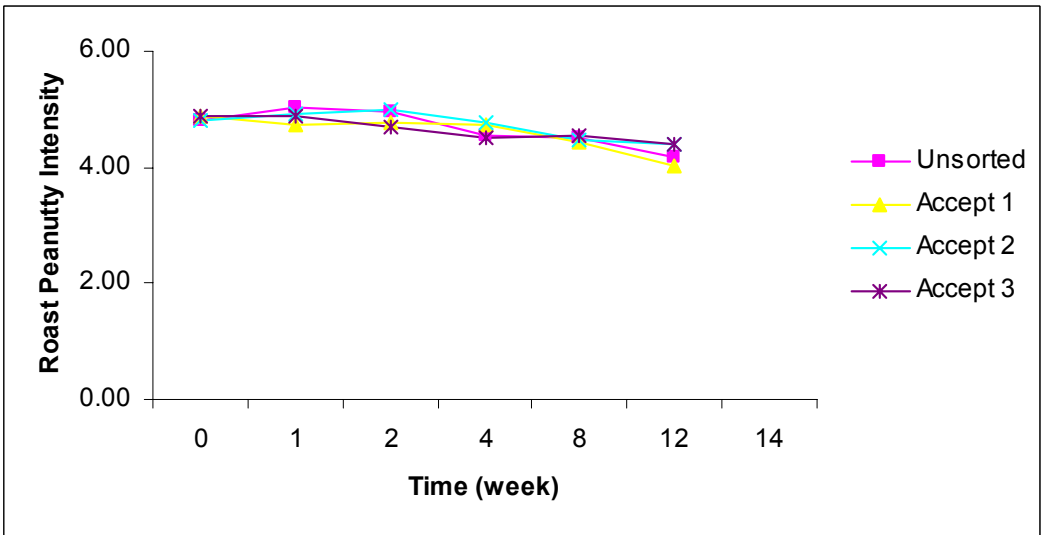


Figure 3.4. Changes in the intensity of roast peanuttty, painty and cardboardy flavor attributes of the unsorted and accepts during storage

Table 3.6. PV and OSI of all samples at time T0 and PV and OSI of unsorted and accepts during storage

<b>Peroxide Value (meq/kg oil)</b>								
Week	Raw	Unsorted	Accept 1	Accept 2	Accept 3	Reject 1	Reject 2	Reject 3
0	0.59	0.60	1.30	1.40	1.40	0.68	0.70	0.74
1		7.30	9.50	9.50	9.00			
2		17.0	19.3	19.0	18.8			
4		32.5	33.5	30.5	31.0			
8		47.5	49.0	50.0	48.5			
12		59.3	61.0	58.7	59.0			
<b>Oxidative Stability Index (hours)</b>								
Week	Raw	Unsorted	Accept 1	Accept 2	Accept 3	Reject 1	Reject 2	Reject 3
0	9.70	15.80	14.36	13.89	13.75	15.25	15.09	16.38
1		10.63	9.74	9.58	10.19			
2		7.84	6.31	6.95	7.85			
4		5.34	4.66	4.23	4.31			
8		3.49	3.70	2.75	3.08			
12		2.20	2.28	2.24	2.30			

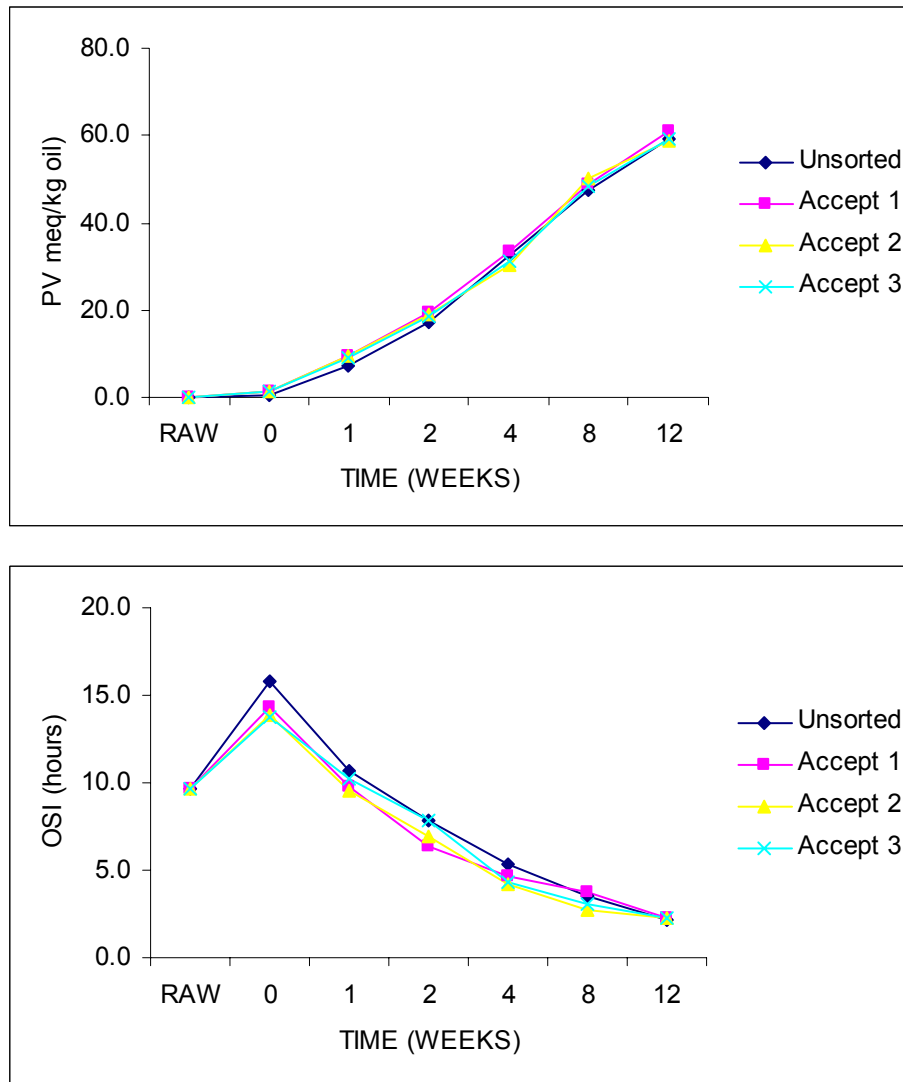


Figure 3.5. PV and OSI values of unsorted and accepts during storage