Development of standardized dry roasting procedures for Virginia type peanuts

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Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science in Life Science
In
Food Science and Technology

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August 11, 2021
Blacksburg, Virginia

Keywords: Peanuts, Colorimetry, Roasting, Optimization, Volatile Analysis

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ABSTRACT

Peanuts are grown around the world and in United States where most peanuts are consumed after roasting. Peanuts are roasted to a specified color on L*a*b* scale as it is correlated with quality and acceptability. Two batches of Virginia type peanuts were acquired, one normal and other a high oleic variety. A surface response model using the Box-Behnken design was developed for Behmor 2000AB and GeneCafe coffee roasters, for normal and high oleic peanuts respectively with sample size, roast time and power/temperature as dependent variables and L* as a response variable. The model for Behmor was not significant ($p>0.05$ and $R^2 =0.87$) but with effect contribution of roast time while the GeneCafe model was significant ($p<0.05$ and $R^2=0.98$) with multiple first and second order effect contributions from temperature and roast time. Each model was validated and Behmor was found to be more consistent and predictable compared to GeneCafe. Both varieties of peanuts were roasted on each roaster and tested for volatile analysis using SPME GC/MS with high variation observed within samples which may be caused by uneven roasting. The volatile results showed similar trends for seventeen compounds between normal and high oleic samples. The Behmor roaster was more effective at predictable roasting for 50 to 100 g sample and more validation is needed on GeneCafe to improve its model. The results can help with quality testing of new varieties of Virginia type peanuts quickly without relying on large sample size typically used in other lab scale studies.

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GENERAL AUDIENCE ABSTRACT

Peanuts are grown around the world and in United States where most of it is consumed as a confection. They are roasted to a specified color on scale as it is correlated with quality and optimization. We wanted to develop a method of small-scale peanut roasting that allows peanut breeders to roast and evaluate quality of small samples of peanuts. We used an optimization method to test two different coffee roasters for peanut roasting (Behmor and GeneCafe roasters), with normal and high oleic peanuts. Behmor was more sensitive to changes in roast time while GeneCafe was more sensitive to temperature, roast time and combined effects. The models were validated on each machine and Behmor was found to be more consistent and predictable compared to GeneCafe. Peanuts were roasted on each roaster and tested for aroma compounds. The aroma compounds were similar between normal and high oleic samples. The Behmor roaster was more effective at predictable roasting of peanuts with sample size ranging from 50 to 100 g. Our results allow us to predictably roast very small lots of peanuts to support determination of flavor quality for peanut breeding research.

DEDICATION

To

My parents Haroon ur Rashid Khan and Sumaira Haroon who supported and persisted with me in failures and successes wholeheartedly.

ACKNOWLEDGEMENTS

In the name of Allah the most Gracious and Merciful. The deepest and most sincere appreciation goes to Virginia Tech food science department especially my advisor Dr. Sean O'Keefe for giving me the opportunity to learn and advance myself academically and personally. Without Dr. O'Keefe's guidance and supervision this project would not be possible. He was a great mentor and teacher. Further,

My committee members Dr. Jacob Lahne and Dr. Yun Yin for their support, guidance and understanding.

The entire VT Engage office, especially Campus Kitchen Staff including my supervisor Catherine Cotrupi, KaSandra Church and Meghan Kuhn. I will forever be grateful for their support and kinship as a Graduate Assistant. Without their assistance and funding I could not have finished my program. They will forever be my friends.

Islamic Society of New River Valley for allowing me to serve the community and accepting me as part of one like a family.

Further thanks to all my peers, faculty and staff in Food Science dept, who helped me finish my work.

TABLE OF CONTENTS

CHAPTER I
INTRODUCTION

Peanut (*Arachis hypogaea*) is grown all over the world including United States where it is an important cash crop. Most varieties are grown to improve yield; however, it is ideal to develop the crop that gives the best roasting quality attribute since most peanuts consumed in United States are consumed post roasting (Gama and Adhikari, 2019). As a first step peanuts are thermally processed, or roasted, in the manufacturing process of the consumer products to attain a explicit flavor, color, and texture (Perren and Escher 2013). Roasting peanuts significantly increases overall acceptance of nuts by enhancing the flavor, color, texture and appearance (Jindal et al. 2011). To improve final quality of the product including flavor and color, identifying roasting conditions that save time, money, or energy, is crucial to the industry (Smith and Barringer 2014). The quality of roasted peanuts is usually based on a specified color, which is correlated to the desired roasted peanut flavor (McDaniel et al. 2012). For optimum roasted peanut attribute sensory response, the CIELAB L* value was reportedly ranged from 58 to 59 ± 2 (Pattee and others 1991). A darker roasted nut would have a lower L* color value while under roasted nuts would have higher values.

Although genotype does affect the overall flavor profile of the roasted product (Pattee et al. 1995), other factors include the type of roasting, variables influencing the roast process, storage conditions and moisture content. (Moss and Otten 1989b; Vercellotti et al. 1992; Pattee and Giesbrecht 1994; Williams et al. 2006; Jindal et al. 2011; Shi et al. 2018; Bagheri et al. 2019).

Moreover, over the last few decades, high oleic trait peanuts have been developed to improve shelf life post processing. Since, carbon-carbon double bond within fatty acids are more susceptible to oxidation, it has been demonstrated that increasing the ratio of oleic (18:1n-9) to linoleic (18:2n-6)

acid reduces the overall oxidation, which improves the flavor profile and shelf life of the peanut product (Jung et al. 2000)(Braddock et al. 1995).

There are different ways to roast peanuts, including deep frying, blister, and dry roasting. Most studies use different convection techniques with high sample size. Beside continuous belt type roasters, drum roasters are also used. They are usually preferred for small scale roasting where a sample is limited in quantity, and roasting is only preferred in finite batches rather than continuous processing. In the USA, drum roasters are primarily used for roasting coffee beans and are thus designed specifically for this purpose.

However, industrial scale may not be replicated or feasible in a lab when small-scale analysis is required for peanut breeding studies. In developing peanut cultivars, the peanut sample available would be very small, and not sufficient to conduct multiple roasting experiments for qualitative analysis.. Therefore, a systematic model at the small scale is needed that would remove the concerns associated with larger scale processing and provide consistent and predictable results.

The primary objective of this study was to develop roast optimization models for small-scale drum roasters (25g-150g). The equipment was primarily designed for roasting green coffee beans but because they operate on the same principles of industrial batch roasting, they would be a good fit for our study. This will help establish the feasibility of using such thermal processing method to test new peanut varieties being grown in Virginia relatively quickly and on a smaller scale, specifically with small sample size associated with developing peanut varieties. The model will ideally allow for predictable and consistent roasting. Furthermore, volatile analysis of roasted peanuts will help establish any quantitative difference caused by roasting on different machines.

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CHAPTER II
LITERATURE REVIEW

2.1 Overview

Peanut is an important world crop for developed and developing markets both for its organoleptic properties and nutritional content. As of 2020 the world peanut production totals about 47 million metric tons with United States as the world's fourth largest producer, after China, India and Nigeria (The Peanut Industry. 2021). The United States annual exports average over 25-30% of production per year with a value exceeding $675 million (USDA. 2021). This is behind some high producing countries including China, India and Argentina. To remain cost competitive globally, US farmers have improved the yield and efficiency gains in crop production (Peanut Country. 2021).

"Of the total world peanut production, 92% comes from Africa, Asia, and South America, however most varieties released, in Africa for instance, have been released to improve yield and resistance to disease and pests" (Gama and Adhikari). A brief overview of the state of peanut crop is referenced in Table 2.1 below.

Commodity	Planted All Purpose Acres	Harvested Acres	Yield	Production	Price per Unit	Value of Production in Dollars
Peanuts	25,000	24,000	4600 LB/ACRE	110,400,000 LB	0.219 $/LB	24,178,000

Table 2.1: Peanut production in Virginia as of 2019 USDA.

However, peanut consumption is driven by sensory appeal, especially flavor post thermal processing. Studies have shown that flavor, just like nutritional content, is affected by genotype among other factors (Pattee et al. 1995; Young et al. 2005; Isleib et al. 2006) and others. One researcher (Lykomitros et al. 2016a) tried to study the impact of wide range of process technologies on peanut flavor formation in different types of peanuts. This was primarily done to verify whether

selection of an appropriate process technology and processing conditions is able to yield final products having similar sensory features, thus minimizing the differences driven by specific genotype and variety.

The United States grows four types of peanuts as follows: (McArthur Verner Grise Harry O Doty and Duane Hacklander, 1982)

Runner	Mostly used in peanut butter. The variety is defined by odd shape and size. It is a dominant variety mostly grown in South Carolina, Georgia, Alabama, Florida, Texas accounting for 50 percent (down 10% since 1981) of total U.S. production.
Virginia	Variety is defined by large kernel size accounts for most of the peanuts roasted and eaten "in shell" . They are mostly grown in Virginia and North Carolina and are roughly 15 percent (down 5% since 1981) of total U.S. production.
Spanish	Variety is defined by small kernel size and primarily used for peanut butter, salted nuts, and confectionaries. They also have a higher oil content than other types. They are mainly grown in Texas and Oklahoma and account for 4 percent (down 7% since 1981) of total U.S. production.
Valencia	Known for sweeter taste and are usually roasted for eating "in shell". They are mainly grown in New Mexico and is less than 1 percent of U.S. production.

Table 2.1.1: Varieties of peanuts grown in USA.

2.2 Functional ingredients and stability

The health benefits associated with peanuts are a reflection of their nutritional profiles, including their nutrient density, fatty acid profiles, and the presence of bioactive compounds. It has

been shown that peanuts and tree nuts are low in saturated fatty acids and high in monounsaturated and polyunsaturated fatty acids (Francisco and Resurreccion 2008a).

Peanut oil, due to its high monounsaturated fat content (~50 to >80%), is considered healthier than oils with higher levels of saturated fat, and is relatively resistant to rancidity (Zhang et al. 2012). Oils high in oleic acid and low in polyunsaturated fatty acids are commercially and nutritionally desirable. Polyunsaturated fatty acids are susceptible to oxidation (Jung et al. 2000). Oxidation of carbon-carbon double bonds causes the degradation of the fatty acids and produces peroxides and hydroperoxides as primary oxidation products, and aldehydes, ketones and other compounds associated with off flavors and odors associated with rancidity as secondary oxidation products. Thus, high levels of unsaturation are indirectly proportional to qualitative stability of products containing peanut oil. Several factors affect the fatty acid composition of peanut oil, including maturity, temperature, planting date, location, market grade, and peanut genotype (Moore 1999).

Peanuts contain about 50% fat, of which about 80% is unsaturated and oleic and linoleic acids are the major fatty acid components. High oleate peanut products are reported to have improved flavor and oxidative stability (Jung et al. 2000). Oxidative rancidity of peanut oil is a major cause of spoilage of roasted peanuts and peanut-based confections during storage. Oxidation leads to the formation of tasteless and odorless hydroperoxides as primary products (Mugendi et al. 1998). For peanuts, high oleic verities are specifically developed to extend shelf life and improve consumer acceptance for the product (Isleib et al. 2000). High oleic verities have been developed with up to 85% oleic acid. Normal peanut varieties have about 50/30 oleic/linoleic acid content (Braddock et al. 1995). Because of the modified fatty acid compositions, these authors have reported

shelf life of high oleic peanuts to be approximately double that of normal peanuts (Braddock et al., 1995).

Peanuts have also been known to have bioactive compounds that serve as antioxidants. Peanuts have flavonoids, which have been demonstrated to have health benefits, large amounts of which are found in skins and shells of the legume (Francisco and Resurreccion 2008b). Some of the beneficial components of peanuts are listed in Table 2.2. Other bioactive compounds found in peanuts include polyphenols, phytosterols and resveratrol (Francisco and Resurreccion 2008b). The benefits, functions and extractions of such compounds have been discussed and reviewed by Francisco and Resurreccion (2008).

Component	Product description	Unit	Amount
Dietary fiber	All types, roasted, no salt	g	8.00
Total monounsaturated fatty acids		g	24.64
Total polyunsaturated fatty acids		g	15.69
Vitamin E (α-tocopherol)		mg	6.93
Folate		mcg	145.00
Magnesium		mg	176.00
Potassium		mg	658.00
Calcium		mg	54.00
Total phytosterols	Runner, dry roasted	mg	60.70
β-sitosterol		mg	47.20
Campesterol		mg	5.80
Stigmasterol		mg	7.70
Total proanthocyanidins	Roasted	mg	15.60
p-Coumaric acid	Georgia Green, raw, normal-oleic	mg	8.82
(-)-Epigallocatechin	All types, oil-roasted, with salt	mg	0.66
trans-Resveratrol	Florunner, roasted	mcg	5.50
Biochanin A	Runner, raw, defatted	mg	0.13
Daidzein		mg	1.75
Genistein		mg	0.23

Table 2.2: Beneficial components present in normal oleic peanuts (value per 100 g peanuts) (USDA Nutrient Database for standard reference) (Francisco and Resurreccion 2008b)

2.3 Peanut Processing

Peanuts are harvested in the field using machinery to mow the top part of the plants, pull them from the ground, followed by field curing. Harvesting is normally followed by drying. To prevent aflatoxin molds from growing, moisture in peanuts is usually kept to between 7-19 percent and definitely below 12 percent, (EPA 1983). Peanuts may be stored for in shell or post shelling processing. A flow diagram demonstrating shelled peanut processing is shown in Figure 2.1.

Dry roasting is done either in batch or continuous processes. Few advantages of batch roasters include adjusting for different moisture contents of peanuts, small scale processing, multiple products can be made at the same time in the same facility and simpler maintenance and quality control. There are different type of continuous dry roasters in use today. Continuous roasting mechanism reduces labor cost, increase process efficiency by delivering constant flow of peanuts and reduces spillage. Continuous roasters may move peanuts through an oven using a conveyor belt or by gravity. In the later type, peanuts are fed by a conveyor into a stream of countercurrent hot air that roasts the peanuts. This type of mechanism ensures even roasting of individual kernels by making sure the hot air envelopes the peanuts as much as possible.

Oil roasting can also be achieved on a batch or continuous basis. The peanuts are blanched to remove the skins. Continuous roasters will move the peanuts continuously through a tank of heated oil. In both batch and continuous roasters, oil is heated to temperatures of 138 to 143°C (280 to 290°F), with roasting times varying from 3 to 10 minutes(EPA. 1983). The roasting process is designed to achieve the desired quality of the final product including color, texture and flavor. A modified form of oil roasting is called blister frying where peanuts are immersed in boiling water that dissolve soluble proteins and sugar which are involved in peanut texture and roasted flavor, followed by deep frying (Shi et al. 2017a). A major side effect for using oil or blister roasting is the

degradation of oil with each use. Oil oxidizes with each roast session and that introduces unwanted off flavors and variables if the same oil is used for another sample. However, this type of roasting allows for faster and more even heat transfer compared to other methods.

Almost all qualitative studies of peanut conduct a roasting process. Most of them differ in various ways including the type of oven, sample size, peanut variety etc. Roasting optimization studies have been demonstrating the effects on desired qualitative aspects by changing roasting parameters. Slade and Levine (2006) optimized roasting process with oil roasting with temperatures ranging between 300-325 degree Fahrenheit (148-177 °C) for 8 minutes. Other studies (Pattee et al. 1982; JOHNSEN et al. 1988; Baker et al. 2003; Shi et al. 2017, 2018; Wang et al. 2017) have used various parameters and roasting technologies to optimize the flavor profile for particular peanut varieties. The sample size for these studies has ranged from 0.1 kg- 2 kg. The nut roasting technologies do have an impact on overall quality. Besides chemical changes by nonenzymatic reactions, the process also leads to changes in peanut microstructure.

The primary factor when choosing the roast type is the rate of heat exchange. Deep frying, blister frying and forced air methods are going to differentiate in how uniform or quick the heat is transferred. The difference in microstructure and moisture due to different roasting techniques has been reported (Shi et al. 2017a). Blister frying causes the most extensive cellular damage to outer epidermal layer while keeping the most moisture. Dry roasting lost the most moisture with minimum microstructure changes. Other studies have used different roasting mechanism such as impingement oven (Wang et al. 2017), gas heated surface combustion dryer (Johnsen et al. 1988), continuous dry roaster (Shi et al. 2018), static infrared roaster (Bagheri et al. 2019), etc. Peanut roasting using microwave has also been reported (Jindal et al. 2011; Smith et al. 2014; Lykomitros et al. 2016a). Some of the reported benefits of microwave roasting includes reduced cost, energy and enhanced

moisture loss (Smith 2014). Higher initial moisture content produced darker colored peanut butter which was less desirable due to reduced flavor quality (Moss and Otten 1989b). Moreover, the color change in higher moisture peanuts was more pronounced compared to low moisture peanuts. Furthermore, the content of soluble carbohydrate and amino acid precursors are effected differently based on moisture content. The amount of amino acids was observed to reduce more in high moisture peanuts compare to low moisture samples, while higher soluble carbohydrate content was observed in high moisture peanuts (Pattee et al. 1982; Chiou et al. 1991).

The changes in microstructure of oil and dry roasted peanuts have been described by Perren and Escher (2007). The increase in porous volume and the accessibility of enzymes and oxidation prone compounds is more important before the roasting process. However, the formation of anti-oxidative compounds through NEB reactions play more important role after roasting. The study also suggests the effect of oil coating in fried peanuts acting as an oxidative barrier and reducing the effect of second order oxidation reactions . The roasting process converts the peanut seed from its slightly sweet, green "beany" flavor in the raw state to a flavor that is nutty and preferred by most consumers (Pattee et al. 1995).

2.4 Important volatile/aroma compounds

Gross analysis of a soluble portion of raw peanuts before and after heating implicated amino acids and carbohydrates as precursors of typical peanut flavor (Newell et al. 1967). Amino acids can give rise to aldehydes by Strecker degradation and can serve as the source of nitrogen for the formation of pyrazine compounds. Data presented in in the literature suggests that amino acids and sugars are the precursors of these volatile flavor components in roasted peanuts (Newell et al. 1967).

The flavor of the roasted peanut is mainly attributed to the pyrazines that are formed upon roasting (Williams et al. 2006). Flavor characteristics of roasted peanuts can change over short-term storage. The concentrations of volatiles such as 2,3-diethylpyrazine, 2- methoxypyrazine, 2,3-dimethylpyrazine, 2-ethyl-3-methylpyrazine, and 2,3,5-trimethylpyrazine were observed to decrease over a 21-day period (Williams et al. 2006). According to a study, the most important positively correlated to roasted peanuts compounds appear to be 2/3-methyl-1H-pyrrole, 5-methyl-2-furancarboxaldehyde, benzeneacetaldehyde, 2,3 dimethyl-1H-pyrrole, 2,5 dimethyl pyrazine, 5-methyl-2-furanmethanol, and maltol, while toluene, ethylbenzene, octane, benzaldehyde and butyrolactone are negatively correlated with roast peanut flavor (Lykomitros et al. 2016b). Earlier studies have also confirmed the role of pyrazines as well as methyl pyrrole when flavor extraction was conducted on roasted peanuts (Mason and Jhonson 1966)(Shu and Waller 1971). Baker et.al (2003) reported that 2,5-dimethylpyrazine was most highly correlated to roasted peanut flavor and aroma. Various other works have isolated roasted peanut volatile compounds that also suggest the role of pyrazines in peanut flavor (Buckholz et al. 1980; Pattee et al. 1982, 1989).

The moisture and oil contents are known to affect the total aroma of roasted peanuts. When defatted peanut meal was roasted, typical roasted volatiles like pyrazines were observed; however, in the presence of extra moisture, carbonyl compounds were the majority of the volatiles (Mason et al. 1969). Furthermore, the effect of seed size and maturity on the volatile concentration in the headspace has also been studied. With the larger seed size, the fruity flavor characteristic is reduced while the roasted peanut flavor characteristic increased in intensity (Pattee et al. 1989). The genotype has perhaps the greatest effect on overall flavor and roasted peanut attribute (Pattee et al. 1995)(Isleib et al. 2000), however this assessment is based on equivalent roasting parameters for the genotypes. There are certain correlations, like sweetness, that are reported between the same

genotype but not with others. Moisture and water activity have also been demonstrated to affect the roast peanut flavor attribute in different storage conditions. Higher water activity and moisture content reduced the sensory roast peanut scores over period of extended storage (Baker et al. 2002). The optimum water activity was reported to be between 0.33 to 0.44. Outside this range, the oxidation increased while higher water activity reduced the crunchiness texture. Moreover, Moss and Otten (1989) reported the effect of maturity of peanuts on the overall roast peanut quality determined using L*a*b* color scale. The data indicated the correlation of moisture content (ratio between 0.5-0.6) with the b* values and the initial chemical composition, which is affected by maturity level of the kernels, was suspected to affect L* and a* values while roasting.

The major precursors of flavor development of peanuts include amino acids and sugars because they are the primary participants in the Mallard reaction. Typical flavor amino acid precursors include aspartic acid, asparagine, glutamic acid, phenylalanine, and histidine. It is not uncommon for some of the amino acids like phenylalanine to increase in concentration during light roasting (Mason et al. 1969). Previous study indicated that aspartic acid, glutamic acid, glutamine, asparagine, histidine, and phenylalanine were associated with the production of typical peanut flavor while threonine, tyrosine and lysine were considered to be precursors of atypical flavor (Newell et al. 1967).

2.5 Colorimetry

The color to which peanuts are roasted has important quality implications. This is due to an association between color and the flavor and aroma, which develops during roasting (Morris et al., 1953). The primary means of color development in roasted peanuts, according to Pattee et.al, (1991) is through the production of melanin by the maillard reaction and sugar caramelization as a secondary factor. Much of the peanut research studies have used Hunter color scale for quantifying

roasted peanut color. Measurement of peanut butter color in establishment of the U.S. peanut butter grade is done by visual comparison to the U.S. Department of Agriculture Color Standards. It is important of note that regardless of roast color, peanut genotype, harvest maturity, planting date, curing and drying also have impacts on roast peanut flavor (Baker et al. 2003)

Both the Hunter L, a, b scale and the CIE L*a*b* scale are visually meaningful; the three values can be easily understood and translated into color. They are, however, calculated differently. The formulas for Hunter L, a, and b are square roots using CIE XYZ, whereas CIELAB is calculated using cube roots of XYZ (Hunter Lab 2019). Pattee et.al 1991 demonstrated that a rapid comparison of CIELAB L* to Hunter L values can be made by subtracting 7 color units from the CIELAB L* values. This conclusion however was based on peanut sample that was converted to paste.

Peanuts roasted to equivalent surface colors at different temperature/time combinations can vary substantially in chemical and physical properties (Moss and Otten 1989b; Pattee et al. 1991; Y-Y Chiou et al. 1994). However, color development is generally used as a method of measuring the degree of roast as it is rapid and inexpensive (Manzocco, Calligaris, Mastrocola, Nicoli, & Lerici, 2000). Most studies involving peanut roasting involves colorimetry (Gama and Adhikari 2019; Moss and Otten 1989a; Y-Y Chiou et al. 1994; Pattee and Giesbrecht 1994; Jindal et al. 2011; Bagheri et al. 2019). Even though these studies use similar color space i.e. Hunter Lab or CIE L*a*b*, the exact methodology sometimes differs. Whereas Pattee et.al 1991 uses CR100 chromameter, which is similar in technology as used in our study, Bagheri et.al 2018 conducted color analysis (on L*a*b* color space) using JPEG format picture. The exact lighting specifications were not provided, however.

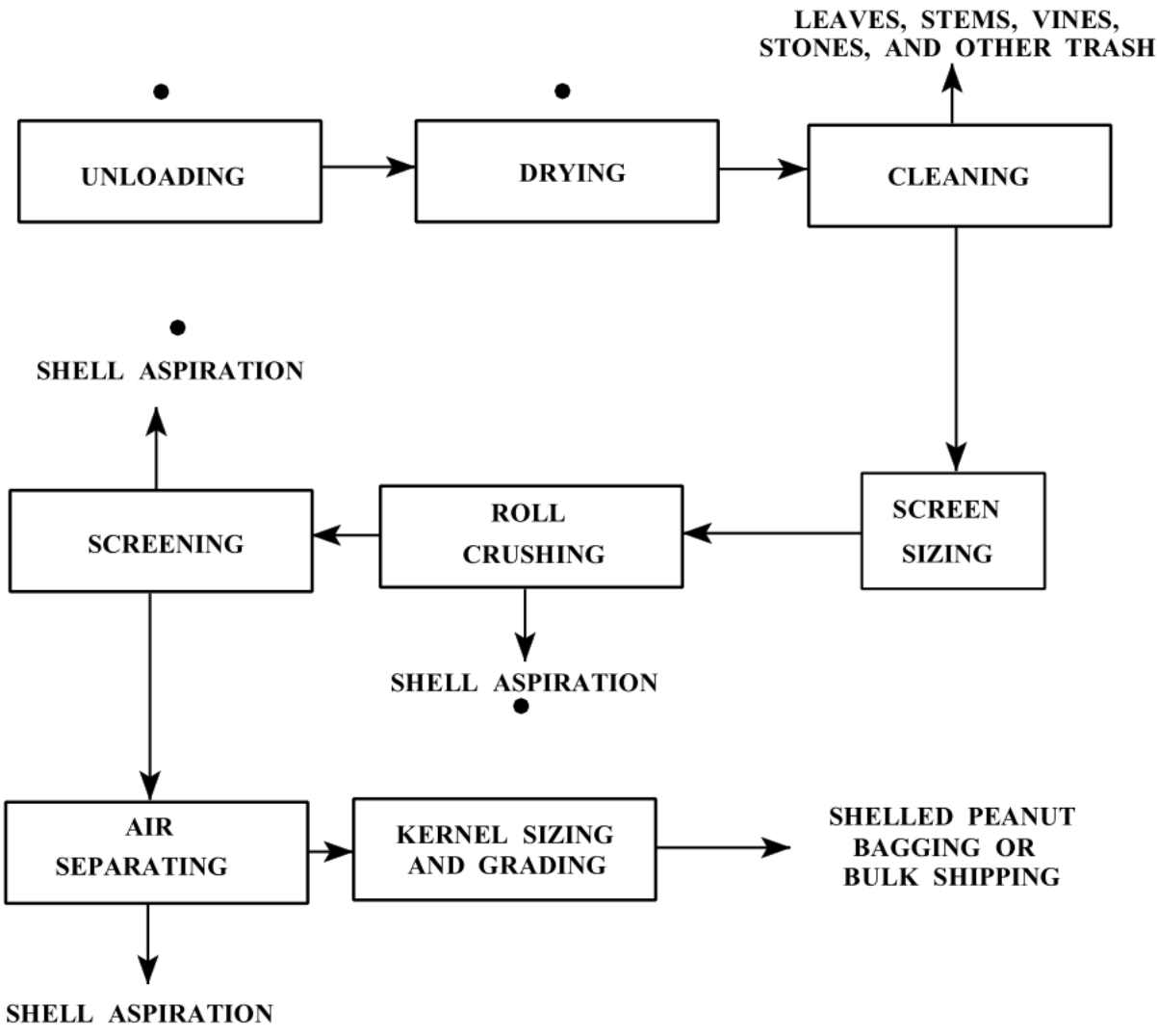

Figure 2.1: Typical shelled peanut processing flow (EPA. 1983).

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CHAPTER III
MATERIALS AND METHODS

This work was done in the FST and HABB1 laboratories in Food Science and Technology Department of Virginia Polytechnic Institute and State University, Virginia, United States of America.

3.1 Materials and equipment

Two separate 45 pound batches of deshelled, blanched Virginia type peanuts (raw, spin blanched, extra-large peanuts) were acquired from Wakefield Peanut Company LLC (Wakefield VA). We considered these to be independent, pooled samples.

The study utilized four different drum roasters acquired from Sweet Maria's (Oakland CA) (see APPENDIX G) . These roasters had been selected on the basis of usability in small-scale batch coffee roasting. They are designed for roasting coffee beans, hence we find some specific features such as chaff chutes, designed to capture dried and flammable dried bean husks (chaff), in these roasters. Thus, one of the goals was to determine the feasibility of such roasters to be used for roasting peanuts. Peanut skins are somewhat similar to coffee chaff, so we thought that the chaff collection could also collect peanut skins during roasting.

Aillio's Bullet R1 (Aillio Ltd, Taipei Taiwan) is a solid steel roaster, which reportedly would be a good option for the home roaster who wants more control and capacity, or light duty commercial coffee roasting. This machine has a capacity to roast up to 1 kg of green coffee beans. Furthermore, the computer connectivity for this roaster allows for real time management of roast parameters such as time, drum and bean temperature, power and fan operation. However, one disadvantage of using this roaster is that the drum cannot be extracted from the main body without significant mechanical disassembly. Preliminary roasting was done on this roaster to determine

optimum roasting parameters for peanuts. It was observed that the roasting drum would be coated with peanut oil residue and multiple roasting schedules charred the drum surface. This was critical since, for scientific experiments, it is crucial to clean the drum between batches. Moreover, the peanuts would stick to the walls of the roaster, which was most obvious when smallest sample sizes were roasted. Due to these observations, it was determined that this roaster would not be feasible for this study.

Hottop Programmable Roaster KN-8828B-2K+ (Hottop USA, Cranston, RI) is a stainless-steel constructed drum roaster. This model also adds the ability to connect to third party computer software for roast profiling. Furthermore, it provides manual control of most parameters (time, drum/bean temperature, fan, power) during the roast. This roaster can be connected to a third-party roast profiling program. Almost all profiling programs are inherently designed for coffee beans, but they do provide real time control of roasting parameters as well as features that help in determine optimum roasting protocol for the particular equipment. This roaster has a reported capacity of up to 300 grams of green coffee. The drum can be extracted from the main body with significant disassembly. Preliminary roasting was done on this roaster to determine optimum roasting parameters for peanuts. The Hottop roaster suffers from similar issues as the Aillio Bullet roaster. The drum itself has grooves inside. Cleaning the drum may require careful cleaning and significant disassembly.

The Gene Cafe (Gene Cafe USA, Plymouth, MA) has a half-pound (~ 227 grams) batch capacity (green coffee beans) and uses a unique off-axis rotation with a hot air heat source. This roaster is different than other equipment mentioned is that the peanuts are not directly exposed to the heating element. The roast is easy to observe due to the glass roast chamber, and the controls make it

easy to modify the time or temperature throughout the roast. The drum for this roaster is detachable and seems easy to clean, however the roaster only provides basic controls (time and temperature).

The Behmor 2000AB Plus (Behmor Inc., Incline NV) is a drum roaster with a reported batch size up to a pound at a time (green coffee beans). This roaster has several pre-programmed roast profiles but can also be used manually. The drum is easily detachable and cleaning is relatively easy as compared to other roasters. The heating mechanism for Behmor is direct exposure to twin halogen 1650 watt total heating elements.

Due to the disadvantages noted for the Hottop and Aillio roasters, after preliminary peanut roasting experiments, further roasting experiments focused on the Behmor and Gene roasters.

3.2 Surface Response Method.

To evaluate factors affecting peanut roasting, a Box Behnken design (BBD) Response Surface Method was selected with three independent factors (sample size, power level/temperature and roasting time) at two levels.

Results from 15 experiments were used for estimating the coefficients of the following second-order model:

$$\gamma = \beta_0 + \sum \beta_i X_i + \sum \beta_{ij} X_i^2 + \sum\sum \beta_{ij} X_i X_j$$

where γ is the response variable, βo is the intercept, and βi , βii and βij are the regression coefficients of variables for linear, quadratic and interaction terms, respectively. Xi and Xj are the independent variables. Different treatment levels in the form of coded units and actual units are shown in Table 3.2. Microsoft Excel and JMP Pro software were used for data analysis and plotting of results.

A preliminary or single-factor experimentation was conducted to determine the dependent factorial range that gave the range of response i.e. color of roasted peanuts, that we are interested in. On the basis of these single factor experiments, major influence parameters (sample size, roasting time and temperature) and their levels were obtained and applied in the RSM design. The CEILAB L* color response range should be between 55-61 for this preliminary testing.

3.3 Colorimetry and Moisture

Surface color of whole peanut kernels was measured using a Minolta CR210 colorimeter (Konica-Minolta, Ramsey, NJ). The color readings were taken using the CIE L*a*b* color space. The peanut samples were spread in a 250 ml beaker to minimize the light bleed from the bottom and sides of the glass container. The process made sure to read the samples as flat as possible to maintain consistency over three readings. The moisture content of raw peanuts was determined by drying 5 samples of each batch weighing 5.0 g in a drying oven at 100 °C for 24h.

3.4 Fatty Acid Analysis.

A modified form of Maxwell and Marmer (1983) method was used for lipid extraction and fatty acid transesterification. 100mg of peanut sample, ground in a food processor (Cuisinart Model DLC-155, Cuisinart East Windsor NJ), was mixed in a glass centrifuge tube with 2 ml isooctane (2,2,4-trimethylpentane) and held for 2 minutes in an ultrasonic bath (Fisher Scientific Model FS20) followed by centrifugation for 10 minutes on medium speed (IEC HN-S, Damon/IEC, Needham Heights, MA). The top isooctane layer was removed to a new tube and 200 microliters of 2N KOH in methanol (1.1g KOH per 10 ml methanol) was added. The mixture was vortexed for 1 min and then centrifuged for 10 minutes on medium speed. The lower layer was discarded by using a glass Pasteur pipet then 0.5 ml saturated ammonium acetate was added and vortexed for 1 minute

followed by removal of lower layer using a pipet. One ml distilled water was added and vortexed for 1 minute followed by removal of bottom later using a pipet, then ~200 mg anhydrous sodium sulfate was tube allowed to sit for 10 minutes. The top layer containing the fatty acid methyl esters (FAME) was transferred into a GC vial and stored in freezer until analysis.

The sample (0.1 µl) was manually injected in the injection port held at 250 °C with a 1:200 split ratio. A Shimazu GC–MS (TQ-8030) system equipped with a Zebron ZB-Wax column (60 m × 0.25mm id and 0.25 µm film) was used for separating the FAME. Helium was used as the carrier gas with a linear velocity of 25 cm/sec. The column was maintained at 140 °C for 1 min, programmed at 2.5 °C/min to the final temperature of 240 °C held for 9 minutes for total run time of 50 minutes. MS detector scanned a mass range (m/z) from 45 to 500 m/z with scan speed 1.666 µ/s.

3.5 Volatile Analysis for Roasted Peanuts

Headspace-solid phase microextraction (HS-SPME) technique was applied for extraction of the volatiles in the roasted peanut samples. GC/MS machine was used for the analysis: a Shimadzu GCMS QP2010 was used with manual sampling. Four grams of roasted half-kernels were prepared in duplicate. The samples were placed in 20 ml amber glass vials with PTFE/silicone septa and screw caps. The samples were equilibrated to 40 °C for 30 minutes followed by 55 minute adsorption on to SPME fiber (2 cm 50/30 um DVB/CAR/PDMS, Supelco, Bellefonte, PA). The volatiles were desorbed into the injection port at 250 degree Celsius for 5 minutes in splitless mode.

The Shimazu GC–MS system equipped with a Zebron ZB-5 column (30m × 0.25 mm i.d. and 0.25 µm film) was used for separating the volatile compounds. Helium was used as the carrier gas with a linear velocity of 25 cm/sec. The column was maintained at 40 °C for 5 min, programmed at 4 °C/min to 200 °C followed by 20°C/min to the final temperature 300 °C held for 5 minutes for

total runtime of 55 minutes. MS detector scanned a mass range (m/z) from 40 to 400 m/z with scan speed 1250 μ/s.

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CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Surface Response Model for Behmor.

The model for Behmor roaster was developed using normal oleic variety first since that batch of peanuts were aquired first. High oleic peanuts were procured later due to shortage in the first batch. It was expected that both batches would be similar however, as discussed in fatty acid analysis late, the second batch of peanuts were of high oleic variety.

The average values of response variables are shown in Table 4.1.1 for the Behmor roaster. This data was used in JMP Pro to construct and evaluate the Box Behnken Model. A surface response plot was derived and shown in Figure 4.1.1. The ANOVA results in Figure 4.1.2 (APPENDIX B) suggests that the overall model is not significant with the $p > 0.05$ with R^2 value of 0.86. The effects tests in Figure 4.1.3 suggests that only the first order "roasting time" variable has a significant effect on the model with $p < 0.05$. All other first and second order effects are above the significant threshold. A prediction expression for this model with L* as a response variable is shown in Figure 4.1.4. The coefficients for the expression suggest the roasting time having the highest absolute effect on the L* response followed by power level and sample size.

Using the prediction expression, the model was validated using the parameters listed in Table 4.1.2. A test using pooled standard deviation was calculated. The results suggest that normal oleic peanuts can be roasted using Behmor roaster with good precision: the roasting can be replicated with low variance. One replicate for the fourth sample had a higher L* response (59.90 +/-0.99) while the other replicate was close to the predictable L* value (56.49 +/- 0.72). The higher value corresponds

with the higher t test result for the fourth sample. We can conclude that Behmor can be used to roast with precision and practically close enough to the desired quality of either light or medium roasts.

4.2 Surface Response Model for GeneCafe.

The average values of response variables are shown in Table 4.2.1 for GeneCafe roaster. A surface response plot was derived and shown in Figure 4.2.1 (APPENDIX C). The ANOVA results in Figure 4.2.2 suggests that the model is significant with the $p < 0.05$ with R^2 value of 0.98. The effects test in Figure 4.2.3 suggests multiple variables have a significant effect on the model with $p < 0.05$ including "roast time" and "temperature". The same variables also have second order effects on the model. A prediction expression for this model with L* as a response variable is shown in Figure 4.2.4. The coefficients for the expression suggest the roasting time having the highest absolute effect on the L* response and sample size having minimal effect. Sample size variable has a higher effect on the roasting result in Behmor roaster.The p-value of sample size on Behmor was 0.06 compared to 0.85 on GeneCafe

Using the prediction expression, the model for GeneCafe was validated using the parameters listed in Table 4.2.2. The results show uncertainty in roasting high oleic peanuts on GeneCafe. This can be explained due to multi-level effects on the model by roast time and temperature. More replicates are needed to validate if the model can be used predictably using the prediction equation. However, using our data we can translate the parameters to roast the peanuts to medium quality. Using the collective data from both roasters, samples of HO and NO peanuts were roasted to medium quality on both roasters in duplicates (Table 4.5.1).

4.3 Colorimetry and Moisture.

The moisture for raw normal and high oleic (NO, HO) acid was measured. High oleic peanuts had a higher moisture content with average value of 4.7% compared to 2.46% for normal oleic variety. Higher moisture content has been shown to have more pronounced effect on the roasting of peanuts (Y-Y Chiou et al. 1991). The moisture content for peanuts is dependent on harvesting and storage conditions. Lower moisture for normal oleic peanuts could be due to their extended storage time. High oleic variety was acquired much later after the end of the fall harvesting season than the first batch, which were normal oleic peanuts.

Initial experiments conducted on small sample size of peanuts had inconsistency on color readings. Most studies that have used similar equipment (Konica-Minolta, Ramsey, NJ), took readings on a high sample size. The peanuts are usually laden flat in a petri dish with a bed depth. Our smallest sample i.e. 25 g, did not create an even flat surface to take the readings from. The higher inconsistency in small sample size resulted from the sensor light leaking from the gaps between individual peanut kernels. Furthermore, it was observed in a validation experiment (Table 4.1.2) that some roasted samples were measured to be similar even though visually they looked very different. We took a picture under standard conditions (Figure 4.3.1 APPENDIX D) of these samples, where sample 4b had L* reading of 59.89 which was similar to sample 2. However, visually sample 4b looks closer to 4a which had an average reading of 56.49. Therefore, to reduce the inconsistency from the equipment, our strategy was to use small container to reduce light bleed between the peanut samples and using the sensor as flat and close to sample as possible. Careful consideration should be given to the future use of similar colorimeters. Even though more consistent reading could be achieved if the samples were chopped using a food processor to get even surface,

this is not a common practice in the industry. Some studies have used processed roasted peanuts into a paste. This we believe introduces more variable in the samples especially if volatile analysis has to be conducted. A simple reason to use such equipment in the first place is that it is convenient and quick. For our research it was deemed impractical in terms of time to further process the peanuts this way.

4.4 Fatty Acid Analysis.

Two batch of peanuts that were obtained for our research were analyzed through GC/MS for fatty acid methyl esters. Raw and roasted peanuts were sampled for this test. The results are shown in Table 4.4.1. There was no significant difference in oleic (18:1ω9**)** acid content between raw and roasted samples. The linoleic acid (18:2ω6) was found reduced after roasting the high oleic variety with slight increase in stearic (18:0) acid. Since, linoleic acid or higher unsaturated fatty acid are prone to degradation this is not unexpected. However, no significant difference was observed in linoleic acid content in normal variety after roasting. Since our data are reported as normalized area %, a decrease in one component may show apparent increases in others. This should be considered more an artifact of the analysis than a true increase.

4.5 Volatile Analysis.

Normal and high oleic variety peanuts were roasted in duplicates according to Table 4.5.1. Volatile analysis of the samples was conducted on GC/MS for seventeen compounds found in literature. The selection of these specific compounds was based on probability of detection according to library match (>90%). The relative quantity of the compounds was based on automatic integration by the GC/MS control software to limit error associated with manual integration. The results are

plotted in Figure 4.5.1, which show high variation within samples. However, we can see the trends between samples.

For the peanuts roasted on Behmor roaster, we saw similar trends for the majority of volatile compounds. Methyl pyrazine was higher in high oleic variety and ethyl pyrazine was only detected in the normal variety. The rest of the volatile components showed similar trends between normal and high oleic peanuts. The samples roasted on GeneCafe roaster show similar trends between normal and high oleic peanuts. No significant difference between the samples exists because of high variance within samples. Similar trends are observed for samples roasted on different roasters. The only difference appeared to be the average amount of volatiles detected. On average, peanuts roasted on Behmor roaster show lower amounts of volatiles compared to the samples roasted on GeneCafe. One possible explanation for this observation may be the way both roasters operate. GeneCafe operates on forced air principle. The air is heated before it is chambered through the drum chamber. This is why the peanuts are roasted more slowly compared to Behmor; which uses heating elements exposed to the samples. The high heat transfer in Behmor may cause ruptured cells on the surface of peanuts allowing more volatiles to escape before the sample is prepared. The slow heat transfer in GeneCafe do not as drastically affect the microstructure of peanuts. This may allow for the volatiles to be retained with the kernels for longer.

Even though some variation in SPME method is expected, a possible explanation for high volatile variation within samples can be expected due to uneven roasting. Each sample prepared for the GC/MS, approximately 4.0 g contains about 5-6 split peanut kernels. For each sample roasted, not all kernels roast equally, some achieve lower L* values than others. The color distribution among single seeds using dry roasting has been demonstrated to be normally distributed (Shi et al. 2017). However, this distribution for medium roast with a standard deviation of 5.34 means that

some kernels were dark or light roasted within the same sample. If each sample contains random peanut kernels with difference in roast quality, then high variation would be expected.

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CHAPTER V

CONCLUSIONS

Two batches of Virginia type peanuts were acquired. One was tested to be normal oleic while the other high oleic variety. Four different drum roasters, Aillio's Bullet R1, Hottop , GeneCafe and Behmor 2000AB were tested for feasibility to roast Virginia type peanuts. Bullet and Hottop were deemed impractical due to factors including high sample threshold and difficult cleaning/maintenance. A surface response model using Box-Behnken design was made for Behmor using normal oleic peanuts and GeneCafe using high oleic variety with sample size, temperature/power, roast time as dependent variable and CIE L*a*b* as a response variable .The overall model for Behmor was not significant with roast time adding the only significant effect contribution while GeneCafe's model had multiple first and second order significant effects from temperature and roast time variables. It was determined through validation tests that Behmor was more consistent and predictable in roasting peanuts using the SRM model. More validation runs would be needed for GeneCafe roaster since it had more inconsistent results. Inconsistency was also observed using Konica colorimeter especially when measuring smaller sample size due to light bleed between solid peanut kernels. Volatile tests for peanuts roasted on both roasters suggested no significant difference between normal and high oleic varieties. The high variance of volatiles within samples was observed for this test and could be explained by uneven roasting within the sample. Based on our results, peanut breeding studies may utilize small drum roasters such as Behmor 2000AB to study roasting quality of new varieties using mall sample. Further study may be undertaken to understand the variation of peanuts within a roasted sample and correlation with flavor perception using sensory testing.

APPENDICES

APPENDIX A

Independent Variables	Symbol	Coded Level		
		-1	0	+1
Weight (g)	X_1	25	87.5	150
Power	X_2	P3 (50%)	P4 (75%)	P5 (100%)
Time (min)	X_3	4	6	8

Table 3.2.1: Values of independent variables in actual and coded units for Behmor roaster.

Independent Variables	Symbol	Coded Level		
		-1	0	+1
Weight (g)	X_1	25	87.5	150
Temperature (°F)	X_2	P3 (50%)	P4 (75%)	P5 (100%)
Time (min)	X_3	4	6	8

Table 3.2.2: Values of independent variables in actual and coded units for Behmor roaster.

APPENDIX B

Experiment	Sample size	Power Level	Roasting Time	L*	a*	b*
1	-1	-1	0	67.520	3.387	25.307
2	1	-1	0	68.610	2.857	22.437
3	-1	1	0	25.950	8.137	11.873
4	1	1	0	59.813	3.953	17.183
5	-1	0	-1	66.033	2.007	17.357
6	1	0	-1	66.190	3.060	22.893
7	-1	0	1	26.317	7.427	11.607
8	1	0	1	59.220	9.750	29.340
9	0	-1	-1	70.643	2.757	24.153
10	0	1	-1	65.800	3.643	24.153
11	0	-1	1	28.663	8.167	12.643
12	0	1	1	44.583	11.083	24.690
C	0	0	0	62.703	5.017	23.323
C	0	0	0	62.153	7.417	27.733
C	0	0	0	60.693	6.837	26.643

Table 4.1.1: Values of response variables determined from peanut roasting experiments on Behmor

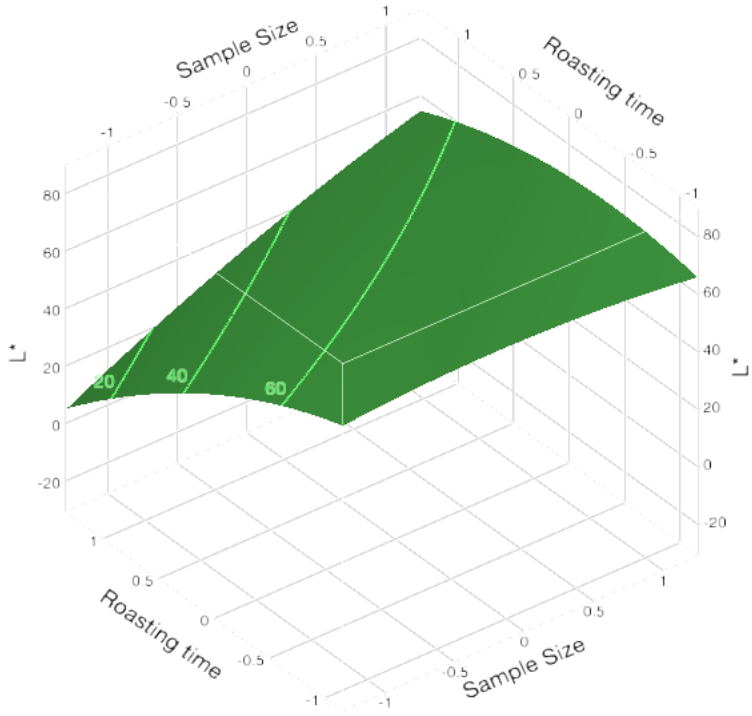


Figure 4.1.1: Surface plot for Behmor while keeping power level constant at P4 (75%).

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	3087.7974	343.089	3.3729
Error	5	508.6033	101.721	Prob > F
C. Total	14	3596.4007		0.0970

Figure 4.1.2 : ANOVA table derived for Behmor.

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Sample Size	1	1	578.2210	5.6844	0.0628
Power Level	1	1	192.9630	1.8970	0.2269
Roasting time	1	1	1509.2842	14.8375	0.0120*
Sample Size*Power Level	1	1	268.5174	2.6398	0.1651
Sample Size*Roasting time	1	1	268.0751	2.6354	0.1654
Power Level*Roasting time	1	1	107.7755	1.0595	0.3505
Sample Size*Sample Size	1	1	17.5366	0.1724	0.6952
Power Level*Power Level	1	1	65.0419	0.6394	0.4602
Roasting time*Roasting time	1	1	101.0082	0.9930	0.3648

Figure 4.1.3 : SRM Effects test for Behmor ; only Roasting time with significant model effect contribution.

Prediction Expression

61.849666667
+ 8.501625 • Sample Size
+ -4.91125 • Power Level
+ -13.735375 • Roasting time
+ Sample Size • (Power Level • 8.19325)
+ Sample Size • (Roasting time • 8.1865)
+ Power Level • (Roasting time • 5.19075)
+ Sample Size • (Sample Size • -2.179333333)
+ Power Level • (Power Level • -4.197083333)
+ Roasting time • (Roasting time • -5.230333333)

Figure 4.1.4 : Model equation coefficients for Behmor.

Sample (NO)	n	Weight (g)	Power(75%)	Time (min)	L*Predicted	Ave L*	Pooled t values
Raw	*	*	*	*	*	67.13± 0.83	*
1	2	50	P4	5:50	60	62.69± 0.89	3.61
2	2	100	P4	6:54	60	59.85± 1.17	-1.00
3	2	50	P4	6:48	55	53.80± 2.58	-1.44
4	2	100	P4	7:25	55	58.19± 2.01	3.18

Table 4.1.2: Validation for Behmor using normal Oleic peanuts; Ave L*+/- std dev $t_{(\alpha, n1+n2-2)}$= 2.776

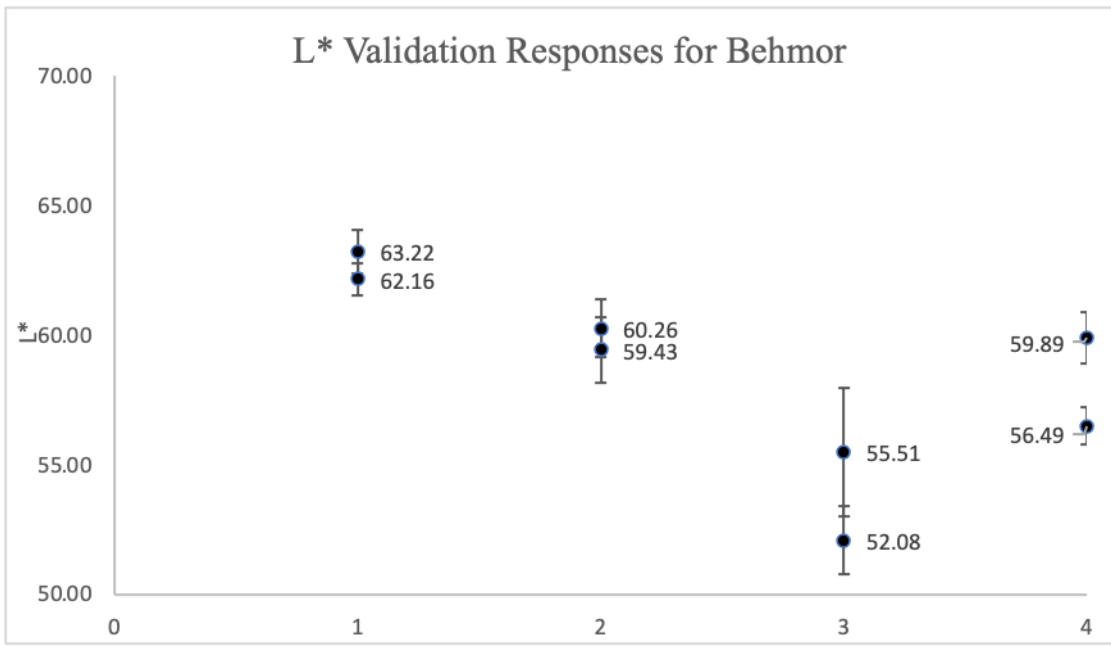


Figure 4.1.5: Validation responses for Behmor roaster; Ave L*+/- std dev.

APPENDIX C

Experiment	Sample size	Temperature	Roasting Time	L*	a*	b*
1	-1	-1	0	66.18	2.74	25.65
2	1	-1	0	65.95	3.68	26.19
3	-1	1	0	34.55	9.82	18.44
4	1	1	0	36.76	10.30	19.80
5	-1	0	-1	60.78	6.34	28.01
6	1	0	-1	62.43	6.21	27.35
7	-1	0	1	52.93	8.04	26.59
8	1	0	1	50.76	10.24	27.96
9	0	-1	-1	65.67	1.87	24.46
10	0	1	-1	51.45	9.34	27.68
11	0	-1	1	63.37	4.47	26.57
12	0	1	1	32.98	9.47	16.76
C	0	0	0	60.02	7.27	26.99
C	0	0	0	59.01	7.87	26.98
C	0	0	0	59.55	7.17	27.44

Table 4.2.1: Values of response variables determined from peanut roasting experiments on GeneCafe

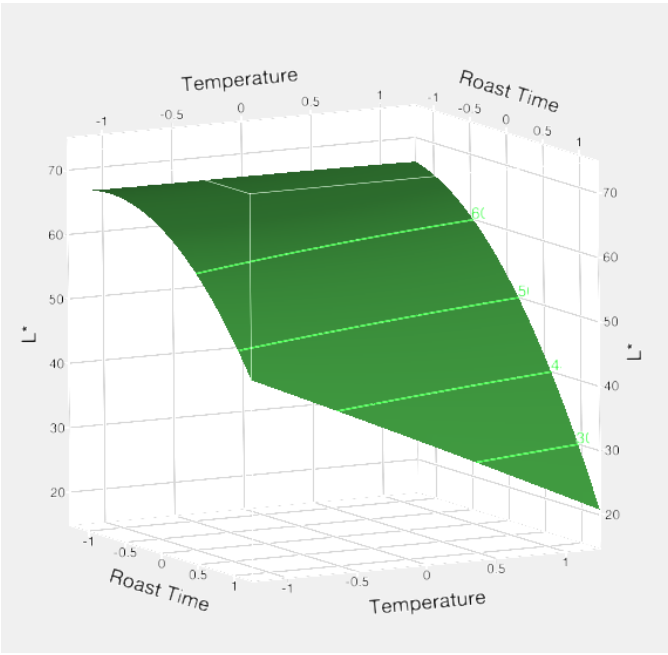


Figure 4.2.1: Surface plot for GeneCafe with constant sample size of 87.5g.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	1815.2554	201.695	29.3734
Error	5	34.3329	6.867	Prob > F
C. Total	14	1849.5884		0.0008*

Figure 4.2.2: ANOVA table derived from SRM of GeneCafe.

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Sample Size	1	1	0.2664	0.0388	0.8516
Roast Time	1	1	1389.4356	202.3473	<.0001*
Temperature	1	1	202.9105	29.5504	0.0029*
Sample Size*Roast Time	1	1	1.4884	0.2168	0.6611
Sample Size*Temperature	1	1	3.6481	0.5313	0.4988
Roast Time*Temperature	1	1	65.3672	9.5196	0.0273*
Sample Size*Sample Size	1	1	26.0190	3.7892	0.1091
Roast Time*Roast Time	1	1	133.4590	19.4360	0.0070*
Temperature*Temperature	1	1	0.0799	0.0116	0.9183

Figure 4.2.3: SRM Effects test for GeneCafe ; significant (<0.05) model contribution from first and second order effects.

Prediction Expression

59.526666667
+ 0.1825 • Sample Size
+ -13.17875 • Roast Time
+ -5.03625 • Temperature
+ Sample Size • (Roast Time • 0.61)
+ Sample Size • (Temperature • -0.955)
+ Roast Time • (Temperature • -4.0425)
+ Sample Size • (Sample Size • -2.654583333)
+ Roast Time • (Roast Time • -6.012083333)
+ Temperature • (Temperature • -0.147083333)

Figure 4.2.4: Model equation coefficients for GeneCafe.

Sample (HO)	n	Weight (g)	Temp(°F)	Time (min)	L*Predicted	Ave L*	Pooled t values
Raw	*	*	*	*	*	67.45± 1.27	*
1	2	100	375	14.0	60	51.80± 1.28	-10.08
2	2	100	325	15.8	60	61.39± 0.84	1.49
3	2	100	375	15.5	55	56.12± 0.86	1.81
4	2	100	325	17.5	55	59.97± 1.53	4.02

Table 4.2.2: Validation for GeneCafe using high Oleic peanuts; Ave L*+/- std dev; $t_{(\alpha, n1+n2-2)}$= 2.776

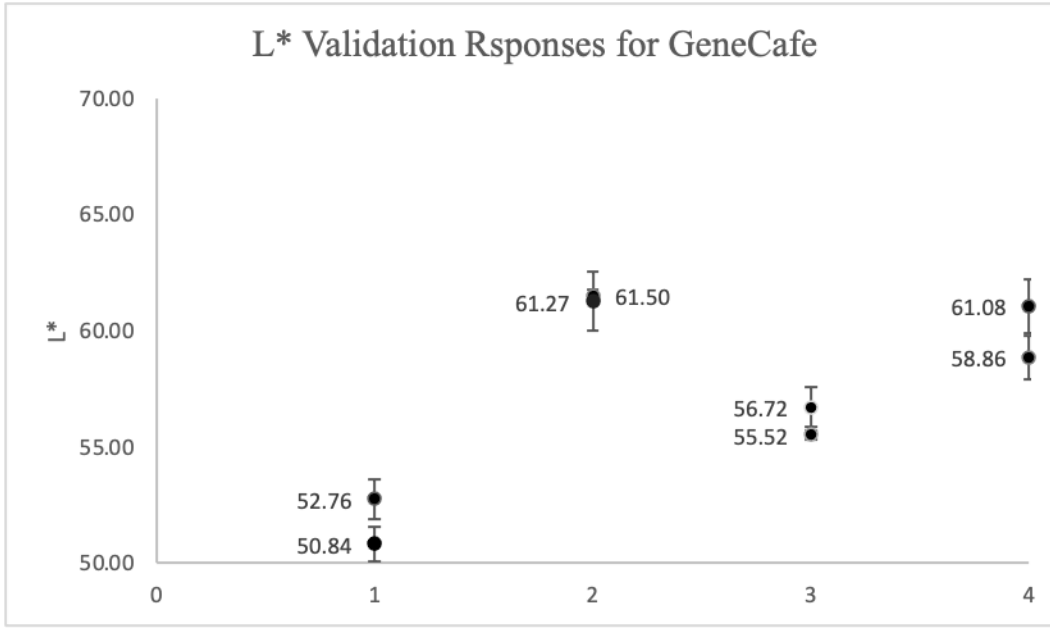


Figure 4.2.5: Validation responses for GeneCafe roaster; Ave L*+/- std dev.

APPENDIX D

Batch (Raw)	Moisture %
Normal Oleic	2.56 ± 0.26
High Oleic	4.70 ± 0.19

Table 4.3 : Moisture % (w/w) ± std dev

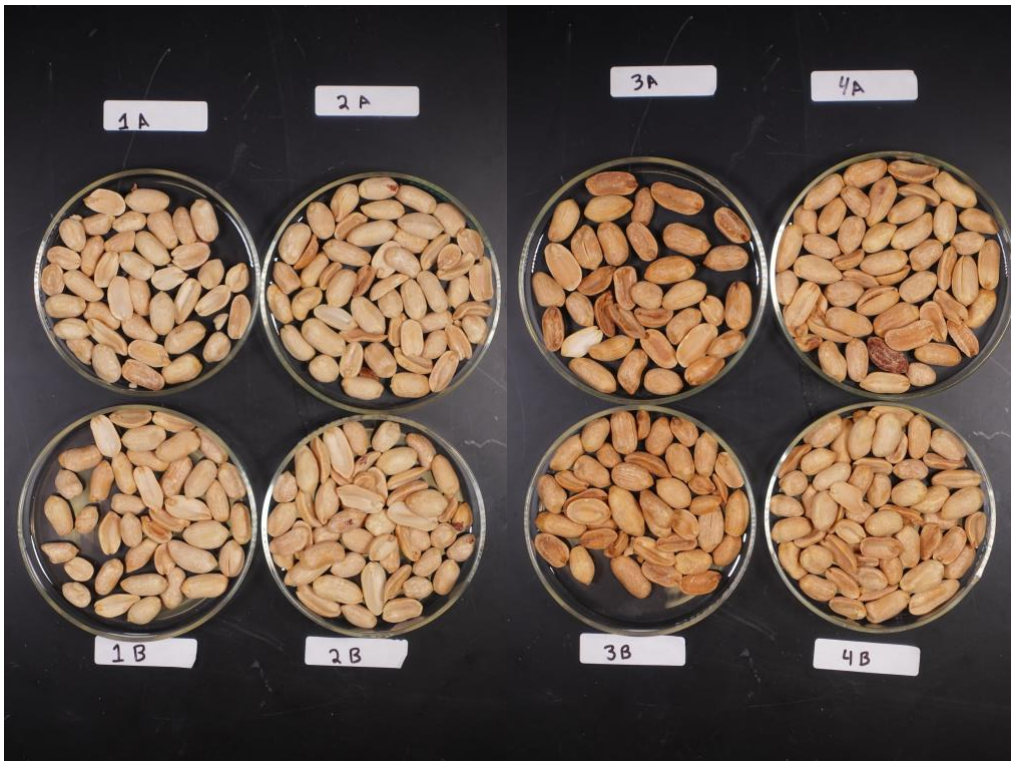


Figure 4.3: Visual comparison of roasted peanuts from Behmor validation (Table 4.1.2); ZV-1 Sony camera, 1/320 shutter speed, F4.0 Aperture, ISO 400, Focal 70mm, 2 lights at 100% brightness and 4500K color temperature. Courtesy Jian Wu

APPENDIX E

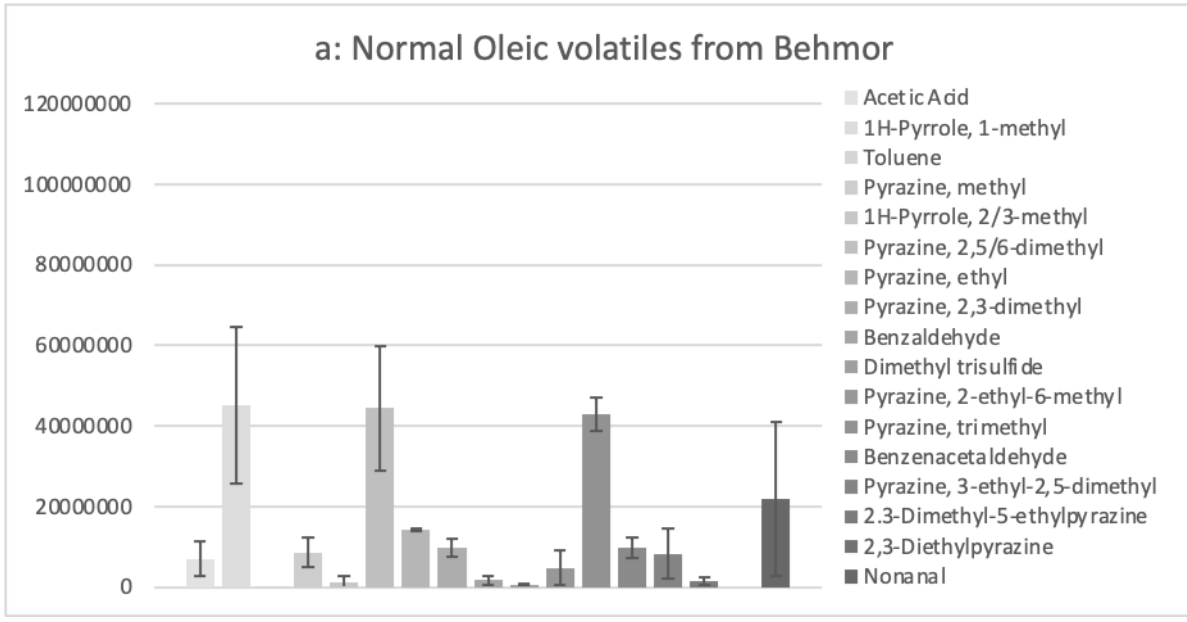
	Normal Oleic		High Oleic	
Fatty Acid	Raw	Roasted	Raw	Roasted
16:0	9.41 ± 0.32	10.30 ± 0.56	6.25 ± 0.12	6.81 ± 0.32
18:0	2.83 ± 0.21	2.85 ± 0.02	2.51 ± 0.04	3.07 ± 0.01
18:1ω9	52.41 ± 0.91	50.69 ± 0.92	72.59 ± 0.70	74.67 ± 0.20
18:1ω7	0.48 ± 0.04	0.54 ± 0.06	0.52 ± 0.08	0.64 ± 0.01
18:2ω6	26.63 ± 0.21	27.54 ± 0.03	10.05 ± 0.34	6.70 ± 0.16
20:0	1.58 ± 0.01	1.68 ± 0.25	1.59 ± 0.11	1.68 ± 0.02
20:1ω9	1.50 ± 0.03	1.57 ± 0.22	1.78 ± 0.09	1.92 ± 0.06
22:0	3.38 ± 0.16	3.19 ± 0.66	2.97 ± 0.01	2.95 ± 0.15
24:0	1.79 ± 0.08	1.66 ± 0.28	1.77 ± 0.01	1.59 ± 0.07

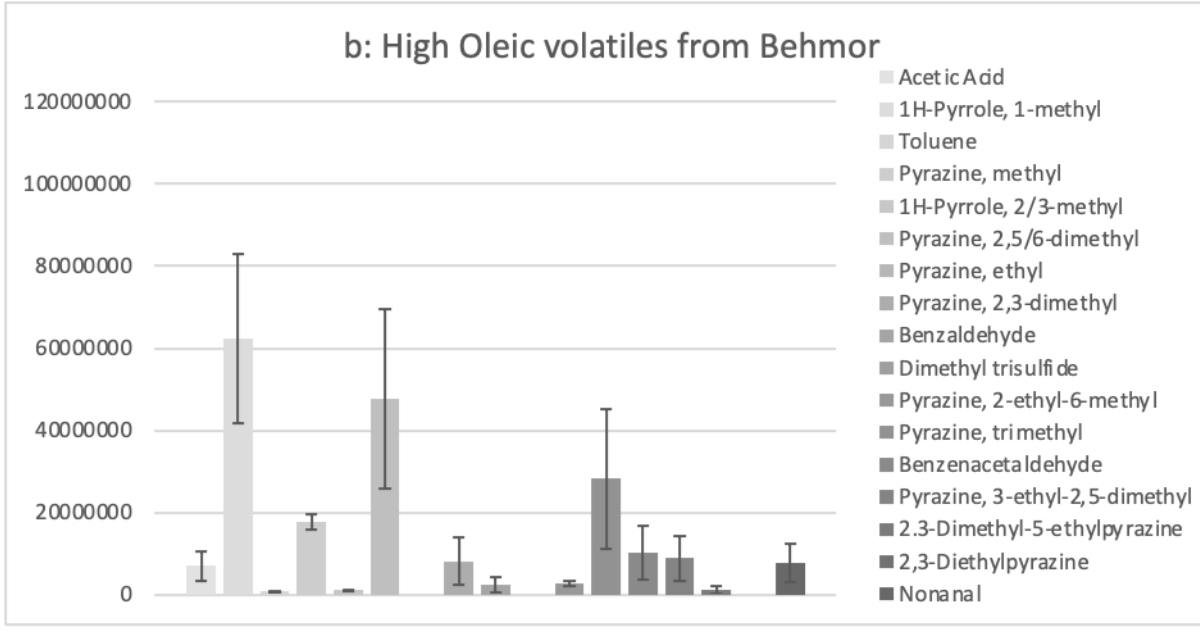
Table 4.4.1: Fatty Acid Analysis, Relative % +/- std dev

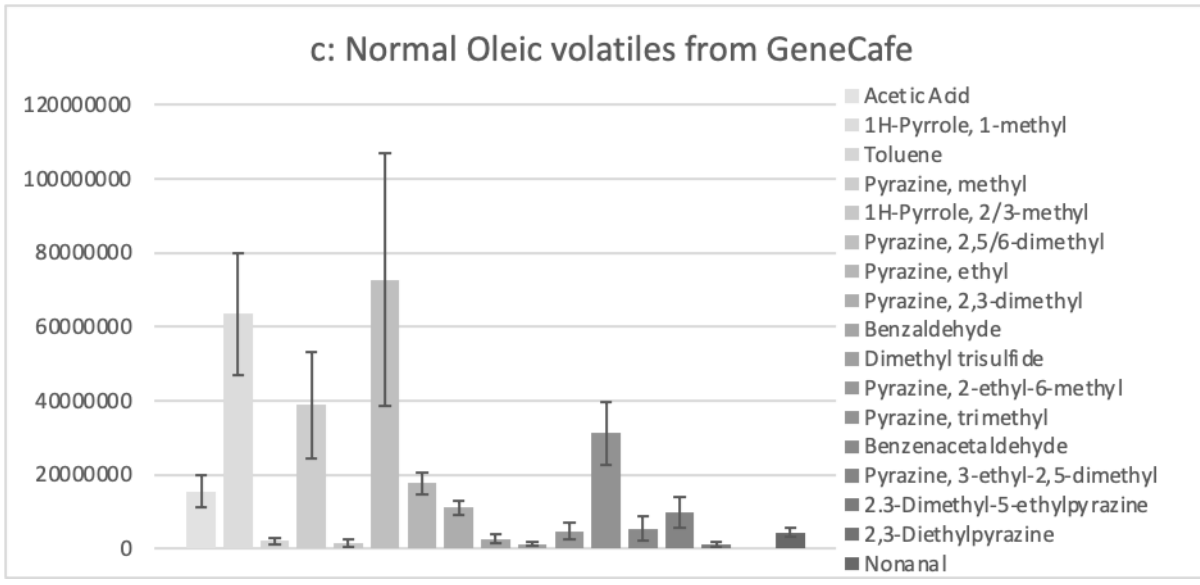
APPENDIX F

Roaster	Batch	weight	Power/Temp	Time	L*Predicted	L* +/- std dev
Behmor	NO	100g	P4	7:25	55	56.74 +/-0.89
	HO	100g	P4	7:25	55	57.72 +/-0.50
GeneCafe	NO	100g	350°F	16:00	55	53.80 +/-2.58
	HO	100g	350°F	16:00	55	58.19 +/-2.01

Table 4.5.1: Data for Normal and High Oleic peanuts roasted to equivalent L* predicted value.


a: Normal Oleic volatiles from Behmor
120000000
100000000
80000000
60000000
40000000
20000000
0
Acetic Acid
1H-Pyrrole, 1-methyl
Toluene
Pyrazine, methyl
1H-Pyrrole, 2/3-methyl
Pyrazine, 2,5/6-dimethyl
Pyrazine, ethyl
Pyrazine, 2,3-dimethyl
Benzaldehyde
Dimethyl trisulfide
Pyrazine, 2-ethyl-6-methyl
Pyrazine, trimethyl
Benzenacetaldehyde
Pyrazine, 3-ethyl-2,5-dimethyl
2.3-Dimethyl-5-ethylpyrazine
2,3-Diethylpyrazine
Nonanal


b: High Oleic volatiles from Behmor
120000000
100000000
80000000
60000000
40000000
20000000
0
Acetic Acid
1H-Pyrrole, 1-methyl
Toluene
Pyrazine, methyl
1H-Pyrrole, 2/3-methyl
Pyrazine, 2,5/6-dimethyl
Pyrazine, ethyl
Pyrazine, 2,3-dimethyl
Benzaldehyde
Dimethyl trisulfide
Pyrazine, 2-ethyl-6-methyl
Pyrazine, trimethyl
Benzenacetaldehyde
Pyrazine, 3-ethyl-2,5-dimethyl
2.3-Dimethyl-5-ethylpyrazine
2,3-Diethylpyrazine
Nonanal



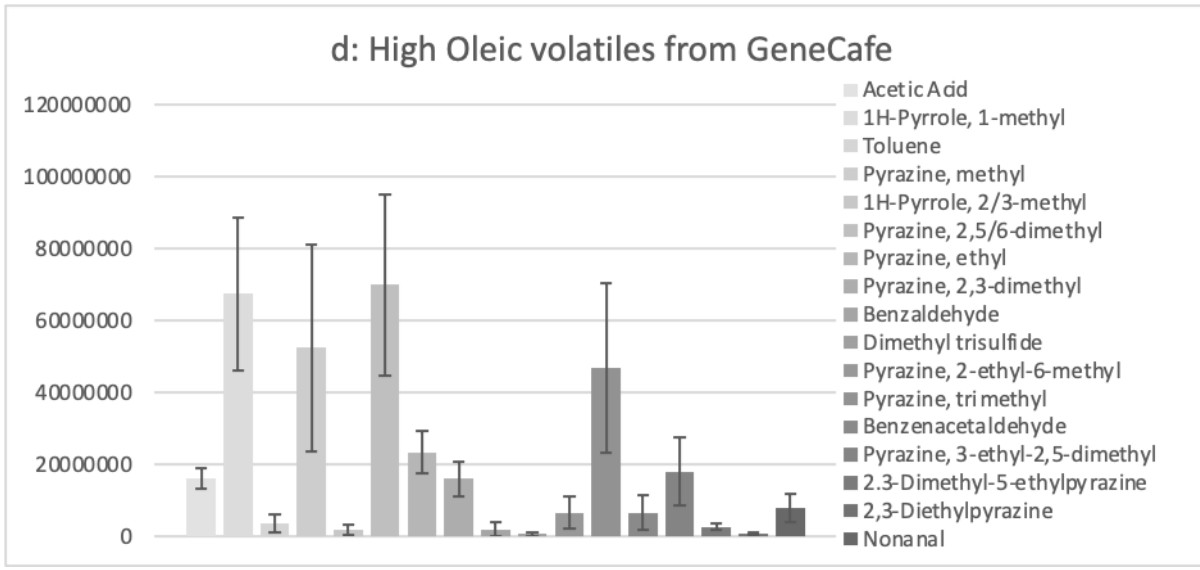


Figure 4.5.1: Volatile Analysis graphs a through d; Integrated area +/- 95% confidence interval (CI)

APPENDIX G

Figure 3.1.1 Aillo Bullet R1

Figure 3.1.2 Hottop programmable roaster

Figure 3.1.3 Behmor 1600AB

Figure 3.1.4 GeneCafe