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Composition, sensory attributes, and flavor of dry- and oil-roasted soynuts after roasting and during storage

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INTRODUCTION

Soybeans (*Glycine max*) have been cultivated and consumed in China for thousands of years. Chinese written records indicate that soybeans were cultivated as early as 2800 B.C. (Watanabe and Kishi 1984). The cultivation of soybeans in the United States however, has been relatively recent. In fact, large-scale production of soybeans in the United States did not begin until the 20th century (Riaz 2006). Since the soybean's introduction to the United States its production has increased enormously. The United States currently produces around 75 million metric tons of soybeans annually. The majority of the soybeans produced (85%) in the world are crushed into soybean meal and vegetable oil (Riaz 2006). The meal is primarily used for animal feed. Only about 10% of the soybeans produced in the world are directly used for human consumption. The remaining soybeans are used for seed or on-the-farm feeding of animals (Riaz 2006).

Although traditional soyfoods are a staple food in many Asian countries, extracted soybean oil is the primary soy product consumed in the United States. The interest in human consumption of more than the extracted oil has increased recently in the U.S. This is due primarily to the approval of a health claim for soy protein by the FDA. This health claim states that diets that are low in saturated fat and cholesterol and that include 6.25 g of soy protein per serving "may" or "might" reduce the risk of heart disease (FDA 1999). Moreover, soy consumption has been associated with other health benefits. Some of these benefits include: cancer prevention, cholesterol-reduction, increased bone density, and reduction in menopausal symptoms (Liu 2000). These benefits are attributed to different components of soybeans including the protein as well as the plethora of phytochemicals found in soybeans.

As purported in the FDA health claim, one of the most important nutrients in soybeans is the protein. Soybean protein is a high quality protein in that it contains all the essential amino acids and has a protein-digestibility-corrected amino acid score between 0.95

and 1.00 (Riaz 2006). Soy, as a protein source, is cholesterol-free and low in saturated fat as opposed to some animal sources of protein which can be high in both. With the prevalence of obesity increasing rapidly in the United States and around the world, studies have begun to analyze the effect of the macronutrient composition of food on satiety. The studies have concluded that protein produces more satiety in humans (Barkeling and others 1990; Vandewater and Vickers 1996; Layman and others 2003).

Soynuts, made from the whole soybean, are produced by first soaking the soybeans, then subjecting them to some type of roasting treatment. The advantage of a soyfood that contains the entire soybean is that all of the beneficial nutrients are consumed. This is in contrast to soy ingredients, such as soy protein isolate, in which only the protein is consumed. Another advantage of soynuts over some other types of soyfoods is that they are shelf-stable. However, their shelf-life is not indefinite.

The objective of this study was to determine the effects of cultivar, roasting method, and storage on the chemical composition, sensory characteristics, and flavor profile of roasted soynuts. This thesis consists of a review of current literature and three articles to be submitted to the Journal of Food Science. The first article discusses compositional changes in roasted soynuts during roasting and after storage. The second article discusses the sensory characteristics of roasted soynuts after roasting and storage. The final article discusses the effects of roasting and storage on the composition of volatile flavor compounds and indices of lipid oxidation.

LITERATURE REVIEW

Soybeans have a long history of production and consumption in China. However in the United States and other parts of the world, soybean production and consumption is relatively recent (Liu 2000). Small-scale production of soybeans began in the U.S. during the 19th century when Asians began immigrating to the U.S. Although it was not until the 1940's that large-scale production and processing began (Riaz 2006). Since then, production of soybeans in the U.S. has greatly increased. In fact, soybean oil is the vegetable oil produced in the highest volume in both the United States and the world (White 2000). Currently, the primary uses for soybeans produced in the United States are feed for animals and oil for human consumption.

American consumers generally dislike the 'beany' flavor associated with traditional Chinese soy products. Despite the taste barrier to consuming soy, Americans' interest in consuming soy has been increasing rapidly. The Food and Drug Administration's (FDA) approval of a health claim for soy protein and Americans greater awareness of the potential health benefits of soy consumption, such as cholesterol-reduction and cancer prevention, has contributed to the increased interest in soy (Liu 2000). The health claim states that diets that are low in saturated fat and cholesterol and that include soy protein ''may'' or ''might'' reduce the risk of heart disease. The health claim can be used on products containing at least 6.25 g of soy protein per serving. The product must also meet nutrient content requirements for a "low fat," a "low saturated fat," and a "low cholesterol" food, unless it consists of or is derived from whole soybeans (FDA 1999). The approval of this health claim has resulted in tremendous growth of soy products in the food industry as companies are eager to capitalize on the health benefits of soyfoods (Liu 2000).

The benefits of soy consumption are multi-faceted. Soy protein is a high quality, complete protein which appeals to vegetarian consumers as well as to people wanting to add more protein to their diet without the added cholesterol and saturated fat that accompanies

most animal proteins. Another important use for soy is infant formulas. Infants allergic to milk are often given soy-based formulas to meet their nutritional needs (Friedman and Brandon 2001). Soy protein is also used by food manufacturers to fortify products with protein because of its functionality and lower cost (Riaz 2006). Soy protein is just one of the components of soy conferring health benefits; isoflavones, omega-3 fatty acids, oligosaccharides, phytosterols, and saponins are also beneficial to health.

Nutrition

Protein

Soy protein has demonstrated hypocholesterolemic effects on total and LDL cholesterol levels, especially in individuals with elevated cholesterol levels. Adults with normal or low cholesterol levels, however, do not appear to benefit (Erdman 2002). The amino acid ratios in soy protein are hypothesized to contribute to the cholesterol-lowering effects. Arginine tends to lower cholesterol levels while lysine and methionine tend to raise them. Compared to other protein sources, soy has a higher ratio of arginine to lysine and methionine. This ratio may lower insulin and glucagon secretion, inhibiting lipogenesis (Erdman 2002). Consumption of soy protein has contributed to a decrease in insulin and glucagon levels in humans with high cholesterol levels (Erdman 2002). In addition, the globulin proteins in soybeans increase LDL receptor activity consequently reducing cholesterol. When soy protein is treated with proteases, two fractions are formed, an insoluble and soluble (globulin) fraction. The insoluble fraction of soy protein lowered blood cholesterol levels in rats by increasing excretion of sterols in feces (Erdman 2002). Many studies conducted on the hypocholesterolemic effects of soy protein have not found a dose-response relationship, and the threshold dose has yet to be determined. While the cholesterol-lowering effects of soy protein are not as great as that of cholesterol-lowering drugs they do, from a population standpoint, have the ability to reduce the incidence of coronary heart disease (Messina 2003).

Isoflavones

Potential health benefits of soy isoflavones include cholesterol reduction and other mechanisms of cardio-protection, cancer prevention, women's health benefits (especially in postmenopausal women), bone loss prevention, and bone density increases. Isoflavones and phytoestrogens are proposed to function like estrogen in exerting cardio-protective effects (Liu 2004). Estrogen is effective at lowering LDL cholesterol and increasing HDL cholesterol (Erdman 2000). Soy isoflavones with soy protein have been reported to significantly lower cholesterol more than soy protein alone in humans. Furthermore, soy protein with isoflavones inhibits the formation of atherosclerotic lesions in primates. Comparatively, soy protein alone showed an intermediate effect in primates (Erdman 2000).

The individual and/or possibly synergistic effects of soy protein and isoflavones on cholesterol reduction have not been determined. The cholesterol-lowering effects of isoflavones demonstrated in many studies are in combination with soy protein consumption. In a study by Setchell and Cassidy (1999), patients with elevated cholesterol levels consumed soy beverages containing 25 grams of soy protein with varying levels of isoflavones ranging from 0-58 mg of isoflavones per day. No significant cholesterol-lowering effects were observed in the beverages containing only soy protein and a linear dose-relationship effect was seen between isoflavone level and cholesterol reduction in the isoflavone-containing beverages. When the isoflavones were removed by alcohol extraction, the hypocholesterolemic effect was eliminated. Although the obvious conclusion is that the isoflavones are the active components involved in cholesterol reduction, other potentially bioactive components, such as saponins, are also removed from the soy protein during alcohol extraction. Additionally, animal studies in which isoflavones were added to casein showed no cholesterol-lowering effects (Setchell and Cassidy 1999). In a study of postmenopausal women where 40 g/d of soy protein and either 56 or 90 mg/d of isoflavones were consumed, both groups consuming soy had better blood profiles (a reduction in non-

HDL cholesterol and an increase in HDL cholesterol) than the casein group which contained no isoflavones. However, no difference was observed between the two isoflavone levels (Erdman 2000). More research needs to be done to determine the role of soy components in cholesterol reduction.

Soy isoflavones may also prevent certain types of cancer. Incidence of breast cancer in Japanese women who consume diets rich in soy isoflavones is very low (Pisani and others 1999). Furthermore, prostrate cancer in Japanese men is rarely fatal (Pisani and others 1999). One study reported that soy isoflavones were able to prevent small tumors (latent cancer) from progressing into large life-threatening tumors in humans (Griffiths 2000). Stopping this progression is crucial to reducing mortality from prostrate cancer. Another study demonstrated that genistein and the isoflavone glucosides inhibit the growth of chemically-induced prostrate tumors and the growth of prostrate tumors in rodents implanted with prostrate cancer cells (Pollard and Walter 2000).

Because the structures of soy isoflavones are so similar to estrogens they are considered to behave like weak estrogens. This plant source of "weaker estrogens" provides the benefits of estrogen without the suspected disadvantages of animal estrogen. Soy isoflavones have been shown to reduce hot flashes that occur during menopause (Setchell and Cassidy 1999). Research shows that isoflavones potentially work like estrogens in preventing bone loss and increasing bone density. In one study of postmenopausal women, genistein was found to be as effective as conventional hormone replacement therapy in preventing bone loss at the spine and hip (Morabito and others 2002).

Lipids

The lipids in soybeans are cholesterol-free, low in saturated fatty acids, and high in unsaturated fatty acids. One of the unsaturated fatty acids in soybean oil is α-linolenic acid, an omega-3 fatty acid. Recent epidemiological studies suggest that consumption of omega-3 fatty acids and α-linolenic acid results in a decrease in risk for cardiovascular disease (CVD).

People without documented coronary heart disease (CHD) are encouraged to eat a variety of fish (especially fatty fish) at least twice per week and include oils and foods rich in α-linolenic acid (flaxseed, canola, and soybean oils; flaxseed and walnuts) in their diets (Kris-Etherton and others 2002).

Oligosaccharides

The predominant oligosaccharides in soybeans are sucrose, raffinose and stachyose. Raffinose and stachyose are three and four monosaccharide unit sugars that are indigestible by human enzymes. These oligosaccharides pass into the gut undigested, but are degraded by bacteria often causing flatulence and abdominal pain. Due to these adverse side effects, the oligosaccharides in soy are often considered undesirable. However, oligosaccharides are believed to have beneficial health effects as prebiotics, enhancing the growth of probiotic bacteria, such as lactobacilli and bifidobacteria (Tomoatsu 1994). Lactobacilli inhabit the upper gut, while bifidobacteria inhabit the colon. According to Tomoatsu (1994), the increase in bifidobacteria leads to a reduction of detrimental bacteria, toxic metabolites, and damaging enzymes in the intestine, prevention of pathogenic and autogenous diarrhea, prevention of constipation, protection of liver function, reduction of serum cholesterol, blood pressure, and cancer risk, and production of nutrients.

Phytosterols

Phytosterols are found in plants such as soybeans. The three primary phytosterols in soybeans are campesterol, β-sitosterol, and stigmasterol. They have lipid-like structures and contain the same ring structure as cholesterol. They are distinguished from cholesterol and from each other by their side chains or, in the case of stigmasterol, an additional double bond (Liu 2004). Phytosterols are important because their consumption can significantly reduce blood cholesterol in humans. Several studies show that an intake of 2-3 g phytosterol per day results in a 10-15% reduction in LDL cholesterol which constitutes an approximately 25% reduction in heart disease risk (Liu 2004). Yamaya and others (2007) analyzed 510 cultivars

of soybeans and determined that their phytosterol contents were between 202 and 843 µg/g seed, depending on the cultivar.

Saponins

Saponins are composed of a steroid or triterpene aglycone bound to a hydrophilic sugar, such as a hexose, pentose, or uronic acid. Because of their amphiphilic nature, saponins have detergent-like properties and many potential health benefits including cholesterol-reduction, cancer-prevention, antiviral activity, immune-modulation, and antioxidant activity (Liu 2004).

Phytic Acid

Phytic acid, present as phytate in soybeans, is generally considered to be anti-nutritional. Phytate is the complex of phytic acid with minerals such as calcium, phosphorus, and potassium. Minerals bound to phytate are relatively insoluble and poorly absorbed by the body. Consuming phytic acid can reduce the availability of important minerals such as calcium, magnesium, zinc, and iron (Liu 2004). However, phytic acid has been shown to have some anticancer activity. This is due to its ability to function as an antioxidant and chelate divalent cations (Liu 2004). Phytic acid's chelating ability is also believed to have a cholesterol-lowering effect (Erdman 2000). Through its ability to chelate zinc, phytic acid reduces the ratio of zinc to copper. High ratios of zinc to copper or copper deficiency result in increase in blood cholesterol. Soybeans contain copper. By chelating the zinc and providing copper, soy effectively reduces the ratio of zinc to copper to a healthier ratio (Erdman 2000).

Trypsin Inhibitors

Trypsin inhibitors are considered to be anti-nutritional because they inhibit proteases necessary for protein digestion. Two types of protease inhibitors are found in soy. The Bowman-Birk inhibitor inhibits both trypsin and chymotrypsin, while the Kunitz trypsin inhibitor inhibits trypsin only. Seventy-five to ninety-five percent of trypsin inhibitor

activity is destroyed by heat during processing (Liu 2004). However, active trypsin inhibitors may also have some beneficial effects. The Bowman-Birk trypsin inhibitor may exert a cholesterol-lowering effect by increasing the secretion of cholecystokinin, which stimulates bile acid synthesis from cholesterol. Cholesterol would then be removed through the gastrointestinal tract (Erdman 2000). In addition to having a hypocholesterolemic effect, the Bowman-Birk inhibitor has been shown to have anticarcinogenic properties at very low doses, although the mechanism has yet to be elucidated (Liu 2004).

Composition of Soybeans

Moisture Content and Water Activity

Raw soybeans should be maintained at a moisture content near 13% during storage Wilcke and others 2005). Moisture contents higher than 13% increase the susceptibility of soybeans to spontaneous heat generation and microbial growth. If soybeans contain significantly less than 13% moisture content they are subject to breakage and splitting. For these reasons soybeans are traded on a 13% moisture basis (Wilcke and others 2005; Acasio 1997).

Moisture content is not the best predictor of shelf-life. The water activity (a_w) in foods, as determined by complex interactions between water and other food components, is more helpful in determining shelf-life than moisture content (Leake 2006). The a_w affects the rate of deteriorative chemical reactions, the physical properties, and the susceptibility to microbial growth of food products. Foods with water activities of 0.6 or higher are particularly susceptible to microbial growth (Leake 2006).

Protein

Soybeans are composed of about 40% protein on a dry-matter basis. The protein in soybeans can be categorized into 3 groups: water-soluble and able to be precipitated at pH 4.5 (globulins), water-soluble and not able to be precipitated (whey), and water-insoluble. The globulin proteins make up the majority of soy protein. These proteins consist primarily

of glycinin and β-conglycinin. Globulin protein subunits are 2S, 7S (β-conglycinin), 11S (glycinin) and 15S. Heating of soybeans typically improves the digestibility of the protein by denaturing the protein slightly and allowing proteolytic enzymes to hydrolyze the protein molecules. Heating also inactivates the typsin inhibitors greatly increasing the digestibility of soy protein (Watanabe and Kishi 1984).

Carbohydrates

Soybeans contain approximately 35% carbohydrates on a dry-matter basis. The soluble carbohydrate fraction consists of the oligosaccharides sucrose, raffinose, and stachyose and the reducing sugars glucose and fructose. These sugars are found in small, but significant amounts. Raffinose and stachyose range from 0.1% to 0.9% and 1.4% to 4.1% respectively, on a dry-matter basis. Sucrose is found in slightly higher concentrations than stachyose and raffinose and the reducing sugars are found in smaller, sometimes non-detectable, amounts. Cellulose, hemicellulose, pectin and a trace amount of starch comprise the insoluble carbohydrate fraction in soybeans (Liu 2004). Most of the carbohydrate in soybeans is considered to be dietary fiber, this includes raffinose and stachyose and the complex polysaccharides (Liu 2004).

Lipids

Soybeans (dry weight basis) contain approximately 20% lipid (American Soybean Association 2006). Soybean lipids are primarily unsaturated. The average composition of refined, bleached, and deodorized commercial soybean oil is 11% palmitic acid, 4 % stearic acid, 24% oleic acid, 54% linoleic acid, and 7% linolenic acid (Hui 1996). Because of the high content of polyunsaturated fatty acids, particularly linoleic and linolenic acids, soybean lipids are prone to oxidative stability problems (Hui 1996).

Effects of Roasting on Soybeans

Effects of Roasting on Proteins

Roasting causes beneficial nutritional changes to occur in soybeans. Anti-nutritional factors such as trypsin inhibitors and haemagglutinins are inactivated up to 95 and 100% respectively during roasting (Ramamani and others 1996). In a study by Ramamani and others (1996), the protein efficiency ratio (PER) increased from a negative value for raw soybeans to 1.8 for roasted soybeans. Albino rats could not grow on a diet of raw soybeans as their source of protein. In addition to the desirable nutritional changes, desirable flavor compounds are also formed. However, roasting does decrease the availability of some essential amino acids, namely lysine, through Maillard browning. For optimal nutrition, the amount of heat treatment needed to inactivate most of the anti-nutritional factors must be balanced with the loss of essential amino acids (Ramamani and others 1996).

Effects of Roasting on Lipids

Effects of roasting soybean fatty acids vary with the temperature and length of roasting. Higher roasting temperatures (150 °C and 170 °C) tended to increase relative contents of saturated and monounsaturated fatty acids and decrease contents of polyunsaturated acids slightly compared to a roasting temperature of 130 °C (Jung and others 1997). Higher roasting temperature also appeared to increase the formation of conjugated dienes and trienes. However, higher roasting temperatures could also induce the formation of interfering substances that could be mistakenly be measured as oxidation products (Jung and others 1997). Isomerization can be induced by roasting, possibly leading to formation of trans fatty acids (Amaral and others 2006). In fact, roasting of hazelnuts caused a small increase in the amount of trans fatty acids as compared to the raw hazelnuts. (Amaral and others 2006).

Effects of Roasting on Carbohydrates

While carbohydrates do not represent the largest or most important component of soybeans they do play an important role in the nutrition and the processing of soybeans. The oligosaccharides are most important nutritionally. As for the effects of processing on soybean carbohydrates, the reducing sugars are most affected. Storage conditions, such as humidity and temperature, and processing conditions can induce hydrolysis of sucrose, raffinose, and stachyose producing more reducing sugars (Locher and Bucheli 1998; Oosterveld and others 2003). The reducing sugars react with free amino acids and peptides during roasting via Maillard browning to create desirable roasted flavors (Ponquett 2002).

During the roasting process of cocoa beans most of the fructose and all of the glucose were degraded. In this study there were no decreases in the non-reducing sugars sucrose, raffinose, stachyose, or verbascose (Redgwell and others 2003).

Maillard Browning

Maillard browning is the predominant type of non-enzymatic browning occurring in thermally-processed foods (Hwang and others 1995). Maillard browning and Strecker degradation are responsible for the formation of pleasant roasted flavor compounds and melanoidin formation (Martins and others 2001; Ponquett 2002). According to Basha and Young (1996), reducing sugars and amino acids are the major precursors of desirable flavor compounds in roasted peanuts.

Maillard browning is initiated when a reducing sugar condenses with a free amino group, usually a free amino acid or amine side chain on a protein to form N-substituted glycosylamine. This reaction is favored during heating at higher pH's. The glycosylamine rearranges to form an Amadori rearrangement product. The type of degradation of the Amadori product is dependent on the pH of the system. The degradation products formed are highly reactive and continue to degrade through a variety of reactions including dehydration, cyclization, retroaldolization, rearrangement, isomerization and further condensation

reactions. Eventually brown nitrogenous polymers and co-polymers, termed melanoidins, are formed. Within this degradation process, desirable flavor and aroma compounds are formed (Martins and others 2001).

Roasted Flavor Compounds and Pyrazine Formation

The compounds responsible for pleasing aromas and flavors in heat-treated foods are primarily heterocyclic compounds including furans, thiazoles, thiophenes, oxazoles, pyrroles, pyridines, and pyrazines (Hwang and others 1995). Pyrazines are the most abundant of the heterocyclic compounds formed during roasting and are responsible for toasted and roasted flavors and yellow color formation in cooked foods (Lee and Shibamoto 2002). There are three groups of pyrazines: alkylpyrazines, bicyclic pyrazines, and acetylpyrazines. Alkylpyrazines contribute significantly to the desirable flavor of heat-treated foods. Monosubstituted-pyrazines typically have nutty and/or roasted notes and higher alkylsubstituted pyrazines have fatty and/or waxy odors. Fried beef, roasted nuts, cocoa, and coffee aromas were identified with alkyl substituted dihydrocyclopentapyrazines (Hwang and others 1995). The quantity and quality of compounds produced in Maillard browning depends on the precursors, thermal processing parameters, pH, and quantitative ratio of amino nitrogen to reducing sugar (Martins and others 2001). According to Hwang and others (1995) bicyclic pyrazines require temperatures over 150°C for formation whereas monocyclic pyrazines form at around 120°C.

Pyrazine formation in food systems is complex and more than one amino acid is present. To better understand the mechanisms of pyrazine formation, model systems consisting of individual amino acids and sugars have been studied extensively. Using a model system, Hwang and others (1995) found that most pyrazines are formed regardless of what amino acids are present, but some higher molecular weight pyrazines are only formed in the presence of certain amino acids. In an aqueous model system at pH 10, 4 amino acids were individually heated with glucose and the amounts of pyrazines were compared.

Arginine heated with glucose and lysine heated with glucose produced the greatest quantity of pyrazines. Histidine and glycine individually paired with glucose produced considerably smaller amounts (Huang and others 1989).

Hwang and others (1995) investigated the effects of heating two amino acids together with glucose. Glycine was chosen as the amino acid that all the other amino acids would be reacted with. Its nitrogen was isotope-labeled and it was reacted with glutamine, glutamic acid, asparagine, lysine, arginine, phenylalanine, or isoleucine at pH 7. Glutamine and glutamic acid, when individually reacted with glycine, resulted in the lowest percentage yield of pyrazine formation and asparagine resulted in the highest percentage yield of pyrazine formation. Asparagine has been shown to have a faster deamination rate than glutamine, perhaps explaining the difference in pyrazine yield. Because the glycine was isotope-labeled it was determined that in a reaction mixture with lysine, glycine had the highest overall pyrazine yield compared to the other amino acids. In a reaction mixture with arginine, glycine had the lowest overall pyrazine yield compared to the other amino acids. Lysine appeared to be a synergist in increasing the reactivity of glycine whereas arginine acted like an inhibitor depressing pyrazine generation ability of other amino acids (Hwang and others 1995).

Effect of Amino Acid Composition on Roasted Flavor

Because the amino acids present in the reaction mixture influence the flavor compounds formed in food during roasting, differences in the free amino acids present in a soybean cultivar have the potential to influence flavor. Basha and Young (1996) stated that free amino acid contents in peanuts differ by variety, planting location, and maturation. Yanagisawa and others (1997) found that differences in free amino acid contents were cultivar specific between vegetable-type and grain-type cultivars of soybeans.

Amino acids considered to be typical roasted flavor precursors in roasted peanuts include aspartic acid, glutamic acid, glutamine, asparagine, histidine, and phenylalanine.

Threonine, tyrosine, and lysine are considered to contribute to atypical flavor in roasted peanuts (Basha and Young 1996). Besides the flavors formed from free amino acids interacting with other compounds such as sugars and lipids during roasting, amino acids have their own flavor attributes. Alanine is highly correlated with sweetness and asparagine and glutamic acid are highly correlated with typical taste of edamame soybeans (Yanagisawa and others 1997).

Roasting Temperature and Oxidative Stability

Roasting temperature affects the color, pyrazine content, and oxidative stability of soybeans and the oil extracted from them. In a study by Jung and others (1997), soybeans were roasted at 130 °C, 150 °C, and 170 °C prior to oil extraction. Increased soybean roasting temperature resulted in the extracted oil being darker, redder, and more yellow. The pyrazine content of the oil increased greatly with increased roasting temperature. Nine alkylpyrazines were identified in the oil. Many of these alkylpyrazines have been previously identified in roasted soybeans (Wilkens and Lin 1970) and in roasted peanuts (Walradt and others 1971). Jung and others (1997) determined that 2,5-dimethylpyrazine was most responsible for the nut-like aroma of oil from roasted soybeans. Higher roasting temperatures greatly increased the oxidative stability of the oil because many of the Maillard reaction products also have antioxidant properties.

Consequences of Roasting

Not only does the Maillard browning reaction produce desirable flavors and colors, but roasting itself contributes to decreases in some of the volatile compounds associated with beany flavor, particularly aliphatic aldehydes and alcohols. Not all of the undesirable flavor compounds decrease upon roasting, however. *N*-hexanol, 1-octen-3-ol and *n*-hexanal were not significantly reduced during roasting of soybeans (Kato and others 1981). Kato and others (1981) concluded that the newly formed desirable volatile compounds were able to mask the beany flavor of the raw soybeans.

The consequences of Maillard browning are both positive and negative. Because proteins are involved in the reaction, a loss of essential amino acids such as lysine and tryptophan can occur, as well as decreased protein digestibility (Martins and others 2001). Formation of mutagens also occurs (Lee and Shibamoto 2002) although none of these compounds have been reported to correlate with human cancer (Martins and others 2001). The formation of these mutagens may be counteracted by the formation of mutagen inhibitors, termed desmutagens, in the Maillard reaction (Martins and others 2001). In addition to desmutagens, antioxidants are also formed in the Maillard reaction that have been shown to protect foods against lipid oxidation (Jung and others 1997; Lee and Shibamoto 2002; Martins and others 2001). Maillard browning is a very complex set of reactions that result in desirable colors, flavors, and antioxidants as well as some undesirable mutagens. The task is to balance the negative effects with the positive effects by controlling processing parameters.

Soybean Lipids and Off-Flavor Generation

The polyunsaturated fatty acids in soybeans make them and the products made from them prone to oxidative stability problems. Linolenic acid with three double bonds is considered to be the most problematic. The off-flavors due to the presence of linolenic acid have led to the development of low-linolenic acid soybean cultivars (Hui 1996). In the past, soybean oils were hydrogenated to improve the stability but with the concern about trans fats, the food industry is interested in the development of more stable soybeans oils that do not require hydrogenation.

Flavor reversion is characteristic of oils containing linolenic acid and contributes to the off-flavors in soy products. Flavor reversion is described as “beany and grassy” at the beginning of oxidation and “fishy or painty” at more advanced stages of oxidation. This reversion develops at peroxide values of 10 or less and is mostly detected organoleptically (Hui 1996). Flavor reversion is often thought to be an oxidative process, but there is some

evidence that it is a non-oxidative process. Antioxidants are ineffective at hindering flavor reversion and hydrogenation is not completely effective in eliminating it, although hydrogenation is able to slow down rancidity (Hui 1996).

Lipoxygenase, an enzyme believed to be a major initiator of peroxidation of lipids is present at approximately 2% of total seed protein in soybeans. Lipid peroxides are formed from the polyunsaturated fatty acids in soybeans, namely linoleic and linolenic acids. These peroxides can also be formed non-enzymatically by the attack of activated oxygen species (Dahuja and Madaan 2003). Lipid peroxides are then broken down further by enzymes such as hydroperoxide lyase or broken down non-enzymatically. This breakdown leads to the formation of off-flavors. The most predominant compounds responsible for off-flavors are medium chain, primarily six carbon, alkylaldehydes or alkenylaldehydes (Dahuja and Madaan 2003; Kobayashi and others 1995). Hexanal is produced by enzymatic oxidation and cleavage of linoleic acid and 2-hexenal and hexenol are produced from the enzymatic oxidation and cleavage of linolenic acid (Kobayashi and others 1995).

Many studies have demonstrated reduced off-flavor formation when low-lipoxygenase or lipoxygenase-free soybeans are used. In soymilk, yields of volatile compounds were greatly decreased when lipoxygenases were lacking (Kobayashi and others 1995). Torres-Penaranda and others (1998) found that soymilk made from lipoxygenase-free soybeans had less cooked beany aroma, cooked beany flavor, and astringency than soymilk made from the normal soybean cultivar. In addition, there were no differences in desirable soymilk attributes between the soymilk made from lipoxygenase-free and normal soybean cultivars (Torres-Penaranda and others 1998). In a study by Dahuja and Madaan (2003), two varieties of low-lipoxygenase soybeans had lower thiobarbituric acid and carbonyl values than normal soybeans also suggesting lipoxygenase's role in producing off flavors.

Soybean's natural health benefits make it an excellent food to incorporate into the American diet. Soybeans have the potential to increase the nutrient density of the diet and

stave off diseases such as cardiovascular disease and cancer. Soynuts are advantageous as a soyfood because the entire bean with all its nutrients is consumed. Furthermore, the roasting process has the potential to overcome the off-flavors typically associated with soy by formation of desirable roasted and nutty flavors.

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COMPOSITIONAL CHANGES OF DRY- AND OIL-ROASTED SOYNUTS DURING ROASTING AND STORAGE

A paper to be submitted for publication in the Food Chemistry and Toxicology section of the Journal of Food Science

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Abstract

Five food-grade soybean cultivars were dry- and oil-roasted and stored for 6 months. The effects of cultivar, roasting, and storage on soybean composition were determined. Composition of roasted soynuts was measured on raw soybeans, roasted soynuts after roasting, and roasted soynuts after six months of storage. Moisture contents decreased after roasting and increased during storage. Oil-roasted soynuts were lower in moisture content than dry-roasted soynuts. Oil-roasted soynuts had significantly higher lipid contents than raw soybeans and dry-roasted soynuts due to the absorption of oil. Reductions were observed in reducing sugars and free amino acids with roasting. Greater reductions were seen in oil-roasted soynuts because of the higher roasting temperature and presumably increased Maillard browning. Storage resulted in minor changes in soluble sugars. Most free amino acid contents decreased during storage.

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Introduction

Understanding the composition of soybeans (*Glycine max*) is important to understanding the quality attributes of the processed product. The moisture content of the finished product will influence its the stability and quality. In the case of a roasted nut-like product such as soynuts, the water activity, a related measure, will affect texture of the final product (Lee and Resurreccion 2006). During the roasting process, sugars and free amino acids are important precursors to the formation of desirable roasted flavors (Oupadissakoon and Young 1984; Bett and Boylston 1992; Basha and Young 1996; Ponquett 2002). The quantity and quality of compounds produced in the Maillard browning reaction depends on the precursors, thermal processing parameters, pH, and quantitative ratio of amino nitrogen to reducing sugar (Martins and others 2001).

Reducing sugars, primarily fructose and glucose, in soybeans react with the free amino acids via Maillard browning to produce furans, thiazoles, thiophenes, oxazoles, pyrroles, pyridines, and pyrazines (Hwang and others 1995). Pyrazines are the most abundant of the heterocyclic compounds formed during roasting and are responsible for toasted and roasted flavors and yellow color formation in cooked foods (Lee and Shibamoto 2002). The oligosaccharides sucrose, raffinose, and stachyose are largely unreactive, but they can undergo hydrolysis to produce reducing sugars. The amino acids present have an influence on the pyrazines formed (Hwang and others 1995). Depending on the types of free amino acids available for reaction typical or atypical flavors can be created. Amino acids considered to be typical roasted flavor precursors in roasted peanuts include aspartic acid, glutamic acid, glutamine, asparagine, histidine, and phenylalanine. Threonine, tyrosine, and lysine are considered to contribute to atypical flavor in roasted peanuts (Basha and Young 1996).

Lipids, which constitute approximately 18% of soybeans by weight (American Soybean Association 2006), also influence the flavor of soy products. Linoleic acid is the

predominant fatty acid found in soybeans and makes up 54% of lipid fraction of soybeans. Soybeans also contain a relatively high amount of linolenic acid, 7% of the lipid fraction. Because of the high content of these two polyunsaturated fatty acids, soybean lipids are prone to oxidative stability problems. Linolenic acid with three double bonds, is the most problematic which has led to the development of low-linolenic acid soybean cultivars (Hui 1996). Soybeans also contain lipoxygenases which further exacerbate stability issues. Lipoxygenases produce hydroperoxides from polyunsaturated fatty acids. These hydroperoxides breakdown either by enzymatic or non-enzymatic processes to produce volatile flavor compounds such as ketones, aldehydes, and alcohols. These compounds are responsible for the 'beany', 'painty', and 'cardboardy' off-flavors that discourage soy consumption by American consumers (Torres-Penaranda and others 1998).

Soybean cultivars vary in their chemical composition. The most dramatic differences are demonstrated in soybeans developed to have specific traits. Some examples are cultivars developed to be high in protein, high in oil, low in linolenic acid, high in oleic acid, low in palmitic acid, or combinations of these characteristics. Composition is also affected by growing conditions. This includes the location, rainfall, and temperature, as well as other environmental parameters (Kumar and others 2006).

The raw composition of soybeans can impact the flavor stability and shelf-life of the final product. The processing impacts the composition of the soy product and vice versa. Shelf-life is very important because it is essential that the taste not only be acceptable after processing, but at the time of consumption. In the case of soynut processing roasting can cause an increase in stability of soybean flavor because many of the Maillard browning products produced from the sugars and amino acids have antioxidant properties. These antioxidants lend stability to the lipid fractions of the soybeans. Changes in soybean components do not occur independently of one another. Even though the Maillard browning reaction primarily involves reducing sugars and free amino acids, lipid oxidation products

can also participate (Hidalgo and Zamora 2004). The interaction between the components in soybeans adds to the complexity of the roasting process. The objective of this study was to determine the effect of cultivar, roasting method, and storage on the chemical composition of roasted soynuts.

Materials and Methods

Soybean Cultivars

Five food grade soybean cultivars, IA 2064, IA 1008 LF, IA 1008, Prairie Brand 299, and Asgrow 2247, were evaluated in this study. IA 2064, IA 1008 LF, and IA 1008 were obtained from the Committee for Agricultural Development at Iowa State University and were grown during the 2004 crop year. Prairie Brand 299 and Asgrow 2247 were obtained from Central Iowa Soy LLC (Jefferson, IA) and were grown during the 2005 crop year. IA 2064 is a low- linolenic acid cultivar. IA 1008 LF is a lipoxygenase-null cultivar derived from the IA 1008 cultivar.

Soybean Roasting

Processing of each cultivar and roasting method (dry- or oil-roasted) was conducted in duplicate. The soybeans were soaked in water (3:1 wt/wt, water:soybeans) for 20-24 hours at 4°C prior to roasting. The dry-roasted soybeans were roasted in 2000 g (soaked weight) batches in a drum roaster (Gold Medal Funfood Equipment & Supplies, Cincinnati, OH, U.S.A.) for three hours. The roaster did not provide temperature control adjustments. After roasting, the soybeans were allowed to cool on paper towels.

Oil-roasted soybeans were roasted in 500 g (soaked weight) batches in a deep-fat fryer (7.5 liter oil capacity; Star Mfg. International Inc., Smithville, TN, U.S.A.) at 177°C for 9 minutes and 10 seconds in vegetable oil (Crisco®, J.M. Smucker Co., Orrville, OH, U.S.A.). After roasting the soybeans were removed from the oil and the excess oil was allowed to drain back into the deep fat fryer for 30 seconds. The soybeans were then allowed to cool on paper towels.

Because the oil quality changes as the frying time increases, the order of roasting of the cultivars was randomized. For optimum flavor, the oil was heated 1½ hours prior to roasting the soybeans and the first batch roasted in the oil was discarded. The total amount of roasting time for all batches was short enough that it was not necessary to change the oil (White 2006). Samples from the fresh oil, the oil after 1½ hours of heating, the oil after 1½ hours of roasting, and the oil at the end of roasting time were collected. Peroxide value, aldehyde content and free fatty acid content were determined to ensure that the oil had not deteriorated excessively.

The SāfTest® System (SāfTest®, Inc., Tempe, AZ, U.S.A.) was used to measure peroxide value, aldehyde content, and free fatty acid content of the oil samples taken during oil roasting. Preparation reagent (isopropyl alcohol) was added to the oil sample in a 10:1 ratio for the peroxide value determination. The oil was analyzed as is for the free fatty acid content and aldehyde content determination. The PeroxySafe™, AldeSafe™, and FASafe™ Kit-STD protocols were followed for each test. Peroxide values were expressed as meq peroxide/kg of sample. Aldehydes were expressed as µmol of malonaldehyde/kg sample. Free fatty acids were expressed as percent oleic acid in the sample.

Peroxide values are useful for initial oil quality measurements, but peroxides breakdown rapidly at elevated temperatures and should not be used to monitor oil processes such as frying (White 2000). Initial peroxide values for oil were 0.12 meq O_2/kg sample or less. Oils with peroxide values of 1 meq O_2/kg or less are considered to be unoxidized and of high quality (Gerde and others 2007). Aldehyde contents were less than 2.0 µmols/kg of sample initially and reached a maximum value of 29.3 µmols/kg of sample at the end of frying. Free fatty acid contents were less than 0.1% even by the end of frying indicating that the oil had not deteriorated markedly. Even fresh refined, bleached, and deodorized oils can contain up to 0.05% free fatty acids (Su and White 2004).

The dry- and oil-roasted soynuts were stored for up to 6 months in individual 7 oz Whirl-Pak bags (3 mil thickness, oxygen permeability 209.5 cc/100 sq in/24 hrs; moisture permeability 0.48 gms/100 sq in/24hrs, Nasco Fort Atkinson, WI, U.S.A) by month, roast, and cultivar. Each bag remained sealed until analyzed. The individual Whirl-Pak bags for each month were stored inside Ziploc® gallon storage bags (S.C. Johnson & Son Inc. Racine, WI, U.S.A.) which were stored in a cupboard to minimize exposure to light. Total storage time of the study was 6 months. Suboptimal packaging was used so that if storage had an effect, it would be demonstrated during the 6 months of storage.

Chemical Analyses

Soybeans were frozen at -18°C overnight and then ground using a Magic Mill III Plus High Speed Flour Mill (Magic Mill, Upper Saddle River, NJ, U.S.A.) on the coarsest setting. The grinding process produces a considerable amount of heat. Freezing the beans prior to grinding minimizes any heat-related reactions that can affect composition. Ground soybeans were used for all chemical analyses.

Moisture Content

Duplicate samples of ground beans (4 g) were dried in an oven at 105°C to a constant weight (AOAC 1984).

Lipid and Fatty Acid Content

Lipids were extracted from the soybeans using a modified Bligh and Dyer method (Lin and others 1995). Duplicate samples of ground beans (5 g) were extracted in 75 ml of $CHCl_3$:CH_3OH (2:1 vol/vol) for one hour with stirring. The samples were then filtered using a Buchner funnel with a No. 1 Whatman paper (Whatman International Ltd, Maidstone, England). The filtrate was washed with 5 ml aliquots of $CHCl_3$:CH_3OH. Twenty milliliters of water (equal to 20% of total volume) was added to the filtered sample. The samples were centrifuged (Beckman Coulter, Inc. Model J2-21; Fullerton, CA, U.S.A.) for 15 minutes at 1000 x g. The methanol layer was removed by aspiration. The chloroform layer was poured

through sodium sulfate. The sodium sulfate was rinsed with 15 ml of chloroform. The samples were then rotary evaporated at 38-40°C and transferred to 10 ml volumetric flasks. Lipid content of the extract was determined by drying 2 – 1ml aliquots under nitrogen. Total lipid content was calculated (g lipid/g sample = x g lipid/1 ml extract x 10 ml extract/y g sample). Results were reported as g lipid/100 g sample on a dry weight basis.

Lipid extract (from above lipid extraction) equivalent to approximately 45 mg of lipid was placed in a 3-ml ReactiVial. Chloroform was removed under a nitrogen stream. The lipids were hydrolyzed and methylated with 1 ml of 14% boron trifluoride in methanol (Alltech Associates Inc., Deerfield, IL, U.S.A.) at 100°C for 30 minutes. The methylated fatty acids were extracted with 1 ml of water and 2 ml of hexane. The samples were then centrifuged (Centrific Centrifuge Model 225; Fisher Scientific Pittsburgh, PA, U.S.A.) at 500 x g for 10 minutes. The fatty acid methyl esters (FAME) were analyzed using a gas chromatograph (Model 6890; Hewlett-Packard, Inc., Wilmington, DE, U.S.A.) with a flame ionization detector. The fatty acid methyl esters were injected at 225°C with a split ratio of 50:1 and separated on a CP-Sil 88 CLA column (50 m x 0.25mm ID; Chrompack, Middlburg, Netherlands). The helium carrier gas was set at a flow rate of 2.4 ml/min and a pressure of 275.8 kPa. Initial oven temperature was 125°C and was held for 2 min. The oven temperature was increased at a rate of 10°C/min to 152°C, at a rate of 1°C/min to 155°C, at a rate of 0.5°C/min to 160°C, and at a rate of 5°C/min to 190°C. The total run time was 28.7 minutes. The temperature of the detector was 225°C. Flow rates of the detector gases were 50 mL/min for hydrogen, 400 mL/min for air, and 25 mL/min for nitrogen, the makeup gas.

Soluble Sugar Content

Duplicate samples of ground soybeans (1.25 g) were vortexed with 5 ml of $CHCl_3$:CH_3OH (1:1, vol/vol). The samples were placed on a shaker for 20 minutes, and vortexed after 10 minutes on the shaker. Milli-Q water (2.5 ml) was added to each sample.

The samples were vortexed for 1 minute. The samples were centrifuged (Centrific Centrifuge Model 225; Fisher Scientific Pittsburgh, PA, U.S.A.) for 10 minutes at 2500 x g. The aqueous layer was transferred to a round bottom flask and rotary evaporated at 38-40°C to remove the methanol. The samples were adjusted to 10 ml with Milli-Q water and centrifuged. Approximate 1 ml portions were filtered through 0.2 µm syringe filters (Minisart-Plus 0.2 µm Syringe Filter with Integral Prefilter; Supleco Inc., Bellefonte, PA, U.S.A.). The extracts (20 µl) were analyzed using HPLC (Waters Associates, Milford, MA, U.S.A.) using a Prevail Carbohydrate Column ES column 250mm x 4.6mm ID and guard cartridge (Alltech Associates, Inc. Deerfield, IL, U.S.A.) and a refractive index detector (Waters Associates, Milford, MA, U.S.A.). The samples were analyzed at 30°C, and acetonitrile:water (75:25 v/v) was used as the mobile phase. The acetonitrile was HPLC grade (Fisher Scientific, Pittsburgh, PA, U.S.A.) and the water was Milli-Q purified (Millipore, Bedford, MA, U.S.A.). A calibration curve was obtained from six concentrations (0.16 mg/ml – 5 mg/ml) of a mixture of standards containing D-glucose, D-fructose, sucrose (Fisher Scientific, Pittsburgh, PA, U.S.A.), D (+)-raffinose pentahydrate and stachyose hydrate (Fluka, Buchs, Switzerland). Sugar contents were expressed as g sugar/100 g soybeans, on a fat-free, dry weight basis.

Free Amino Acid Content

Free amino acids were extracted from duplicate ground soybean samples (1 g) using 9 ml of 5% trichloroacetic acid. The samples were vortexed until they were homogenized. They were then centrifuged (Centrific Centrifuge Model 225; Fisher Scientific, Pittsburgh, PA, U.S.A.) 3 minutes at 2500 x g. If present, a top layer of oil was skimmed off and discarded. The sample was then filtered using No. 1 Whatman paper (Whatman International Ltd., Maidstone, England). The free amino acid extracts were derivatized according to the EZ:faast™ kit protocol (Phenomenex, Torrance, CA, U.S.A.) and analyzed by gas chromatography (Model 6890; Hewlett-Packard, Inc., Wilmington, DE, U.S.A.) with a split

injection port and a flame ionization detector (FID). One µl samples were injected with a 5:1 split ratio at 220°C. A Zebron ZB-AAA column (10m x 0.25mm; Phenomenex, Torrance, CA, U.S.A.) was used to separate the derivatized amino acids. Helium was the carrier gas at a flow rate of 1.5 mL/min. The pressure was set at 60 kPa. Initial oven temperature was 110°C and held for 0.5 min. The temperature was increased at a rate of 30°C/min to 200°C, at a rate of 20°C/min to 250°C, and at a rate of 50°C/min to 320°C. The total run time was 9.9 minutes. The detector temperature was 320°C. Flow rates of the detector gases were 30 mL/min for hydrogen and 400 mL/min for air. Amino acids in the samples were identified by comparison to standards included in the EZ:faast™ kit.

Statistical Analysis

The experiment was a split-plot design with cultivar and treatment as the main factors. Treatment encompasses both the roasting method and the storage time. Analysis of variance and Honest Significant Difference using Tukey's adjustment was conducted to determine the effects of the main factors and interactions. Statistical analyses were performed (SYSTAT ver. 9.01; SPSS, Inc.; Chicago, IL, U.S.A.) with a significance level of $p < 0.05$. The processing treatments were replicated two times, with analyses of each sample conducted in duplicate.

Results and Discussion

Moisture Content

The greatest difference in moisture content was in the raw beans. The raw Prairie Brand soybeans contained more moisture than the other cultivars (Table 1). The moisture contents of the raw beans were all within an acceptable safety range where deteriorative reactions would be slowed. However, only the raw Prairie Brand soybeans had a moisture content of approximately 13%, which is the moisture content that soybeans are traded at and is considered to be the most appropriate for storage. The soybeans are more susceptible to breakage at moisture contents substantially below 13% (Acasio 1997; Wilcke and others

2005). Above 13% moisture content chemical and microbial spoilage reactions become an issue. Cultivars from the 2004 crop year (IA 1008, IA 1008 LF and IA 2064) were stored longer before roasting and likely lost moisture during that storage time.

At month 0, the dry-roasted soynuts exhibited some cultivar variation in moisture content. This variation indicates that the dry-roasted soynuts did not all reach the same moisture content during roasting (Table 1). The oil-roasted soynuts showed no significant cultivar effects. Oil-roasting the soynuts removed significantly more moisture from the soybeans than dry-roasting. The higher temperature differential between the oil and the soybeans during oil-roasting resulted in more moisture removal. Both the dry-roasted and oil-roasted beans gained moisture during storage. Because the storage study included the humid summer months and the packaging was not impermeable to air or moisture the samples gained moisture during storage.

Total Lipid and Fatty Acid Contents

On average, the lipid content of soybeans is 18% lipid by mass at 13% moisture content on a wet basis (American Soybean Association 2007); however, certain soybean genotypes have been developed to contain more or less lipid. Genotype has a significant effect on oil content and fatty acid composition of soybeans. Soybean cultivars specifically developed to have certain fatty acid profiles, such as low-palmitic and low-linolenic acid content (Cherrak and others 2003), demonstrate the most dramatic differences. Environmental factors such as location, temperature, and rainfall also influence the lipid composition of soybeans (Kumar and others 2006). With the exception of IA 1008, the cultivars used in this study contained slightly less than 18% total lipid (Table 2). There were no significant differences in total lipid, palmitic acid, stearic acid, oleic acid, or linoleic acid among cultivars in the in the raw soybeans. IA 2064, a cultivar developed to contain 1% or less of linolenic acid, had the lowest linolenic acid content.

Storage time and roasting type both had significant effects on total lipid and fatty acid contents (Table 3). Oil-roasted treatments contained the highest amounts of total lipid and individual fatty acids due to oil absorption during roasting. Individual fatty acid contents of the dry-roasted treatments were not significantly different from the raw soybeans. However, the total lipid content was significantly higher in the dry-roasted month 6 soynuts than the raw soybeans. Total lipid and fatty acids tended to be higher at month 6 than at month 0 for the oil-roasted treatments. Lipid extractability may increase during storage. The interaction between cultivar and treatment is significant for linolenic acid primarily because of the low-linolenic cultivar, IA 2064 (Table 4).

Previous research has shown that higher roasting temperatures of soybeans and hazelnuts leads to changes in their fatty acid composition. Higher dry-roasting temperature (150°C) of soybeans resulted in the extracted oil having higher ratios of palmitic and oleic contents to linoleic and linolenic contents than oil from soybeans roasted at a lower temperature (130°C) (Jung and others 1997). Increased roasting time and temperature increased the relative amounts of oleic and saturated fatty acid contents compared to the linoleic acid content in dry-roasted hazelnuts (Amaral and others 2006). In the present study the oil-roasted treatments experienced higher roasting temperatures than the dry-roasted treatments but the relative amounts saturated and monounsaturated fatty acids did not increase relative to that of the polyunsaturated fatty acids (data not shown).

Soluble Sugar Contents

Fructose, glucose, sucrose, raffinose, and stachyose contents were not significantly different between soybean cultivars (Table 5). Contents of sugars were in agreement with other studies in which soluble soybean sugar contents were analyzed (Kawamura and others 1978; Erickson 1995; Locher and Bucheli 1998). Sucrose, stachyose, and raffinose were present in the greatest amounts and the monosaccharides were present in much smaller amounts. In a storage study of four cultivars, conducted by Locher and Bucheli (1998),

cultivar differences in soluble sugar contents were largely insignificant. Variation in sugar content is generally low between soybean cultivars.

Table 6 shows the effects of treatment on sugar concentrations. In general, dry- and oil-roasted soynuts had higher sugar concentrations than the raw soybeans. The roasting process may increase the ease of extractability of the sugars. Storage time also appears to make the sugars easier to extract as the sugar contents at 6 months are typically higher than at month 0. The differences in soluble sugar contents between dry- and oil-roasting were small. There were no differences between roasting method for the non-reducing sugars, sucrose, raffinose, and stachyose. Fructose content was lower in the oil-roasted soynuts compared to the dry-roasted soynuts for 0 months and 6 months. The higher roasting temperatures that the oil-roasted beans experienced could have contributed to more Maillard browning between fructose and the free amino acids. The Maillard browning reaction is probably responsible for the generally larger decrease in reducing sugar fructose and amino acids in the oil-roasted soynuts compared to the dry-roasted soynuts.

Roasting-induced decreases in reducing sugars is typical (Redgwell and others 2003). However, Oosterveld and others (2003) found that though light and medium roasting of coffee beans decreased contents of reducing sugars, dark roasting actually increased the content of glucose as a result of the degradation of more complex sugars.

Free Amino Contents

Cultivar did not have a significant effect on free amino acid contents, however; cultivar x treatment interactions were significant for glutamic acid, glutamine, and histidine (Table 7). Treatment differences were significant for many of the free amino acids (Table 8). There were some inconsistencies in the free amino acid data. The samples having to be run at different times may play a role in these inconsistencies. In general, the raw soybeans were highest in free amino acids, followed by the roasted treatments. Roasted treatments underwent non-enzymatic or Maillard browning reactions in which the free amino acids

interacted with the reducing sugars to form roasted flavor compounds. The oil-roasted soynuts were roasted at a higher temperature than the dry-roasted soynuts so the expectation is that more roasted compounds were formed thus utilizing more of the free amino acids and reducing sugars (Tables 6 and 8). In addition, the lipid oxidation products formed during oil roasting and absorbed by the soynuts provided more carbonyl substrate to react with the free amino acids (Hidalgo and Zamora 2004).

Raw soybeans contained the highest concentrations of amino acids valine, leucine, isoleucine, proline, asparagine, aspartic acid, glutamic acid, lysine, and tryptophan followed by the roasted treatments (Table 8). Some of these amino acids also decreased during storage. Alanine, glycine, methionine, and phenylalanine contents stayed relatively constant for the different treatments.

The basic side chain of lysine is very reactive in Maillard browning as demonstrated in model systems (Hwang and others 1995; Huang and others 1989). Furthermore, lysine increased the reactivity of glycine in a model system containing lysine, glycine, wheat starch and glucose (Hwang and others 1995). In the present study, glycine concentration stayed constant over time indicating that it did not readily participate in Maillard browning in the roasted soynuts even though lysine was present (Table 8). Threonine and serine had unexpectedly high concentrations at month 6 for both types of roasting. Some release of these amino acids from the protein matrix could have occurred, although it is not likely that such a large amount of these amino acids were released.

Interactions between cultivar and treatment in glutamic acid were because of the differences in cultivars in the raw treatment; raw IA 1008 soybeans contained significantly more glutamic acid than the other cultivars (Table 9). The interaction between cultivar and treatment in glutamine and histidine is a result of the very high means of these two amino acids in Prairie Brand, oil roast, month 6 and the significantly higher histidine content of the raw Prairie Brand soybeans (Table 10 and Table 11). These amino acids were not created

over storage, and it is unlikely that such a significant amount of these amino acids became freed from the protein matrix over storage. The sample extracts may have been more concentrated than they should have been or the different sample running times contributed to this discrepancy (data not shown). Tyrosine concentration increased significantly in the month 6 oil-roasted treatment also, although there was no significant cultivar-treatment interaction. Compared to the study of Maillard browning in model systems, the soybean substrate is much more complex. Many amino acids, not just one or two, compete to react with the reducing sugars. Furthermore, the amino acids have potentially synergistic or inhibitory effects on each other's reactivity. The sugars present in the system also add to the complexity because more than one reducing sugar is present in the soybeans. The complexity of the reactants in a food system makes determining the effect of one component on another difficult to ascertain.

Conclusions

Moisture content was significantly affected by roasting type and storage. The type of roast had a greater effect on the lipid composition of the final product than did the lipid composition of the raw soybeans. Sugars and free amino acids did not show much variation between cultivars, but presumably played an important role in flavor development. The type of roast greatly influenced the changes in the sugar, free amino acid, and lipid contents in the soynuts. The higher temperature of oil-roasting resulted in increased the amount of Maillard browning in the oil-roasted soynuts as compared to the dry-roasted soynuts, as shown by the reduced contents of reducing sugars and free amino acids in the oil-roasted soynuts. Knowing the different effects that dry- and oil-roasting have on soybean composition allows a soynut manufacturer to make informed decisions on which type of roast would be most appropriate for the type of product that they would like to manufacture and market.

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Table 1 - Effect of cultivar and roasting and storage treatments on moisture content of soybeans[a]

	Treatment					
	Raw	Dry Roasted		Oil Roasted		
Cultivar		0 Months	6 Months	0 Months	6 Months	Overall Cultivar[c]
IA 1008	7.85 dx	4.37 bcy	5.25 cx	1.95 ax	3.92 bx	4.67 x
IA 1008 LF	7.50 dx	4.06 by	5.47 cx	1.89 ax	3.44 bx	4.47 x
IA 2064	7.74 dx	3.48 bxy	5.21 cx	1.55 ax	3.50 bx	4.29 x
Asgrow	8.99 dy	2.95 abx	4.92 cx	1.59 ax	3.42 bx	4.37 x
Prairie Brand	13.41 dz	3.07 bx	5.20 cx	1.68 ax	3.17 bx	5.31 x
Overall Treatment[b]	9.10 d	3.59 b	5.21 c	1.73 a	3.49 b	

[a]Means are moisture content per 100 g of soybeans and represent duplicate analyses of 2 replications. Means within a row with different letters (a-d; treatment effects) and within a column with different letters (x-z; cultivar effects) are significantly different at ($p<0.05$).

[b]Means are duplicate analyses of 2 replications of 5 cultivars. Cultivars are pooled.

[c]Means are duplicate analyses of 2 replications of 5 treatments. Treatments are pooled.

Table 2 - Total lipid and fatty acid content[a] of raw soybeans[b]

	Cultivar				
	IA 1008	IA 1008 LF	IA 2064	Prairie Brand	Asgrow
Total Lipid	18.6 a	17.6 a	17.7 a	16.2 a	16.8 a
Palmitic Acid	3.01 a	2.60 a	2.06 a	2.33 a	2.09 a
Stearic Acid	0.95 a	0.77 a	0.84 a	0.77 a	0.70 a
Oleic Acid	3.71 a	3.35 a	3.98 a	3.27 a	3.21 a
Linoleic Acid	9.36 a	9.27 a	10.5 a	8.71 a	9.49 a
Linolenic Acid	1.57 b	1.61 b	0.31 a	1.09 b	1.31 b

[a]g lipid per 100 g of soybeans on a dry weight basis

[b]Means represent duplicate analyses of 2 replications. Means within a row with different letters (a-b) are significantly different ($p<0.05$).

Table 3 - Effect of roasting and storage on total lipid and fatty acid content[a] of soybeans[b]

	Treatment				
	Raw	Dry Roasted		Oil Roasted	
		0 Months	6 Months	0 Months	6 Months
Total Lipid	17.4 a	18.6 ab	20.0 b	28.9 c	35.8 d
Palmitic Acid	2.42 a	2.37 a	3.13 a	4.18 b	4.49 b
Stearic Acid	0.80 a	0.75 a	0.90 a	1.22 b	1.53 c
Oleic Acid	3.50 a	3.72 a	3.85 a	5.90 b	7.49 c
Linoleic Acid	9.47 a	10.4 a	10.75 a	15.5 b	19.7 c
Linolenic Acid*	1.18	1.30	1.41	2.09	2.56

[a]g lipid per 100 g of soybeans on a dry weight basis

[b]Means represent duplicate analyses of 2 replications pooled for cultivar. Means within a row with different letters (a-d) are significantly different ($p<0.05$).

*Interaction between cultivar and treatment is significant.

Table 4 - Effect of cultivar and roasting and storage treatments on linolenic acid content[a] of soybeans[b]

	Treatment			
	Dry Roasted		Oil Roasted	
Cultivar	0 Months	6 Months	0 Months	6 Months
IA 1008	1.47 ay	1.67 ayz	2.47 by	2.75 by
IA 1008 LF	1.59 ay	1.86 abyz	2.32 bcy	2.80 cy
IA 2064	0.43 ax	0.27 ax	1.37 bx	1.57 bx
Prairie Brand	1.46 ay	1.91 az	2.22 by	2.92 cy
Asgrow	1.57 aby	1.32 ay	2.07 by	2.74 cy

[a]g lipid per 100 g of soybeans on a dry weight basis

[b]Means represent duplicate analyses of 2 replications. Means within a row and column with different letters (a-d; treatment effects) and (x-z; cultivar effects) respectively, are significantly different ($p<0.05$).

Table 5 - Soluble sugar content[a] of soybean cultivars[b]

	Cultivar				
	Asgrow	IA 1008	IA 2064	IA 1008 LF	Prairie Brand
Fructose	0.26 a	0.31 a	0.20 a	0.27 a	0.35 a
Glucose	0.13 a	0.01 a	0.01 a	0.002 a	0.02 a
Sucrose	1.92 a	4.04 a	2.90 a	3.57 a	3.63 a
Raffinose	0.46 a	0.53 a	0.35 a	0.47 a	0.69 a
Stachyose	1.51 a	2.36 a	1.86 a	2.14 a	2.40 a

[a]g sugar/100 g of soybeans on a dry weight and lipid-free basis

[b]Means represent duplicate analyses of 2 replications with data for treatments pooled. Cultivar did not have a significant effect on the sugar content ($p<0.05$).

Table 6 - Effect of roasting and storage treatments on soybean soluble sugar content[a]

	Treatment				
	Raw	Dry Roasted		Oil Roasted	
		0 Months	6 Months	0 Months	6 Months
Fructose	0.23 ab	0.32 bc	0.41 d	0.21 a	0.33 c
Glucose	ND a	0.02 a	0.01 a	ND a	ND a
Sucrose	2.94 a	3.44 ab	3.71 b	3.38 ab	3.56 b
Raffinose	0.44 a	0.53 a	0.55 a	0.56 a	0.60 a
Stachyose	1.64 a	2.24 ab	2.41 b	2.09 ab	2.52 b

[a]Means are g sugar per 100 g of soybeans on a dry weight and lipid-free basis and represent duplicate analyses of 2 replications with data for cultivars pooled. Means within a row with different letters (a-d) are significantly different ($p<0.05$).

Table 7 - Free amino acid contents[a] of soybean cultivars[b]

	Cultivar				
	Asgrow	IA 1008	IA 2064	IA 1008 LF	Prairie Brand
Alanine	521.3	850.4	736.8	716.4	1347.2
Glycine	234.8	294.7	229.1	297.2	407.4
Valine	138.1	252.1	148.3	214.2	228.3
Leucine	145.2	254.5	207.9	217.9	217.3
Isoleucine	77.1	168.9	107.2	137.3	157.3
Threonine	367.2	498.2	409.3	416.1	604.7
Serine	537.2	632.3	680.5	550.0	706.9
Proline	140.5	537.6	396.1	450.2	384.1
Asparagine	496.3	1523.4	654.2	1530.9	831.8
Aspartic Acid	594.6	970.6	880.3	698.7	762.6
Methionine	97.4	122.7	144.2	127.3	142.2
Glutamic Acid*	713.8	948.6	498.8	564.9	754.0
Phenylalanine	195.8	290.0	274.6	287.7	305.8
Glutamine*	437.0	475.7	517.0	517.4	952.5
Lysine	446.7	708.1	591.3	605.2	694.8
Histidine*	646.8	729.7	730.5	768.2	1058.9
Tyrosine	1243.7	1045.5	1124.2	897.9	1801.2
Tryptophan	418.9	344.9	302.8	346.7	323.3

[a]nmoles/g of soybean on a dry weight and lipid-free basis

[b]Means represent duplicate analyses of 2 replications with data for storage and roast pooled. No significant differences ($p<0.05$) between cultivars, except those in which interactions between cultivar and treatment are significant (*).

Table 8 - Free amino acid contents[a] of raw and roasted soynuts[b]

	Treatment				
	Raw	Dry Roasted		Oil Roasted	
Amino Acid		0 Months	6 Months	0 Months	6 Months
Alanine	1195.6 a	909.6 a	669.8 a	679.9 a	717.2 a
Glycine	366.9 a	234.6 a	282.9 a	308.6 a	270.2 a
Valine	340.8 c	242.3 bc	168.2 ab	162.7 ab	67.1 a
Leucine	280.0 b	309.9 b	278.3 b	114.2 a	60.5 a
Isoleucine	284.4 d	163.3 c	45.6 ab	118.1 bc	36.3 a
Threonine	349.1 a	279.4 a	883.7 b	264.9 a	518.5 a
Serine	262.6 a	226.9 a	1281.1 b	165.6 a	1170.8 b
Proline	759.5 b	316.6 a	262.3 a	319.1 a	251.0 a
Asparagine	1344.2 b	1116.0 ab	856.7 a	1013.4 ab	706.3 a
Aspartic Acid	2016.7 b	659.3 a	562.9 a	478.5 a	189.4 a
Methionine	174.5 b	160.3 b	133.0 b	37.2 a	128.8 b
Glutamic Acid*	2090.9	401.9	429.6	417.9	139.8
Phenylalanine	337.6 b	371.5 b	262.2 b	267.0 b	115.7 a
Glutamine*	559.2	287.4	687.5	294.1	1071.4
Lysine	1427.8 b	623.0 a	280.5 a	444.7 a	270.1 a
Histidine*	1171.1	438.2	765.9	501.9	1057.0
Tyrosine	676.5 a	614.8 a	1090.9 a	862.5 a	2867.9 b
Tryptophan	698.4 b	162.0 a	329.5 a	180.1 a	366.6 a

[a]nmoles/g of soybean on a dry weight and lipid-free basis

[b]Means represent duplicate analyses of 2 replications with data for cultivar pooled. Means within a row with different letters (a-c) are significantly different ($p<0.05$).

*Interaction between cultivar and treatment is significant.

Table 9 - Cultivar*treatment interaction means for glutamic acid in soybeans cultivars[a]

	Cultivar				
Treatment	Asgrow	IA 1008	IA 2064	IA 1008 LF	Prairie Brand
Raw	1943.5 ay	3355.0 by	1372.1 ay	1514.6 ay	2269.4 ay
Dry 0 Months	477.6 ax	422.5 ax	378.7 ax	404.3 ax	380.1 ax
Dry 6 Months	422.8 ax	360.7 ax	410.0 ax	432.1 ax	522.3 ax
Oil 0 Months	451.2 ax	532.9 ax	286.5 ax	527.6 ax	291.6 ax
Oil 6 Months	274.1 ax	71.9 ax	46.6 ax	0.0 ax	306.5 ax

[a]Means are nmoles amino acid/g of soybean on a dry weight and lipid-free basis and represent duplicate analyses of 2 replications. Means within a row with different letters (a-b; cultivar effects) and within a column with different letters (x-y; treatment effects) are significantly different at ($p<0.05$).

Table 10 - Cultivar*treatment interaction means for glutamine in soybeans cultivars[a]

	Cultivar				
Treatment	Asgrow	IA 1008	IA 2064	IA 1008 LF	Prairie Brand
Raw	324.2 ax	404.1 ax	796.3 ax	680.0 ax	591.4 ax
Dry 0 Months	255.4 ax	314.8 ax	313.0 ax	304.7 ax	248.9 ax
Dry 6 Months	746.0 ax	686.9 ax	751.4 ax	695.3 ax	557.9 ax
Oil 0 Months	265.7 ax	441.3 ax	186.6 ax	244.1 ax	332.8 ax
Oil 6 Months	593.6 ax	531.6 ax	537.7 ax	662.9 ax	3031.5 by

[a]Means are nmoles amino acid/g of soybean on a dry weight and lipid-free basis and represent duplicate analyses of 2 replications. Means within a row with different letters (a-b; cultivar effects) and within a column with different letters (x-y; treatment effects) are significantly different at ($p<0.05$).

Table 11 - Cultivar*treatment interaction means for histidine in soybeans[a]

	Cultivar				
Treatment	Asgrow	IA 1008	IA 2064	IA 1008 LF	Prairie Brand
Raw	792.5 ax	972.5 ax	1077.5 ax	1013.9 ax	1998.9 by
Dry 0 Months	337.2 ax	490.4 ax	602.1 ax	442.7 ax	456.6 ax
Dry 6 Months	748.3 ax	729.7 ax	764.0 ax	785.3 ax	802.1 ax
Oil 0 Months	404.6 ax	506.0 ax	469.5 ax	695.2 ax	434.3 ax
Oil 6 Months	951.2 ax	949.9 ax	877.5 ax	904.0 ax	1602.7 ay

[a]Means are nmoles amino acid/g of soybean on a dry weight and lipid-free basis and represent duplicate analyses of 2 replications. Means within a row with different letters (a-b; cultivar effects) and within a column with different letters (x-y; treatment effects) are significantly different at ($p<0.05$).

SENSORY CHARACTERISTICS OF DRY- AND OIL-ROASTED SOYNUTS

A paper to be submitted for publication in the Sensory and Nutritive Qualities of Food Section of the Journal of Food Science

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Abstract

Five food-grade soybean cultivars were dry- and oil-roasted and stored for 6 months. The sensory characteristics of the roasted soynuts were determined by a descriptive analysis panel and a consumer acceptability panel. The descriptive analysis panels were conducted after 1, 3, and 6 months of storage. The consumer acceptability panel was conducted after 3 months of storage. Roasting method and storage time significantly affected sensory attributes. Soybean cultivar had a minimal effect on sensory characteristics. Dry-roasted soynuts had more cereal-like aroma, bitter flavor, and beany flavor intensity than oil-roasted soynuts. The higher roasting temperatures of the oil-roasting and the oil absorption led to the oil-roasted soynuts having higher roasted aroma, rancid aroma, roasted flavor, nutty flavor, sweet flavor, and oily flavor intensities compared to the dry-roasted soynuts. Oil-roasted soynuts fractured more easily than dry-roasted soynuts and were less hard and less gritty. Flavor and aroma attributes tended to decrease during storage for both roasts. Fracturability

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did not change over storage. Hardness stayed constant for oil-roasted soynuts, but decreased in dry-roasted soynuts. Grittiness increased in oil-roasted soynuts over time and remained constant in dry-roasted soynuts. Consumer panelists preferred the appearance, flavor, and texture of the oil-roasted soynuts compared to the dry-roasted soynuts.

Introduction

Soybeans (*Glycine max*) are a nutrient-dense source of high quality and complete protein. They are low in saturated fat and cholesterol-free. In addition, consumption of soy is associated with potential health benefits such as cholesterol reduction, cancer prevention, positive gut health, bone-loss prevention, and menopausal symptom relief (Liu 2000; Erdman 2002; Messina 2003).

The Food and Drug Administration (FDA) approval of a health claim for soy protein has increased Americans' interest in consuming soy and has resulted in tremendous growth of soy products in the food industry as companies are eager to capitalize on the health benefits of soy foods (Liu 2000). The health claim states that diets that are low in saturated fat and cholesterol and that include soy protein ''may'' or ''might'' reduce the risk of heart disease. The health claim can be used on products containing at least 6.25 g of soy protein per serving. The product must also meet nutrient content requirements for a "low fat," a "low saturated fat," and a "low cholesterol" food, unless it consists of or is derived from whole soybeans (FDA 1999).

Despite the health benefits of soy, many Americans do not consume soy products because of the 'beany' flavor that accompanies many of these products. Soybeans contain significant amounts of the polyunsaturated fatty acids, linoleic acid (25-60 g/100 g lipid) and linolenic acid (1-15 g/100 g lipid) (Liu 2004). Both fatty acids are subject to oxidation, but linolenic acid is especially problematic because of its higher degree of unsaturation. This

makes soybeans prone to flavor stability problems. In addition, soybeans contain lipoxygenase enzymes which catalyze the production of hydroperoxides from polyunsaturated fatty acids. These peroxides eventually breakdown and form medium chain alkylaldehydes or alkenylaldehydes which contribute to beany, grassy, fishy, and painty flavors (Kobayashi and others 1995; Hui 1996; Dahuja and Madaan 2003). Because of the relationship between linolenic acid and lipoxygenase and oxidative stability in soy foods, cultivars have been developed that are low in linolenic acid or contain reduced or no lipoxygenase compared to traditional varieties to reduce the potential for beany flavor formation in soy foods (Cherrak and others 2003).

The compositional differences between cultivars have the potential to affect the flavor and the flavor stability during storage of roasted soynuts. Lipoxygenase-free soybeans have been shown to have less beany flavor than normal soybeans (Torres-Penaranda and others 1998). Low-linolenic cultivars are expected to have better flavor stability than traditional cultivars. However, normal soybean oil was shown to have a lower rate of formation of polar compounds during frying than a low linolenic variety. The authors hypothesized that this was partly do to the lower content of tocopherols in the low linolenic variety (Norman and others 2003).

Consuming roasted soynuts may provide greater nutritional benefits than consuming soy products that only contain part of the soybean. Erdman (2000) noted that there is an apparent synergy of consuming the components of soy intact. Furthermore, the roasting process produces desirable flavors via Maillard browning. Not only do these desirable flavors positively affect taste, but many of the Maillard reaction products also function as antioxidants. These antioxidants contribute to the stability of the soybean lipids and are a good source of antioxidants for the consumer (Lee and Shibamoto 2002).

Roasting method has a significant impact on the sensory characteristics of a food product. Oil-roasting changes the composition of the soynuts by increasing the oil content. Additionally, the oil is a much hotter roasting medium and thus the roasting time is much shorter for the oil-roasted soynuts. The roasting method influences the appearance, flavor, and texture of a product. In two studies of roasted peanuts, oil-roasted peanuts were found to have superior flavor to dry-roasted peanuts as determined by a sensory panel (Metwalli and others 1976; How 1986). The objective of this study was to determine the effect of cultivar, roasting method, and storage time on the sensory characteristics of dry-and oil-roasted soynuts by conducting descriptive analysis and consumer acceptability panels.

Materials and Methods

Soybean Cultivars

Five food grade soybean cultivars, IA 2064, IA 1008 LF, IA 1008, Prairie Brand 299, and Asgrow 2247, were evaluated in this study. IA 2064, IA 1008 LF, and IA 1008 were obtained from the Committee for Agricultural Development at Iowa State University and were grown during the 2004 crop year. Prairie Brand 299 and Asgrow 2247 were obtained from Central Iowa Soy LLC (Jefferson, IA) and were grown during the 2005 crop year. IA 2064 is a low- linolenic acid cultivar. IA 1008 LF is a lipoxygenase-null cultivar derived from the IA 1008 cultivar.

Soybean Roasting

Processing of each cultivar and roasting method (dry- or oil-roasted) was conducted in duplicate. The soybeans were soaked in water (3:1 wt/wt, water:soybeans) for 20-24 hours at 4°C prior to roasting. The dry-roasted soybeans were roasted in 2000 g (soaked weight) batches in a drum roaster (Gold Medal Funfood Equipment & Supplies, Cincinnati, OH,

U.S.A.) for three hours. The roaster did not provide temperature control adjustments. After roasting, the soybeans were allowed to cool on paper towels.

Oil-roasted soybeans were roasted in 500 g (soaked weight) batches in a deep-fat fryer (7.5 liter oil capacity; Star Mfg. International Inc., Smithville, TN, U.S.A.) at 177°C for 9 minutes and 10 seconds in vegetable oil (Crisco®, J.M. Smucker Co., Orrville, OH, U.S.A.). After roasting the soybeans were removed from the oil and the excess oil was allowed to drain back into the deep fat fryer for 30 seconds. The soybeans were then allowed to cool on paper towels.

Because the oil quality changes as the frying time increases, the order of roasting of the cultivars was randomized. For optimum flavor, the oil was heated 1½ hours prior to roasting the soybeans and the first batch roasted in the oil was discarded. The total amount of roasting time for all batches was short enough that it was not necessary to change the oil (White 2006). Samples from the fresh oil, the oil after 1½ hours of heating, the oil after 1½ hours of roasting, and the oil at the end of roasting time were collected. Peroxide value, aldehyde content and free fatty acid content were determined to ensure that the oil had not deteriorated excessively.

The SāfTest® System (SāfTest®, Inc., Tempe, AZ, U.S.A.) was used to measure peroxide value, aldehyde content, and free fatty acid content of the oil samples taken during oil roasting. Preparation reagent (isopropyl alcohol) was added to the oil sample in a 10:1 ratio for the peroxide value determination. The oil was analyzed as is for the free fatty acid content and aldehyde content determination. The PeroxySafe™, AldeSafe™, and FASafe™ Kit-STD protocols were followed for each test. Peroxide values were expressed as meq peroxide/kg of sample. Aldehydes were expressed as µmol of malonaldehyde/kg sample. Free fatty acids were expressed as percent oleic acid in the sample.

Peroxide values are useful for initial oil quality measurements, but peroxides breakdown rapidly at elevated temperatures and should not be used to monitor oil processes such as frying (White 2000). Initial peroxide values for oil were 0.12 meq O_2/kg sample or less. Oils with peroxide values of 1 meq O_2/kg or less are considered to be unoxidized and of high quality (Gerde and others 2007). Aldehyde contents reached a maximum value of 29.3 µmols/kg of sample at the end of frying. Free fatty acid contents were less than 0.1% even by the end of frying indicating that the oil had not deteriorated markedly. Even fresh refined, bleached, and deodorized oils can contain up to 0.05% free fatty acids (Su and White 2004).

The dry- and oil-roasted soynuts were stored for up to 6 months in individual 7 oz Whirl-Pak bags (3 mil thickness, oxygen permeability 209.5 cc/100 sq in/24 hrs; moisture permeability 0.48 gms/100 sq in/24hrs, Nasco Fort Atkinson, WI, U.S.A) by month, roast, and cultivar. Each bag remained sealed until analyzed. The individual Whirl-Pak bags for each month were stored inside Ziploc® gallon storage bags (S.C. Johnson & Son Inc. Racine, WI, U.S.A.) which were stored in a cupboard to minimize exposure to light. Total storage time of the study was 6 months. Suboptimal packaging was used so that if storage had an effect, it would be demonstrated during the 6 months of storage.

Sensory Evaluation Procedures

Sensory evaluation procedures were approved by the Iowa State University Institutional Review Board to comply with Office for Human Research Protections (OHRP) guidelines and Health Insurance Portability and Accountability Act (HIPAA) regulations.

Descriptive sensory evaluation panel

Training. Dry and oil-roasted soynuts were evaluated by a descriptive sensory panel (Meilgaard and others 1999) composed of ten panelists. Two training sessions were conducted before the first panel. During these sessions, panelists were given samples of

roasted soynuts and asked to identify the aroma, flavor, and texture attributes present in the soynuts. The panel identified 3 aroma attributes (cereal-like, roasted and rancid), 8 flavor attributes (bitter, roasted, rancid, beany, cereal-like/grainy, nutty, sweet, and oily) and 3 texture attributes (fracturability, hardness, and grittiness). Attribute intensities were evaluated using a 15-cm line scale where "0" corresponded to "None" and "15" corresponded to "Intense". During training, reference standards were presented and the panelists came to a consensus on where the standards scored on a 15-cm line scale (Table 1). Initial training occurred before the 1 month panel and refresher trainings were conducted a week before the 3 and 6 month panels. Refresher trainings consisted of a review of standards and evaluation of two soynut samples.

Evaluation. Panels were conducted after 1, 3, and 6 months of storage. Samples (10 soynuts) were presented at room temperature in a random order for each panelist in 2 oz plastic soufflé cups (Solo Cup Company, Highland Park, IL, U.S.A.) with lids labeled with 3-digit random codes. Red lights were used in partitioned panel booths to minimize the effect of color on the perception of aroma, flavor, and texture attributes. Panelists were instructed to remove the lid from the container and sniff to evaluate the intensity of the aroma attributes. To evaluate flavor attributes, panelists placed 2-3 beans in their mouths and chewed 5-10 times before evaluating the intensity of the flavor and texture attributes. Water, table of reference standards with their score on 15 cm line, and expectorate cup were provided during panel sessions.

Consumer acceptability panel

Five oil-roasted samples and one dry-roasted sample were chosen to be evaluated by a consumer acceptability panel. Only one dry-roasted sample was chosen for evaluation because the results from month 1 of the descriptive panel showed that the flavor variability

between cultivars was lower for the dry-roasted samples than for the oil-roasted samples. Bitter flavor and hard texture were the predominant characteristics of the dry-roasted samples, regardless of the cultivar. So that acceptability of both dry- and oil-roasted samples could be determined one dry-roasted sample was included in the evaluation. The soynuts were evaluated after 3 months of storage. Fifty untrained consumers participated in the panel. The panelists answered demographic questions and soy product consumption questions prior to evaluating the samples. Using a 9-point hedonic scale the consumer panelists rated the appearance, flavor, texture, and overall acceptability of the soynuts. "1" corresponded to "dislike extremely" and "9" corresponded to "like extremely."

Statistical Analysis

The descriptive analysis experiment was a split-plot design with cultivar, roasting method, and storage time as the main factors. The consumer acceptability experiment was designed as a 1-way factorial with sample as the main factor. "Sample" encompassed the cultivar and the type of roast. For each panel, analysis of variance and Tukey's Honest Significant Difference (HSD) multiple comparisons were conducted to determine the effects of the main factors and interactions on the sensory attributes. Statistical analyses were performed (SYSTAT ver. 9.01; SPSS, Inc.; Chicago, IL, U.S.A.) with a significance level of $p < 0.05$. Processing treatments were replicated 2 times.

Results and Discussion

Descriptive sensory evaluation panel

Storage time (month) and roasting method had the greatest effects on the sensory attributes. Of the 14 sensory attributes, 8 attributes had storage x roast interactions. Attributes with storage and roast interactions were rancid aroma, roasted flavor, beany flavor, sweet flavor, oily flavor, fracturability, hardness, and grittiness. Only a few sensory

attributes were affected by cultivar. These attributes include nutty, sweet, oily, and grittiness. One attribute, beany flavor, had an interaction between cultivar and month.

Effects of Roasting Method and Storage Time

In the both the oil- and dry-roasted soynuts desirable aroma and flavor characteristics (cereal-like and roasted aroma, roasted, cereal-like/grainy, and nutty flavors) as well as some of the undesirable characteristics (rancid aroma, rancid and beany flavor) tended to decrease with storage (Table 2).

Cereal-like aroma was significantly less intense at months 3 and 6 than at month 1 for both types of roasts. Pooled for month, dry-roasted soynuts had more cereal-like aroma intensity than the oil-roasted soynuts (Table 3). Cereal-like grainy flavor also decreased over time and was higher in the dry-roasted soynuts than the oil-roasted soynuts.

Roasted aroma significantly decreased at both month 3 and month 6 for both roasts. The oil-roasted soynuts had more roasted aroma intensity than the dry-roasted soynuts when pooled for month. The higher temperature of oil-roasting presumably contributed to the formation of more desirable roasted aromas. Furthermore, oils and fats are able to provide the preferred "flavor release" that is absent in foods with less fat (White 2000). Roasted flavor, like roasted aroma decreased in intensity over time. In oil-roasted soynuts, roasted flavor decreased from month 1 to month 3 and in dry-roasted soynuts roasted flavor decreased significantly at both month 3 and month 6. Nutty flavor intensity followed the same type of trend as roasted aroma and roasted flavor. Nutty flavor intensity decreased from month 1 to month 3 and stayed constant from month 3 to month 6 for both roasts. Similar to roasted aroma, nutty flavor intensity was higher in oil-roasted soynuts than dry-roasted soynuts. The pyrazines formed by the Maillard browning reaction in roasted foods

contribute to both nutty and roasted flavor formation so it is not unexpected that the trends were similar for these attributes.

Rancid aroma intensity decreased at month 3 and 6 for the oil-roasted soynuts but remained constant for the dry-roasted soynuts. Rancid flavor intensity was higher in the oil-roasted soynuts than the dry-roasted soynuts. In both roasts rancid flavor intensity decreased from month 1 to month 3. The absorbed oil on the outside of the oil-roasted soynuts provided more substrate for lipid oxidation reactions which contributed to more rancid aroma and rancid flavor formation in the oil-roasted soynuts. Soybeans and soybean oil are high in polyunsaturated fatty acids which increases their susceptibility to lipid oxidation (Boge and others 2007). The decrease in rancid aroma and flavor during storage could be due to the further breakdown of these compounds or their volatilization.

Beany flavor intensity stayed constant over storage for oil-roasted soynuts and decreased significantly between month 1 and month 3 for dry-roasted soynuts. Dry-roasted soynuts were perceived as having beanier flavor overall than the oil-roasted soynuts. The dry-roasted soynuts were roasted at a lower temperature than the oil-roasted soynuts allowing the lipoxygenase a longer time to be active before it was destroyed by heat. This could have contributed to the dry-roasted soynuts having a more beany flavor. The beany flavor may also be masked by the higher intensity of desirable roasted flavors in the oil-roasted soynuts (Kato and others 1981; Metwalli and others 1975).

Panelists perceived a more intense bitter flavor in the dry-roasted soynuts than in the oil-roasted soynuts. Bitter flavor formation may have been more favorable in dry-roasted soynuts. Alternatively, the oil-roasting conditions may have been more favorable to the degradation of bitter compounds, or the higher content of desirable flavor compounds in the oil-roasted soynuts could have masked the bitter flavor. Hydrophobic amino acids are

responsible for the bitter flavor of small peptides (Kato and others 1989) and the dry-roasted soynuts tended to be higher in hydrophobic free amino acid content than the oil-roasted soynuts (Boge and others 2007). Furthermore, Jung and others (1997) found that higher roasting temperatures lead to greater non-enzymatic browning between reducing sugars and free amino acids. The oil-roasted soynuts experienced a higher roasting temperature and greater amino acid content reduction than the dry-roasted soynuts (Boge and others 2007).

Sweet flavor intensity was relatively constant over time for both roasts; however, oil-roasted soynuts were perceived as sweeter at month 6 than for the other storage times. The greater bitter flavor intensity in the dry-roasted soynuts may contribute to a lower perceived intensity of sweetness in the dry-roasted soynuts than the oil-roasted soynuts.

The oily flavor was more intense in the oil-roasted soynuts and increased during storage. In the dry-roasted soynuts oily flavor intensity remained constant over storage. The evident oil absorption on the surface of the soynuts as well as the oil tending to leach out during storage contributed to the perception of increased oiliness of the oil-roasted samples.

The decrease in desirable roasted flavors over storage time agrees with the results from studies on roasted peanuts (Bett and Boylston 1992; Williams and others 2006). Bett and Boylston (1992) found that the roasted peanutty flavor decreased over 12 weeks of accelerated storage conditions. As lipid oxidation occurs in the roasted soynuts during storage, the concentration of roasted flavors may decrease as they become entrained by complexes between proteins and lipid hydroperoxides or the further breakdown of these products (Williams and others 2006). Masking of desirable flavors by lipid breakdown products could have also occurred during storage (Bett and Boylston 1992). Williams and others (2006) found that pyrazine content decreased during storage and attributed pyrazine degradation rather than masking as the cause of the decrease in roasted peanut flavor, at least

in short term storage (21 d). The general decrease in both desirable and undesirable flavors in the roasted soynuts may be attributed to the volatilization of the flavor compounds with time and adsorption of the flavor compounds by the packaging material. In the case of rancid aroma and rancid flavor, the intensities of these attributes were not high to begin with, so the decreases may not represent great intensity changes.

Oil-roasted soynuts fractured more easily than the dry-roasted samples. Fracturability remained constant over storage for both roasting methods. Hardness was significantly less in the oil-roasted soynuts and was not affected by storage. Dry-roasted soynuts significantly decreased in hardness from month 1 to month 3. However, perceived hardness for months 1 and 6 were not different. The dry-roasted soynuts remained whole during roasting, unlike the oil-roasted soynuts. The intact soybean was harder in texture and less easy to fracture. In addition, the longer roasting time and lower temperature encountered by the dry-roasted soynuts contributed to a higher moisture content (Boge and others 2007) and presumably less fracturability and a harder texture. The higher moisture content may also have played a role in the dry-roasted soynuts having a more gritty texture although the effect of a lower roasting temperature is likely to be a greater factor. Grittiness increased in oil-roasted soynuts at month 6 and stayed constant in dry-roasted soynuts. Increased grittiness in the oil-roasted samples could be a consequence of texture breakdown as the water activity increased in the soynuts over storage (data not shown). Roasted peanuts with higher water activities had lower texture acceptance than roasted peanuts with water activities less than 0.5 (Lee and others 2006). Oil leaching out of the oil-roasted soynuts and the chemical reactions of the lipid and other compounds could also contribute to the texture breakdown and subsequent grittiness increase.

Effects of Cultivar

Only 4 sensory attributes were significantly affected by cultivar (Table 4). One interaction occurred between cultivar and month and that was for beany flavor (Table 5). No interactions occurred between cultivar and roast. There were no significant cultivar effects for cereal-like, roasted, and rancid aromas, bitter, rancid, beany, and cereal-like/grainy flavors, or fracturability and hardness when cultivar was pooled over roast and month (Table 2). Asgrow was the least nutty and IA 1008 LF was the nuttiest of the cultivars. Asgrow was the least sweet, Prairie Brand and IA 2064 had intermediate sweetness, and IA 1008 and IA 1008 LF were the sweetest. The flavor attribute oily followed a similar trend with Asgrow being the least oily and IA 1008 being the oiliest. IA 1008 LF was the grittiest and Asgrow was the least gritty. There were no significant differences in aroma, flavor, or texture attributes between cultivars IA 1008, IA 1008 LF, Prairie Brand, and IA 2064. Overall the effect of cultivar on sensory attributes was minimal. Asgrow tends to have lower flavor intensity than the rest of the cultivars for some attributes, but is otherwise very similar.

Consumer Acceptability Panel

Consumer panelists' demographics are shown (Table 6). Consumer panelists preferred the appearance of oil-roasted soynuts to dry-roasted soynuts (Table 7). The oil-roasted samples had more of a roasted appearance as they had a more intense color due to the higher heat treatment and therefore greater Maillard browning. In addition, the oil absorption gave the oil-roasted soynuts a shiny appearance. IA 2064, the only cultivar with a black hilum, was scored lower in appearance compared to the other oil-roasted cultivars. Many panelists commented that the appearance of this cultivar was undesirable because of the 'black spots.' The flavor, texture, and overall acceptability scores were significantly higher for the oil-roasted samples than for the dry-roasted sample with no significant differences

between the cultivars of oil-roasted samples. Lee and others (2006) noted that in consumer acceptance, texture is one of the most important criteria.

The higher flavor, texture, and overall acceptability scores of the oil-roasted soynuts, as determined by the consumer panel, agree with the results of the descriptive panel. The oil-roasted soynuts in the descriptive panel typically had higher intensities of desirable aroma (roasted aroma), flavor (nutty and sweet), and texture (fracturability) attributes. The texture of the oil-roasted samples was less hard and easier to fracture according to the descriptive panel results. The consumer panel indicated that that the oil-roasted sample had a more desirable texture. These results are consistent with a study of roasted peanuts. Metwalli and others (1976) noted that fried peanuts had a crisp texture and a more desirable color and flavor than roasted peanuts. In both the descriptive and consumer panels, roasting method had a greater effect on the sensory attributes than did soybean cultivar.

Conclusions

Type of roast and storage had significant effects on the sensory characteristics of roasted soynuts. Oil-roasted soynuts were preferred in a consumer acceptability panel. Roasted aroma, nutty flavor, and fracturability of oil-roasted soynuts were scored higher in the descriptive panel. The descriptive panel also perceived the oil-roasted soynuts to be less hard and less gritty. The most significant cultivar effect was demonstrated in the appearance of the soynuts, in which the black hilas detracted from the soynuts appearance and overall acceptability. The lack of significant cultivar effects and interactions between cultivar and roast indicates that all of the cultivars are equally suitable for both oil- and dry-roasting. Shelf-life is an important consideration in roasted soynuts. Increased storage time generally decreased aroma and flavor attribute intensities of both desirable and undesirable aromas and flavors, but had a minimal effect on texture attributes.

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Table 1 - Reference standards for analytical sensory panel training

Attribute	Reference	Intensity (cm)
Bitterness	Caffeine	5 to 7.5
Rancid/Oxidized	Oxidized Kretschmer® Original Toasted Wheat Germ	15
Beany	Raw Soybeans	15
Cereal-like/Grainy	Kretschmer® Original Toasted Wheat Germ	11.25
Nutty	Planters® Dry Roasted Peanuts Lightly Salted	11.25
Oily/Buttery	Planters® Oil Roasted Peanuts Lightly Salted	7.5
Fracturability	Planters® Dry Roasted Peanuts Lightly Salted	7.5
Hardness	Planters® Dry Roasted Peanuts Lightly Salted	7.5

"0" corresponds to "None" on 15-cm line scale and "15" corresponds to "Intense."

Table 2 - The effects of storage time on the sensory attributes of oil-roasted soynuts as scored by a descriptive sensory evaluation panel[a]

	Oil			Dry		
	Month			Month		
Sensory Attribute	1	3	6	1	3	6
Aroma Attributes						
Cereal-like	5.15 b[b]	4.13 a	4.26 a	6.15 y[b]	5.48 x	4.29 x
Roasted	6.33 c	5.54 b	4.69 a	5.87 z	5.18 y	4.05 x
Rancid*	5.46 c	3.40 b	2.60 a	2.51 x	2.36 x	1.65 x
Flavor Attributes						
Bitter	3.75 b	2.48 a	1.93 a	6.96 y	4.60 x	4.14 x
Rancid	4.61 b	3.20 a	2.88 a	3.25 y	2.40 x	1.92 x
Roasted*	6.68 b	5.65 a	5.06 a	8.57 z	6.59 y	5.36 x
Beany*	2.40 a	1.82 a	1.96 a	3.91 y	2.53 x	2.69 x
Cereal-like/Grainy	5.70 c	4.82 b	4.26 a	6.74 z	5.14 y	4.40 x
Nutty	7.22 b	5.87 a	5.18 a	6.30 y	3.80 x	3.41 x
Sweet*	3.26 a	3.55 a	4.80 b	1.51 x	2.27 x	2.29 x
Oily*	5.44 a	6.55 b	7.54 c	1.33 x	1.85 x	2.08 x
Texture Attributes						
Fracturability*	9.89 a	10.39 a	8.85 a	8.39 x	7.14 x	6.62 x
Hardness*	4.85 a	4.77 a	5.37 a	10.9 y	9.24 x	10.7 xy
Grittiness*	5.94 ab	5.27 a	7.11 b	8.44 x	7.75 x	7.96 x

[a]Results are interaction means of 2 replications and responses of 10 panelists. Data for cultivar was pooled.

[b]Means within a row and within a roast with different letters (a-c for oil-roasted, x-z for dry-roasted) are significantly different ($p<0.05$).

"0" corresponds to "None" on 15-cm line scale and "15" corresponds to "Intense."

*Interaction between roast and month is significant.

Table 3 - The effect of roasting type on the sensory attributes of soynuts as scored by a descriptive sensory evaluation panel[a]

	Roast	
	Oil	Dry
Aroma Attributes		
Cereal-like	4.54 a	5.35 b
Roasted	5.55 b	5.07 a
Rancid*	3.88	2.20
Flavor Attributes		
Bitter	2.76 a	5.24 b
Rancid	3.60 b	2.54 a
Roasted*	5.83	6.88
Beany*	2.08	3.03
Cereal-like/Grainy	4.95 a	5.45 b
Nutty	6.13 b	4.51 a
Sweet*	3.01	2.05
Oily*	6.54	1.78
Texture Attributes		
Fracturability*	9.71	7.40
Hardness*	4.99	10.21
Grittiness*	6.11	8.04

[a]Results are means of 2 replications and responses of 10 panelists. Data for cultivar and month was pooled.

[b]Means within a row with different letters (a-c) are significantly different ($p<0.05$).

"0" corresponds to "None" on 15-cm line scale and "15" corresponds to "Intense."

*Interaction between roast and month is significant.

Table 4 - Effect of soybean cultivars on sensory attributes[a] as determined by a descriptive sensory evaluation panel

Sensory Attribute	Cultivar				
	Asgrow	Prairie Brand	IA 2064	IA 1008	IA 1008 LF
Aroma Attributes					
Cereal-like	5.49 a	4.86 a	4.91 a	4.82 a	4.95 a
Roasted	5.44 a	5.17 a	5.26 a	5.32 a	5.32 a
Rancid	2.88 a	3.04 a	2.83 a	3.17 a	3.03 a
Flavor Attributes					
Bitter	3.95 a	3.85 a	4.36 a	3.70 a	4.30 a
Rancid	2.89 a	3.19 a	2.90 a	3.23 a	3.00 a
Roasted	6.88 a	5.89 a	6.42 a	6.27 a	6.44 a
Beany*	2.61	2.77	2.26	5.32	2.73
Cereal-like/Grainy	5.49 a	4.98 a	5.12 a	5.25 a	5.24 a
Nutty	4.74 a	5.09 ab	5.13 ab	5.51 ab	5.98 b
Sweet	2.44 a	2.80 ab	2.97 ab	3.07 b	3.34 b
Oily	3.79 a	3.80 ab	3.99 ab	4.41 b	4.42 b
Texture Attributes					
Fracturability	8.65 a	8.88 a	8.62 a	8.40 a	8.22 a
Hardness	7.05 a	7.13 a	7.60 a	7.84 a	8.39 a
Grittiness	6.37 a	6.85 ab	6.85 ab	7.49 ab	7.58 b

[a]Results are main effect means of 2 replications and responses of 10 panelists. Data for storage and roast were pooled. Means within a row with different letters (a,b) are significantly different ($p<0.05$).
"0" corresponds to "None" on 15-cm line scale and "15" corresponds to "Intense."
*Interaction between cultivar and month is significant.

Table 5 - Effect of soybean cultivars on beany flavor[a] as determined by a descriptive sensory evaluation panel

	Month		
Beany	1	3	6
IA 2064	2.63 ax	1.87 ax	2.28 ax
IA 1008 LF	2.75 axy	2.85 ax	2.61 ax
Asgrow	3.05 axy	2.54 ax	2.21 ax
Prairie Brand	3.68 axy	2.15 ax	2.45 ax
IA 1008	3.88 by	2.01 ax	2.07 ax

[a]Results are interaction means of 2 replications and responses of 10 panelists. Data for roast was pooled. Means within a row and column with different letters (a-c; month effects) and (x-z; cultivar effects), respectively, are significantly different at ($p<0.05$). "0" corresponds to "None" on 15-cm line scale and "15" corresponds to "Intense."

Table 6 - Demographic information of consumer acceptability panelists

Demographic	Category	Number of Panelists
Age	18-25 years	17
	25-35 years	14
	35-45 years	3
	45-55 years	13
	over 55 years	3
Gender	Male	27
	Female	23
Frequency of Soyfoods Consumption	Never	3
	Once/Month	15
	Twice/Month	6
	Once/Week	6
	3 Times/Week	2
	Once/Day	8
Have Tried Soynuts	Yes	34
	No	16
Frequency of Soynut Consumption	< Once/Month	7
	Once/Month	24
	Twice/Month	1
	Once/Week	4
	3 Times/Week	0
	Once/Day	0

Consumer panel consisted of 50 panelists.

Table 7 - Consumer acceptability panel results for five oil-roasted cultivars and one dry-roasted cultivar[a]

	Sample					
Sensory Attribute	IA 1008 Dry	IA 2064 Oil	IA 1008 LF Oil	IA 1008 Oil	Prairie Brand Oil	Asgrow Oil
Appearance	3.78 a[b]	4.80 b	5.48 bc	5.76 c	5.82 c	5.88 c
Flavor	4.04 a	5.26 b	5.32 b	5.48 b	5.74 b	6.06 b
Texture	4.01 a	5.80 b	6.00 b	6.09 b	6.24 b	6.50 b
Overall Acceptablity	4.01 a	5.26 b	5.54 b	5.59 b	5.78 b	5.94 b

[a]Results are mean values of 50 panelists.

[b]Means within a row with different letters (a-c) are significantly different ($p<0.05$).

"1" on 9-point hedonic scale corresponds to "dislike extremely" and "9" corresponds to "like extremely."

FLAVOR AND COLOR OF DRY- AND OIL-ROASTED SOYNUTS

A paper to be submitted for publication in the Food Chemistry and Toxicology section of the Journal of Food Science

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Abstract

Flavor quality of the lipid components of roasted soynuts is important to their overall flavor quality. The presence of linolenic acid in soybeans makes them prone to oxidative stability problems. In the current study, five food-grade soybean cultivars, including a low-linolenic cultivar and a lipoxygenase-free cultivar, were dry- and oil-roasted. The peroxide value, aldehyde content, free fatty acid content, volatile flavor compounds and color were determined on the roasted soynuts at each month during a 6-month storage study. Cultivar did not have significant effect on peroxide value, aldehyde content, free fatty acid content or volatile flavor compounds. Roasting method was significant for peroxide value. Peroxide values for dry-roasted soynuts were constant over time and were less than 0.5 meq O_2/kg at most storage times. Peroxide values for oil-roasted soynuts increased from approximately 1.0 meq O_2/kg following roasting to 4.3 O_2/kg at the end of six months of storage. Aldehyde contents increased somewhat during storage. Dry- and oil-roasted soynuts had aldehyde

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contents of 12 and 7 µmol malonaldehyde/kg sample at month 0 and 14 and 16 µmol malonaldehyde/kg sample at month 6, respectively. Means for months were not significantly different between roasts. Free fatty acid contents were higher for dry-roasted soynuts (0.80% oleic acid for all months) than for oil-roasted soynuts (0.22% oleic acid for all months). Free fatty acid contents were constant during storage. Desirable flavor compounds such as pyrazines and undesirable compounds such as aldehydes varied considerably with respect to the effect of roasting method and storage. Cultivar did not have a significant effect. Cultivar and storage had very little effect on color. Oil-roasted soynuts had higher a* and b* values and subsequently higher chromaticity than dry-roasted soynuts. Lightness and hue angle did not differ between roasts. Hue angle and chroma for oil- and dry-roasted soynuts were 52.0 and 53.0 and 21.24 and 16.85, respectively.

Introduction

Soybeans (*Glycine max*) contain many nutrients beneficial to health. Consumption of soy has been associated with health benefits such as cholesterol reduction and cancer prevention. Americans are increasingly more interested in consuming soy due in large part to the FDA approval of the health claims for soy protein (Liu 2000). However, consumption of soyfoods in the U.S. is limited due to the 'beany' flavor typically associated with them.

The roasting process produces desirable nutty and roasted flavors in soynuts that are not present in the raw soybeans or other processed soyfoods. Maillard browning is the predominant type of non-enzymatic browning occurring in roasted foods. Maillard browning and Strecker degradation reactions are responsible for the formation of pleasant roasted flavor compounds and melanoidin formation (Daniel and Weaver 2000). According to Basha and Young (1996), reducing sugars and amino acids are the major precursors of the desirable flavor in roasted peanuts. These flavor compounds are primarily heterocyclic compounds

including furans, thiazoles, thiophenes, oxazoles, pyrroles, pyridines, and pyrazines (Hwang and others 1995).

Pyrazines are the most abundant of the heterocyclic compounds formed during roasting and are responsible for the toasted and roasted flavors and yellow color formation in cooked foods (Lee and Shibamoto 2002). There are three groups of pyrazines: alkylpyrazines, bicyclic pyrazines, and acetylpyrazines. Alkylpyrazines significantly contribute to the flavor of heat-treated foods. Monosubstituted-pyrazines typically have nutty and/or roasted notes and higher alkylsubstituted pyrazines have fatty and/or waxy odors. Fried beef, roasted nuts, cocoa, and coffee aromas were identified with alkyl substituted dihydrocyclopentapyrazines (Hwang and others 1995). The quantity and quality of compounds produced in Maillard browning depends on the precursors, thermal processing parameters, pH, and quantitative ratio of amino nitrogen to reducing sugar (Martins and others 2001).

Roasting temperature affects the color, pyrazine content, and oxidative stability of soybeans and the oil extracted from them. In a study by Jung and others (1997), increased soybean roasting temperature resulted in the extracted oil being darker, redder, and more yellow. The pyrazine content of the oil increased greatly with increased roasting temperature. Nine alkylpyrazines were identified in the oil. Many of which had been previously identified in roasted soybeans (Wilkens and Lin 1970) and in roasted peanuts (Walradt and others 1971). Jung and others (1997) determined that 2,5-dimethylpyrazine was most responsible for the nut-like aroma of oil from roasted soybeans. Higher roasting temperatures greatly increased the oxidative stability of the oil because many of the Maillard reaction products also have antioxidant properties.

Flavor quality of lipids is very important to the overall flavor of a food. Lipids contribute both pleasant, desirable flavors to foods as well as off- and undesirable flavors. Furthermore, fats and oils have solvent-like properties that make them excellent carriers of good-tasting components in foods (White 2000). The lipid component of soybeans is primarily responsible for the off-flavor in soybeans. Linoleic acid is the predominant fatty acid found in soybeans and makes up 54% of lipid fraction of soybeans. Soybeans also contain a relatively high amount of linolenic acid, 7% of the lipid fraction. Because of the high content of polyunsaturated fatty acids, soybean lipids are prone to oxidative stability problems. Linolenic acid, with three double bonds, is considered to be the most problematic, which led to the development of low linolenic acid soybean cultivars (Hui 1996). Flavor reversion is characteristic of oils containing linolenic acid as well as being responsible for the off-flavors in soy products. Flavor reversion is described as "beany and grassy" at the beginning of oxidation and "fishy or painty" at more advanced stages of oxidation.

Lipoxygenase, an enzyme believed to be a major initiator of peroxidation of lipids, is present at approximately 2% of total seed protein in soybeans. Lipid peroxides are formed from the polyunsaturated fatty acids. These peroxides can also be formed non-enzymatically by the attack of activated oxygen species (Dahuja and Madaan 2003). Lipid peroxides are then broken down further by enzymes such as hydroperoxide lyase or broken down non-enzymatically. This breakdown leads to the formation of off-flavors. The most predominant compounds responsible for off-flavors are medium chain, primarily six carbon, alkylaldehydes or alkenylaldehydes (Dahuja and Madaan 2003; Kobayashi and others 1995).

Many studies have shown reduced off-flavor formation when low-lipoxygenase or lipoxygenase-free soybeans are used. Torres-Penaranda and others (1998) found that soymilk made from lipoxygenase-free soybeans had less cooked beany aroma, less cooked

beany flavor, and less astringency than soymilk made from the normal soybean cultivar. In a study by Dahuja and Madaan (2003), two varieties of low-lipoxygenase soybeans had lower thiobarbituric acid and carbonyl values than normal soybeans also suggesting lipoxygenase's role in producing off-flavors. The objective of this study was to determine the effects of cultivar, roasting method, and storage on the flavor and color of roasted soynuts.

Materials and Methods

Soybean Cultivars

Five food grade soybean cultivars, IA 2064, IA 1008 LF, IA 1008, Prairie Brand 299, and Asgrow 2247, were evaluated in this study. IA 2064, IA 1008 LF, and IA 1008 were obtained from the Committee for Agricultural Development at Iowa State University and were grown during the 2004 crop year. Prairie Brand 299 and Asgrow 2247 were obtained from Central Iowa Soy LLC (Jefferson, IA) and were grown during the 2005 crop year. IA 2064 is a low-linolenic acid cultivar. IA 1008 LF is a lipoxygenase-null cultivar derived from the IA 1008 cultivar.

Soybean Roasting

Processing of each cultivar and roasting method (dry- or oil-roasted) was conducted in duplicate. The soybeans were soaked in water (3:1 wt/wt, water:soybeans) for 20-24 hours at 4°C prior to roasting. The dry-roasted soybeans were roasted in 2000 g (soaked weight) batches in a drum roaster (Gold Medal Funfood Equipment & Supplies, Cincinnati, OH, U.S.A.) for three hours. The roaster did not provide temperature control adjustments. After roasting, the soybeans were allowed to cool on paper towels.

Oil-roasted soybeans were roasted in 500 g (soaked weight) batches in a deep-fat fryer (7.5 liter oil capacity; Star Mfg. International Inc., Smithville, TN, U.S.A.) at 177°C for 9 minutes and 10 seconds in vegetable oil (Crisco®, J.M. Smucker Co., Orrville, OH,

U.S.A.). After roasting the soybeans were removed from the oil and the excess oil was allowed to drain back into the deep fat fryer for 30 seconds. The soybeans were then allowed to cool on paper towels.

Because the oil quality changes as the frying time increases, the order of roasting of the cultivars was randomized. For optimum flavor, the oil was heated 1½ hours prior to roasting the soybeans and the first batch roasted in the oil was discarded. The total amount of roasting time for all batches was short enough that it was not necessary to change the oil (White 2006). Samples from the fresh oil, the oil after 1½ hours of heating, the oil after 1½ hours of roasting, and the oil at the end of roasting time were collected. Peroxide value, aldehyde content and free fatty acid content were determined to ensure that the oil had not deteriorated excessively.

The SāfTest® System (SāfTest®, Inc., Tempe, AZ, U.S.A.) was used to measure peroxide value, aldehyde content, and free fatty acid content of the oil samples taken during oil roasting. Preparation reagent (isopropyl alcohol) was added to the oil sample in a 10:1 ratio for the peroxide value determination. The oil was analyzed as is for the free fatty acid content and aldehyde content determination. The PeroxySafe™, AldeSafe™, and FASafe™ Kit-STD protocols were followed for each test. Peroxide values were expressed as meq peroxide/kg of sample. Aldehydes were expressed as μmol of malonaldehyde/kg sample. Free fatty acids were expressed as percent oleic acid in the sample.

Peroxide values are useful for initial oil quality measurements, but peroxides breakdown rapidly at elevated temperatures and should not be used to monitor oil processes such as frying (White 2000). Initial peroxide values for oil were 0.12 meq O_2/kg sample or less. Oils with peroxide values of 1 meq O_2/kg or less are considered to be unoxidized and of high quality (Gerde and others 2007). Aldehyde contents reached a maximum value of 29.3

µmols/kg of sample at the end of frying. Free fatty acid contents were less than 0.1% even by the end of frying indicating that the oil had not deteriorated markedly. Even fresh refined, bleached, and deodorized oils can contain up to 0.05% free fatty acids (Su and White 2004).

The dry- and oil-roasted soynuts were stored for up to 6 months in individual 7 oz Whirl-Pak bags (3 mil thickness, oxygen permeability 209.5 cc/100 sq in/24 hrs; moisture permeability 0.48 gms/100 sq in/24hrs, Nasco Fort Atkinson, WI, U.S.A) by month, roast, and cultivar. Each bag remained sealed until analyzed. The individual Whirl-Pak bags for each month were stored inside Ziploc® gallon storage bags (S.C. Johnson & Son Inc. Racine, WI, U.S.A.) which were stored in a cupboard to minimize exposure to light. Total storage time of the study was 6 months. Suboptimal packaging was used so that if storage had an effect, it would be demonstrated during the 6 months of storage.

Chemical Analyses

Soybeans were frozen at -18°C overnight and then ground using a Magic Mill III Plus High Speed Flour Mill (Magic Mill, Upper Saddle River, NJ, U.S.A.) on the coarsest setting. The grinding process produces a considerable amount of heat. Freezing the beans prior to grinding minimizes any heat-related reactions that can affect composition. Ground soybeans were used for all chemical analyses.

The SāfTest® System (SāfTest®, Inc., Tempe, AZ, U.S.A.) was used to measure peroxide value, aldehyde content, and free fatty acid content of the ground soybeans and the oil used for frying. Lipids were extracted from duplicate samples of ground soybeans (1g) by adding 3-mL of preparation reagent to the samples and vacuum filtration using the membrane filters as per the SāfTest® protocol. The PeroxySafe™, AldeSafe™, and FASafe™ Kit-STD protocols were followed for each test. Peroxide values were expressed as meq

peroxide/kg of sample. Aldehydes were expressed as μmol of malonaldehyde/kg sample. Free fatty acids were expressed as percent oleic acid in the sample.

Volatile Flavor Analysis

Volatile compounds of roasted soybeans were collected using solid-phase microextraction (SPME). Duplicate samples of twelve grams of whole, roasted soybeans and 30 g of water were placed in 100-mL headspace bottles and sealed with a Teflon septum. The samples were placed into a 40°C water bath with constant stirring for 45 minutes. The volatile compounds were absorbed onto the SPME fiber (2 cm 50/30 μm divinylbenzene/carboxen/polydimethylsiloxane; Supelco, Inc. Bellefonte, PA., U.S.A.)

Volatile flavor compounds were separated on a Hewlett-Packard gas chromatograph (Model 6890; Hewlett-Packard, Inc., Wilmington, DE) equipped with a splitless injection port and a flame ionization detector (FID). The volatile flavor compounds were thermally desorbed at 220°C from the SPME fiber for 3 minutes at the GC injection port. The compounds were then separated using a fused-silica capillary column (SPB-5 30 m x 0.25 mm x 0.25 μm film thickness; Supleco, Inc. Bellefonte, PA, U.S.A.). The column pressure was set at 124.0 kPa and the helium flow rate was 1.9 ml/sec. The initial oven temperature was 30°C. This temperature was held for 3 min before increasing to 110°C at 3.5°C/min. A final temperature of 200°C was reached by increasing at a rate of 10°C/min. The final temperature was held for 5 min. The detector temperature was 220°C. Detector gas flow rates were hydrogen, 30 ml/min; air, 400 ml/min; and nitrogen make up gas, 25 ml/min. Peak areas were determined, with duplicate analyses averaged. Regression analysis was

conducted, with storage time as the x-axis value, to determine the initial peak area at 0 month (intercept) and rate of change during storage (slope).

Identification of the volatile flavor compounds was identified using authentic standards (Sigma-Aldrich, Milwaukee, WI) and gas chromatography-mass spectrometry (GC-MS) (Micromass GCT, Waters Corp. Milford, MA). Samples were absorbed onto the SPME fiber as for GC analysis and desorbed onto a fused silica capillary column (SPB-5, 30 m x 0.25 mm x 0.25 µm film thickness, Supelco, Inc.) via the split GC injection port with a 100:1 split ratio. The GC had an initial temperature of 38°C with a 3 min hold, increased to to 110°C at 3.5°C/min, then to a final temperature of 200°C at a rate of 10°C/min. The mass spectrometer conditions were set as the following: electron ionization positive (EI+) polarity, source electron energy at 70 eV, source current at 200 µA, ion source temperature at 180°C, source ion repeller at 0.8 V, electron multiplier voltage at 2700 V, scan range from 41 to 400 m/z, at a scanning cycle frequency of 0.75 seconds. Volatile flavor compounds from GC-MS were analyzed using MassLynx version 4.0 (Waters Corp., Milford, MA) for identification and were compared to a spectral library (Wiley Library).

Color Analysis

Color of raw and roasted soybeans was determined using the Hunter MiniScan XE Plus 45/0 LAV Spectrophotometer (Model 45/0-L; Hunter Associates Laboratory, Inc., Reston, VA, U.S.A.). Illuminant D65 and 10° observer were used. Fifty gram soybean samples were placed into 7 oz clear WhirlPak® bags. The bags were placed onto the white tile for measurement. The same 50 g roasted soybean samples were read each month. The samples were read in triplicate on three different places. Hue angle and chroma were calculated (Hue Angle = ArcTan(b*/a*) x (360/2π), Chroma = $(a^{*2} + b^{*2})^{0.5}$).

Statistical Analysis

The experiment was a split-plot design with cultivar, roast, and month as main factors. Analysis of variance and Honest Significant Difference (HSD) using Tukey's adjustment was conducted to determine the effects of the main factors and interactions. Statistical analyses were performed (SYSTAT ver. 9.01; SPSS, Inc.; Chicago, IL, U.S.A.) with a significance level of $p < 0.05$. Processing treatments and analyses were replicated.

Results and Discussion

Peroxide Value, Aldehyde Content, Free Fatty Acid Content

Peroxide values (PV), aldehyde contents, and free fatty acid contents were not significantly different between cultivars (Table 1). Studies have shown that soymilk made from lipoxygenase-free soybeans have less beany flavor and aroma and lower yields of the volatile compounds responsible for the off-flavors in soymilk than soymilk made from normal soybeans (Kobayashi and others 1995 and Torres-Penaranda and others 1998). However, White (2000) stated that although lipoxygenase does promote the formation of hydroperoxides its contribution to overall oxidation and flavor quality of oils is questionable. Fatty acid composition tends to have a greater effect on flavor quality then the presence of lipoxygenase in oils (White 2000). But, differences in lipid oxidation measures were not observed in the low-linolenic soybeans either.

Method of roast and month interactions were significant for PV's of roasted soynuts. The PV's for the dry-roasted soynuts were very low (Figure 1). With the exception of two points they were less than 0.5 meq O_2/kg, and they stayed constant over the storage period. There were no significant differences in PV's between months for dry-roasted soynuts. The PV's of the oil-roasted soynuts increased significantly during the storage period from approximately 1.0 meq O_2/kg following roasting to approximately 4.25 O_2/kg after 6 months of storage. The oil-roasted soynuts were more prone to lipid oxidation because of their

higher lipid content. Because the absorbed oil was on the surface of the soynuts, it was exposed to oxygen. Both types of roasts had comparably low peroxide values even at the end of the study. Nepote and others (2006) determined 20 meq O_2/kg as the end of shelf-life for fried peanut quality. Maguire and others (2004) measured PV on ground walnuts, almonds, peanuts, hazelnuts, and macadamia nuts purchased from a local health food store. Almonds had the lowest peroxide value (0.19 meq O_2/kg) and hazelnuts had the highest (0.43 meq O_2/kg). Based on these levels the researchers determined that the nuts were of good quality from an oxidative stability standpoint. Dry-roasted soynuts were largely within this range, but the oil-roasted soynuts had higher PV values (Figure 1).

Roast and month interactions were significant for aldehyde content (Figure 2). However, the interactions are due to small fluctuations in aldehyde contents during storage. There are no significant differences in aldehyde content between oil- and dry-roasted soynuts at any of the months (data not shown). There were no interactions with cultivar. Aldehyde contents increased with storage for both roasts. At month 0 the mean aldehyde content for all cultivars was approximately 12 μmol malonaldehyde/kg sample for dry-roasted soynuts and approximately 7 μmol malonaldehyde/kg sample for oil-roasted soynuts. At the end of 6 months the mean aldehyde content for all cultivars was approximately 14 μmol malonaldehyde/kg sample for dry-roasted soynuts and approximately 16 μmol malonaldehyde/kg sample for oil-roasted soynuts (Figure 2).

Interactions between month and roast were significant for free fatty acid contents. No significant interactions were seen with cultivar. The free fatty acid contents of the oil-roasted soynuts were significantly lower than the free fatty acid contents of the dry-roasted soynuts at each month (Figure 3). A considerable amount of hydrolysis would be expected to occur in the oil absorbed by the oil-roasted soynuts. Hydrolysis of fatty acids from the glycerol

backbone is enhanced by high temperatures and accumulation of moisture from the food that is being fried (White 2000). However, the higher temperature of oil-roasting compared to dry-roasting also resulted in more Maillard browning in the oil-roasted soynuts. Free fatty acids can participate in Maillard browning to produce desirable flavors (White 2000). Thus, the free fatty acids produced during oil-roasting possibly reacted with free amino acids to produce Maillard reaction products. Free fatty acid contents stayed relatively constant during storage for both roasts. Free fatty acid contents in peanuts increased with storage from 0.14 to 0.21% at the beginning of storage to 0.25 to 0.54% after 4 months of storage (Metwelli and others 1978). Free fatty acid contents of dry-roasted soynuts were higher than this averaging 0.80% oleic acid for all months and oil-roasted soynuts were comparable to peanuts in free fatty acid contents averaging 0.22% oleic acid for all months (Metwelli and others 1978).

Volatile Flavor Analysis

Volatile flavor compounds were most affected by the type of roast and the month of storage. Cultivar had an insignificant effect except for a few interactions with roast. Twenty-seven volatile flavor compounds were identified using GC-MS (Gas Chromatograph-Mass Spectroscopy) (Table 2). For the purpose of this paper, only 8 compounds will be discussed. The organoleptic properties of these 8 compounds are shown (Table 3).

Aldehydes, ketones, and alcohols are often considered to contribute off-flavors to foods. Hexanal, 1-octen-3-ol, 2-pentyl furan, and nonanal are typically associated with fishy, beany, and green flavors. With the exception of hexanal these flavor compounds were higher in the dry-roasted soynuts than the oil-roasted soynuts at time 0. Initial contents of 1-octen-3-ol and nonanal were higher in the dry-roasted soynuts than in the oil-roasted soynuts.

Storage had a greater effect on the decrease in the content of 1-octen-3-ol in the dry-roasted soynuts than in the oil-roasted soynuts. The change in nonanal content during storage was not significantly different between the two roasts. The initial content of 2-pentyl furan content was only significantly different between roasts for one cultivar (Table 4). Its rate of decrease was faster in the dry-roasted soynuts than the oil-roasted soynuts. The general greater decrease of these compounds in the dry-roasted soynuts is likely to their ability to volatilize more easily. The absorbed oil in the oil-roasted soynuts helps to bind to flavor compounds making them less able to volatilize. It is also possible that because these compounds were generally higher in the dry-roasted soynuts there was more to lose over time.

Hexanal content was significantly higher in the oil-roasted soynuts and it had a significantly higher rate of increase during storage than in the dry-roasted soynuts. Lipid oxidation products that were higher initially in the dry-roasted soynuts most likely owed the bulk of their formation to lipoxygenase action. Hexanal formation, however, was more likely to be a result the increased oil content of the oil-roasted soynuts which provided more substrate for lipid oxidation. Furthermore, the oil absorbed during oil-roasting was on the outside of the soynuts thus readily exposing it to oxygen. This resulted in not only a higher hexanal content at time 0, but also in a higher rate of increase during storage.

Lipid autoxidation and lipoxygenase reactions are the primary mechanisms for the formation of the lipid oxidation compounds in the roasted soynuts. The differences temperature and time of roasting potentially affects which of these reactions predominate. The lipoxygenase enzyme was likely inactivated very quickly during oil-roasting than during dry-roasting because of the higher temperature, and thus, more rapid denaturation of the lipoxygenase. In the oil-roasted soynuts, formation of hexanal and other lipid oxidation

products was more likely a result the increased oil content of the oil-roasted soynuts which provided more substrate for lipid oxidation. Furthermore, the oil absorbed during oil-roasting was on the outside of the soynuts thus readily exposing it to oxygen. During storage, it is expected that lipid autoxidation was the predominant reaction for both the oil- and dry-roasted soynuts.

Pyrazines and other heterocyclic compounds are primarily responsible for the desirable roasted and nutty flavors found roasted foods. Dimethyl pyrazine and 1-pentyl-1H-pyrrole contents were significantly higher in the oil-roasted soynuts than in the dry-roasted soynuts at time 0. 2-Ethyl-5-methyl pyrazine content was only significantly different between roasts for the Asgrow cultivar (Table 4). 2,3-Diethyl-5-methyl pyrazine content was higher in the dry-roasted soynuts than in the oil-roasted soynuts. Ho and others (2007) noted that pyrazines required both a minimum reaction time temperature before they would form in palm sap. The oil-roasting in this study was conducted at a much higher temperature which may explain why the content of some of the pyrazines were higher in the oil-roasted soynuts. 2,3-Diethyl-5-methyl pyrazine content, however, was higher in the dry-roasted soynuts. Ho and others (2007) determined that 2,3-Diethyl-5-methyl pyrazine was formed at 180 minutes of heating in palm sap (Ho and others 2007). Perhaps the longer roasting time of the dry-roasted soynuts provided more optimum conditions for the formation of 2,3-diethyl-5-methyl pyrazine. Ho and others also noted that though this compound was formed in small amounts it has a low odor threshold and significantly contributes to flavor even at small concentrations. Braddock and others (1995), noted that ethylpyrazine had a distinctly rich, dark toasted/roasted aroma. If 2,3-diethyl-5-methyl pyrazine has a similar flavor profile this could explain why a sensory evaluation panel scored the dry-roasted soynuts higher in

roasted flavor and noted during training that the dry-roasted soynuts has a burnt, coffee note (Boge and others 2007).

The effect of roasting method on the rates of change for desirable flavor compounds in roasted soynuts differed by compound. Several of the desirable compounds, including dimethyl pyrazine, 1-pentyl-1H-pyrrole, and 2,3-diethyl-5-methylpyrazine, decreased more readily in the oil-roasted soynuts than in the dry-roasted soynuts during storage. This could be due degradation of these compounds by lipid radicals or volatilization (Bett and Boylston 1992).

Color

Cultivar and storage treatments did not have a significant effect on color (data not shown). Dry- and oil-roasted soynuts did not differ in lightness or hue angle (Table 5). Dry- and oil-roasted soynuts had hue angles of 53.0 and 52.0 respectively. These hue angles are in the yellow-orange region of the CIE LAB color space. The greater Maillard browning due to higher roasting temperatures occurring in the oil-roasted soynuts led to more intense color formation. Furthermore, the oil absorption during roasting increased the amount of carbonyl substrate for the Maillard reaction in the form of free fatty acids and lipid oxidation products (Lee and Shibamoto 2002; Hidalgo and Zamora 2004). Oil-roasted soynuts were redder and more yellow in color which made the color more intense or greater in chroma. Increased redness and yellowness agreed with a study by Jung and others (1997) where increased soybean roasting temperature resulted in the extracted oil being darker, redder, and more yellow.

Conclusions

Peroxide values were significantly higher for oil-roasted soynuts than for dry-roasted soynuts. Aldehyde contents were not significantly different between roasting types. Oil-

roasted soynuts were significantly lower in free fatty acids than dry-roasted soynuts. Storage of roasted soynuts tended to increase their peroxide values and aldehyde contents, but free fatty acid contents were largely unaffected by storage. Cultivar did not have a significant effect on the peroxide value, aldehyde content, or free fatty acid content of roasted soynuts. Volatile flavor compound formation differed between roasts and was affected by storage, but cultivar had a largely insignificant effect. Roasting method significantly affected the Hunter a* and b* values and chroma of the roasted soynuts, but the hue angle and lightness were not significantly different between roasts. Cultivar did not have a significant effect on the color of roasted soynuts. To optimize the production of flavor producing compounds in roasted soynuts the roasting method is a more important consideration than the cultivar.

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Table 1 - Peroxide value, aldehyde content and free fatty acid content of roasted soynuts[a]

	Analysis		
Cultivar	PV[b]	Aldehydes[c]	FFAs[d]
Asgrow	1.78 a	13.83 a	0.45 a
IA 1008	1.60 a	12.47 a	0.49 a
IA 2064	1.50 a	11.47 a	0.50 a
IA 1008 LF	1.64 a	13.31 a	0.54 a
Prairie Brand	1.49 a	12.79 a	0.57 a

[a]Means are duplicate analysis of 2 replications, pooled for month and roast. Cultivars are not significantly different at ($p<0.05$).

[b]meq peroxide/kg of sample

[c]µmol of malonaldehyde/kg sample

[d]percent oleic acid in the sample

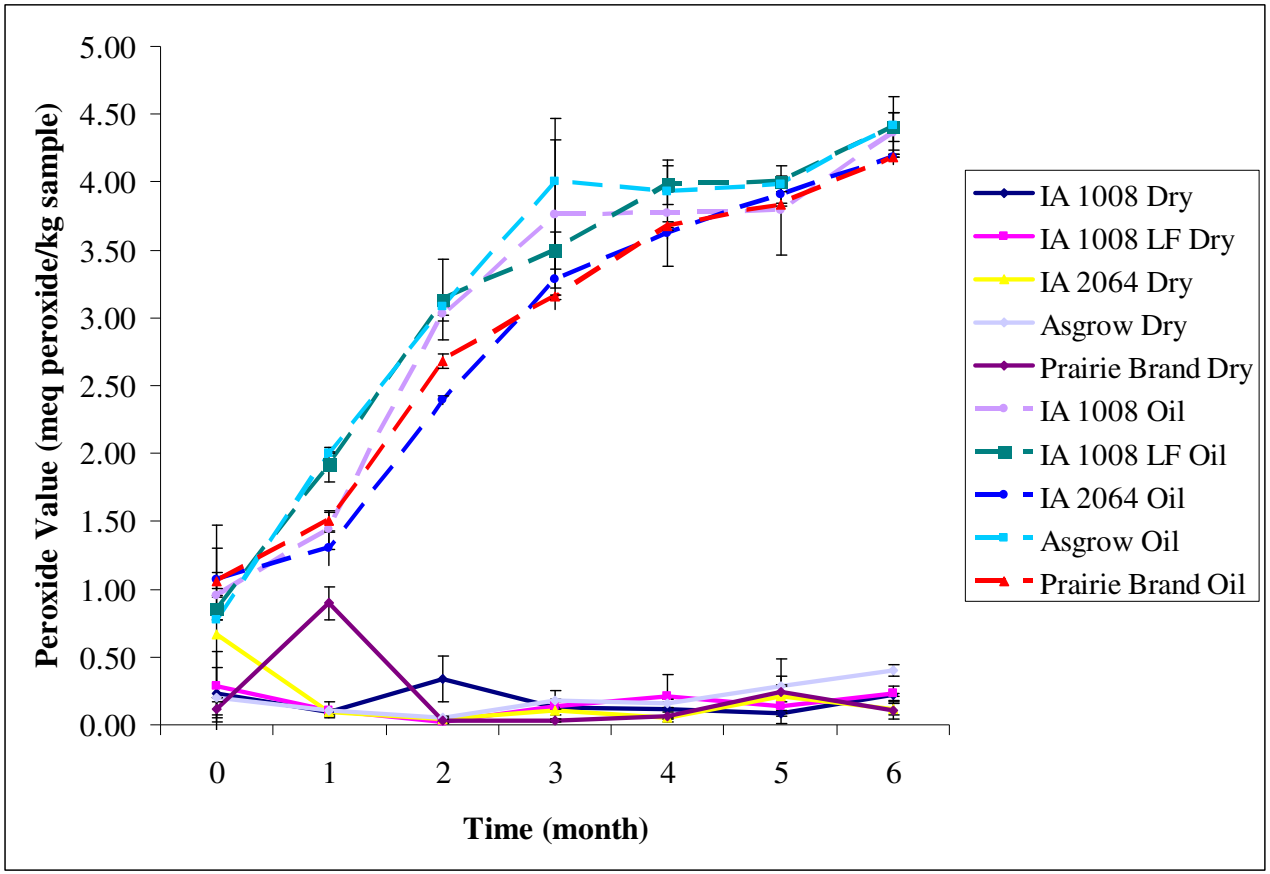

Figure 1 - Peroxide value of oil- and dry-roasted soynuts during six months of storage. Means represent duplicate analyses of 2 replications. Error bars represent the standard error of the means.

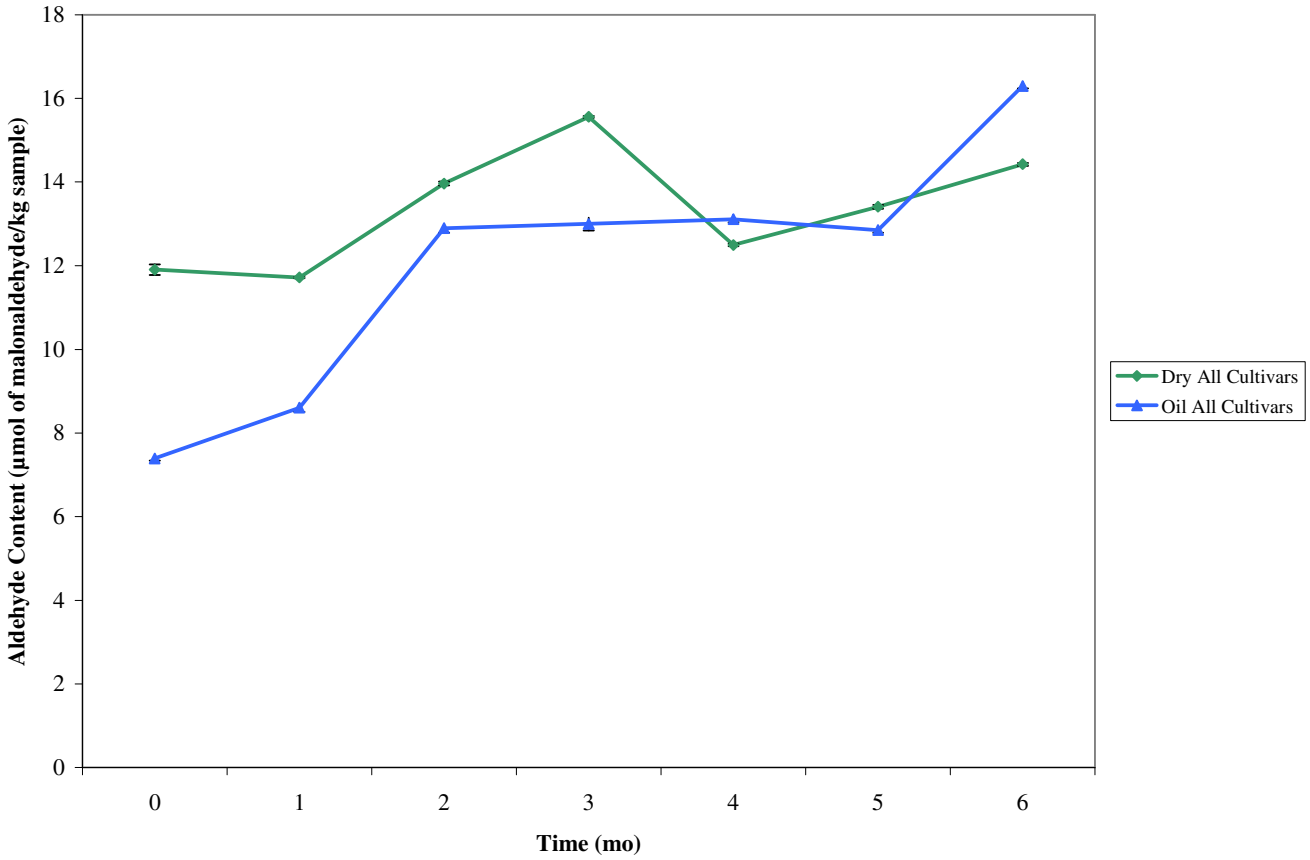

Figure 2 - Aldehyde content of oil- and dry-roasted soynuts during six months of storage. Means represent duplicate analyses of 2 replications with data for cultivar pooled. Error bars represent the standard error of the means.

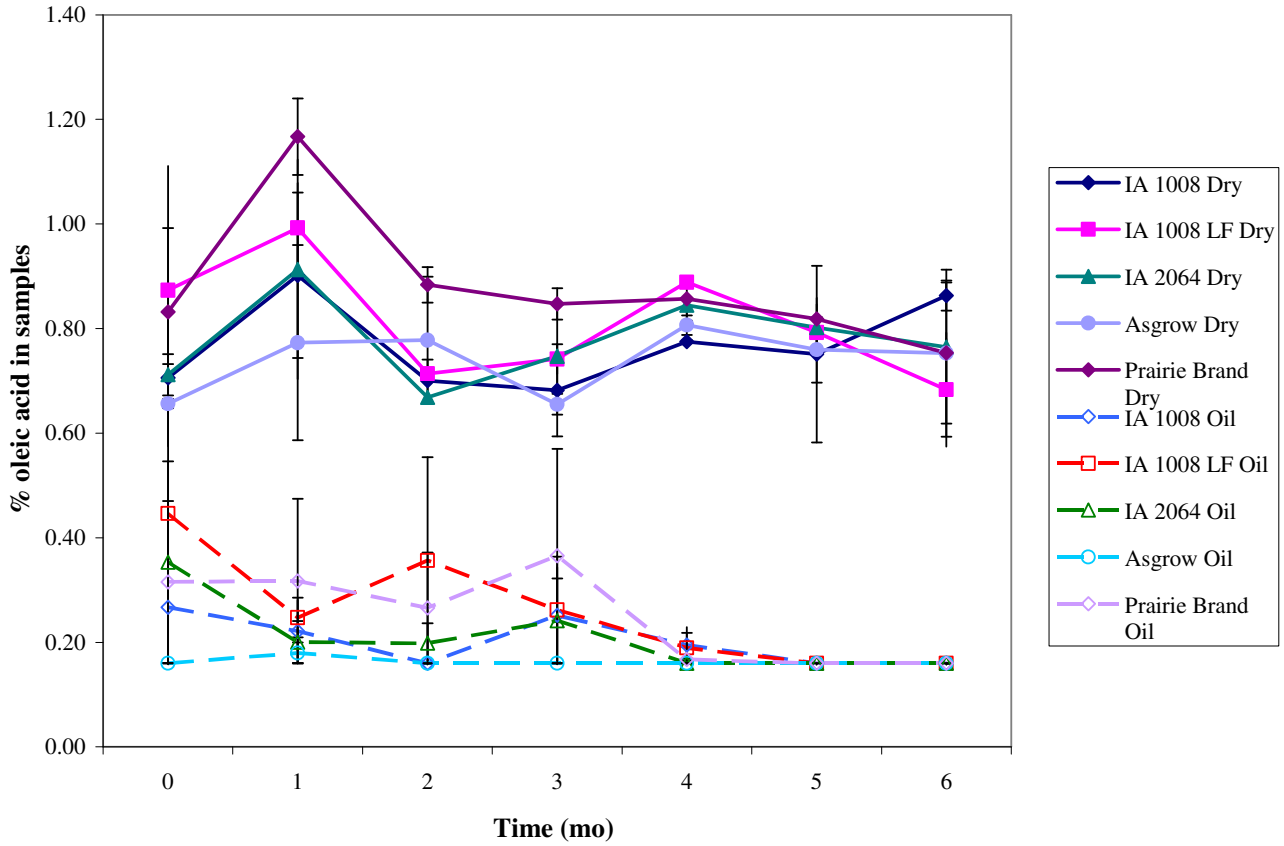

Figure 3 - Free fatty acid content of oil- and dry-roasted soynuts during six months of storage. Means represent duplicate analyses of 2 replications. Error bars represent the standard error of the means.

Table 2 - Effect of roasting method and storage on volatile flavor compounds[a] in roasted soynuts

	Intercept		Slope	
	Dry-Roasted	Oil-Roasted	Dry-Roasted	Oil-Roasted
3-Methyl-1-H-pyrrole-1-methyl-1-H-pyrrole	13.17 a	56.82 b	3.68 b	-4.02 a
Dimethyl Sulfide	95.39 a	94.10 a	62.43*	13.20*
Hexanal	68.65 a	135.89 b	2.42 a	60.83 b
2-Heptanone	101.34 a	75.78 a	-4.36 a	-9.48 a
Heptanol	16.31 a	26.22 b	0.97 a	-0.92 a
Dimethyl pyrazine	92.31 a	184.67 b	-4.88 a	-8.45 a
Ethyl pyrazine	83.60 b	1.53 a	-16.63 a	1.05 b
Benzaldehyde	66.06 a	142.14 b	11.39 b	-29.42 a
Dimethyl trisulfide	22.02 a	26.61 a	8.21 b	3.21 a
1-Octen-3-ol	944.05 b	96.32 a	-68.80 a	-1.21 b
2-Pentyl furan	340.22*	155.14*	-39.13 a	-14.82 b
2-Ethyl-5-methyl pyrazine	741.07*	609.38*	-8.44 b	-39.80 a
Octanal	19.60 a	43.74 b	-1.31 a	-1.96 a
Isopropenyl pyrazine	26.22 a	16.38 a	-3.89 a	9.52 b
Limonene	31.04 a	20.67 a	-4.76 a	16.63 b
Phenylacetaldhyde	1.00 a	11.53 b	0.00 a	12.19 b
1-Pentyl-1H-pyrrole	134.22 a	248.03 b	-5.88 a	-10.26 a
Octenal	81.03 b	21.16 a	-7.53 a	14.56 b
3,5-Octadien-2-one	31.62 a	34.87 a	-6.91 a	18.48 b
2,6-Diethyl pyrazine	6.92 a	13.81 a	-0.65 a	41.05 b
Diethyl pyrazine	14.29 a	15.16 a	-1.24 a	11.75 b
Nonanal	187.70 b	101.71 a	-5.97 a	6.79 a
2-Butyl-3-methyl pyrazine	5.83 a	16.67 b	-1.00 a	2.52 b
2,3-Diethyl-5-methyl pyrazine	13.38 b	2.27 a	-0.63 a	3.96 b
2-Tert-butyl-3,6-dimethyl pyrazine	10.59 a	6.59 a	-1.97 a	7.67 b
2,6-Dimethyl-3-isobutyl pyrazine	132.54 b	57.66 a	-5.88 a	1.47 a
2,4-Decadienal	14.37 a	189.37 b	-3.05 b	-42.22 a

[a]Intercept is the peak area/12 g of roasted soynuts at time 0. Slope is the change in peak area/12 g of roasted soynuts during storage. Means represent duplicate analyses from 2 replications and are pooled for cultivar.
*Cultivar*roast interaction

Table 3 - Organoleptic properties of select flavor compounds in roasted soynuts

Hexanal	fatty, fruity, green
1-Octen-3-ol	cheese, creamy, herbaceous, earthy, fishy, meaty, vegetable
2-Pentyl furan	green, vegetable
Nonanal	apple, coconut, grape, grapefruit, lemon, lime, melon, oily, orange, waxy, citrus, fatty, nutty, peach, rose, vegetable, meaty, fishy
Dimethyl pyrazine	meaty, nutty
2-Ethyl-5-methyl pyrazine	-
1-Pentyl-1H-pyrrole	-
2,3-Diethyl-5-methyl pyrazine	hazelnut, vegetable, meaty

Flavor descriptors from Sigma-Aldrich online catalog

Table 4 - Effect of cultivar and roasting method on the content[a] of 2-pentyl furan and 2-Ethyl-5methyl pyrazine at time zero and the rate of decrease[b] of Dimethyl sulfide during storage of roasted soynuts[c]

2-Pentyl furan - Intercept	Asgrow	IA 1008	IA 2064	IA 1008 LF	Prairie Brand
Dry	274.42 ax	254.70 ax	638.76 by	193.12 ax	340.12 ax
Oil	142.16 ax	153.30 ax	176.64 ax	147.51 ax	156.10 ax
2-Ethyl-5-methyl pyrazine - Intercept					
Dry	1008.65 ax	554.10 ax	680.10 ax	799.52 ax	662.98 ax
Oil	493.82 ay	653.42 ax	609.14 ax	671.96 ax	618.53 ax
Dimethyl sulfide - Slope					
Dry	117.93 by	32.24 ax	66.62 ay	42.31 ax	53.07 ax
Oil	13.47 ax	7.86 ax	16.77 ax	10.92 ax	16.97 ax

[a]Intercept is the peak area/12 g of roasted soynuts at time 0.

[b]Slope is the change in peak area/12 g of roasted soynuts during storage.

[c]Means represent duplicate analyses of 2 replications. Means within a row and column with different letters (a-b; roast effects) and (x-y; cultivar effects) respectively, are significantly different ($p<0.05$).

Table 5 - Color of roasted soynuts[c]

	Roast	
	Dry	Oil
L*[a]	53.78 a	53.10 a
a*[a]	9.97 a	12.99 b
b*[a]	13.42 a	16.69 b
Hue Angle[b]	53.03 a	52.00 a
Chroma[b]	16.85 a	21.24 b

[a]Means are triplicate readings of 2 replications, cultivar and month are pooled.

[b]Calculated from a* and b* readings.

[c]Means within a row with different letters (a,b) are significantly different ($p<0.05$).

CONCLUSIONS

The roasting method had the most significant effect on the composition, sensory attributes, and flavor characteristics of roasted soynuts. Storage also had a significant effect, but cultivar effects were largely insignificant. Moisture content of roasted soynuts was affected by roasting type and storage. The oil-roasted soynuts had significantly lower moisture contents than the dry-roasted soynuts and soynuts of both roasts gained moisture during storage.

The difference in temperature and roasting medium between the two roasting types greatly influenced the sugar, free amino acid and lipid contents of the roasted soynuts. Reducing sugar and free amino acid contents were lower in the oil-roasted soynuts than in the dry-roasted soynuts as a consequence of the higher roasting temperature and presumably increased Maillard browning in the oil-roasted soynuts. The fatty acid profiles did not differ significantly between roasts, but the contents differed because of the absorbed oil in the oil-roasted soynuts. Storage appeared to increase the extractability of the sugars and lipids.

Oil-roasted soynuts tend to score higher than the dry-roasted soynuts in the desirable aroma, flavor, and texture attributes. The consumer acceptability panel demonstrated that oil-roasted soynuts were preferred over the dry-roasted soynuts. Storage of roasted soynuts decreased both desirable and undesirable aroma and flavor attributes but had only a small effect on texture attributes. Cultivar had some significant effects. According to the descriptive panel the Asgrow cultivar had lower flavor intensity in nuttiness, sweetness, and oiliness and was the least gritty. The black hilas in the low-linolenic acid cultivar detracted

from their appearance in the consumer acceptability panel. There were no cultivar roast interactions indicating that all the cultivars were equally suitable for both types of roasting.

Peroxide values and free fatty acid contents significantly differed between roasts. Peroxide value was higher in oil-roasted soynuts, but free fatty acid content was higher in dry-roasted soynuts. Aldehyde contents did not differ between roasting types. Peroxide values and aldehyde contents increased with storage of roasted soynuts whereas free fatty acid contents remained relatively constant. There were no significant differences between cultivar for peroxide value, aldehyde content, or free fatty acid content.

Both desirable and undesirable flavor compounds were formed in roasted soynuts. Most of the roasted, nutty flavor compounds such as the pyrazines, were formed in greater amounts in the oil-roasted soynuts. This is most likely due to the higher roasting temperature of the oil-roasting. Off-flavor compounds such as aldehydes were formed in both dry- and oil-roasted soynuts. The lower roasting temperature and longer time of the dry-roasting process allowed the lipoxygenase enzyme to be active longer, catalyzing hydroperoxide formation, and leading to the formation of lipid oxidation products. The oil-roasted soynuts had absorbed oil on their outer surface which provided substrate for lipid oxidation.

Color of roasted soynuts was significantly affected by the type of roasted. Storage and cultivar did not affect the color. Oil-roasted soynuts were higher in Hunter a* and b* values and chromaticity than dry-roasted soynuts. The lightness and hue angles were not affected by type of roast.

Composition, sensory characteristics, and flavor attributes of roasted soynuts were most affected by the type of roast. Shelf-life is also an important factor as many of the soynut characteristics change during storage. Cultivar however, has a minor effect. Further research on roasted soynuts should focus on the roasting type. Both oil-roasting and dry-roasting conditions and batch sizes should be optimized at a pilot scale. More in depth study of the effects of time, temperature and roasting medium on the composition, sensory attributes, and flavor characteristic could lead to greater understanding of the Maillard browning reaction in roasted soynuts. This information could then be used to create a soynut product with a desirable flavor profile and longer shelf-life.

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