A Comparison of Flavor Differences between Pecan Cultivars in Raw and Roasted Forms

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Abstract: The objective of this research was to explore sensory differences among 8 different pecan cultivars ("Pawnee," "Witte," "Kanza," "Major," "Lakota," "Giles," "Maramec," "Chetopa") in raw and roasted forms. The cultivars were collected from 2 growing seasons (2013 and 2014) and evaluated separately. Trained panelists evaluated each cultivar from each season in raw and roasted forms, measuring intensities of 20 flavor attributes using descriptive analysis. The intensities of 10 of the 20 flavor attributes were higher for the roasted pecans across all cultivars. These included pecan ID, overall nutty, nutty-woody, nutty-grainlike, nutty-buttery, brown, caramelized, roasted, overall sweet, and sweet. The cultivars exhibited significant differences from one another for 8 attributes: pecan ID, nutty-buttery, caramelized, acrid, woody, oily, astringent, and bitter. Each of the cultivars displayed unique flavor profiles with some demonstrating extremes of certain attributes, for example the high astringency of "Lakota" or the buttery characteristics of "Pawnee." These results may help pecan growers and pecan product manufacturers understand flavor differences between different varieties of pecans, both in raw and roasted states, and the changes that occur during this process.

Keywords: descriptive analysis, flavor, pecan, roasted, sensory

Practical Application: Results from this article can assist pecan growers in understanding how the roasting process changes the flavor of pecan cultivars. This study shows which cultivars have similar flavors, which have flavor defects, and which have unique flavors that can be valuable to manufacturers or consumers. Understanding the sensory profiles of the pecans will assist in the reduction of product waste, the increase of consumer application, and the economic growth of the pecan industry.

Introduction

The pecan (*Carya illinoinensis*) is the most commercially important nut tree native to North America. Pecans are growing in popularity and demand due to an increased awareness of their desirable nutritional properties. Pecans contain phenolic compounds that possess antioxidant properties. Studies have found that antioxidants have the ability to lower the incidence of chronic diseases such as Alzheimer's disease, Parkinson's disease, some types of cancer, and other degenerative diseases (Mertens-Talcott and Percival 2005; Tam and others 2006). Pecans also have high levels of unsaturated fatty acids, which may have a role in reducing the risk of heart disease (Rajaram and others 2000, 2001).

Pecans are a high value crop with its timber and pecan kernels having applications in industry. In the United States, in 2013 alone, 106569000 pounds of nutmeat was produced and brought into the market, generating a revenue of $460390000 (NASS 2015). Similarly, in 2014, $513591000 was generated from 101858000 pounds of nutmeat produced (NASS 2015). With 161 patented cultivars of pecans grown in the U.S., the variety of flavors, sizes, and applications is expansive (Grauke and Thompson 2016). Pecan nut kernels are used in baking, confections, and ice cream. The nut kernels are sold as gift-packs, retail cello packs, and in bulk boxes to wholesale outlets or various food service outlets (Wood 2001). Purchasing pecans in a prepared form such as chocolate-covered or roasted is also popular (Lombardini and others 2008). Roasting is a process that intensifies the color, texture, appearance, and flavor of pecans. Along with some flavor changes, the resulting product has different textural properties such as higher crispness and brittleness (Saklar and others 1999). Though the effect of roasting has been described for other nuts, only 1 study has been conducted for how roasting impacts pecans (Erickson and others 1994).

Erickson and others (1994) assessed the oxidative stability in both raw and roasted pecans. The focus of this research was on evaluation of crunchiness, internal lightness, and rancid aroma and flavor. The attribute intensities were recorded on a 150 mm line scale with appropriate anchor words. No significant differences were found in the rancid aroma and flavor of the raw and roasted pecan samples. No significant difference for internal lightness among the samples was found either.

Since research on the evaluation of flavor differences between raw and roasted pecans has been limited in the past, mainly focusing on how flavor changes in the context of oxidation, describing how flavor attributes change during roasting may be useful for pecan growers and pecan product manufacturers who want to gather more information on how the cultivars perform in different applications. Further, creating and comparing flavor profiles of different pecan cultivars would allow for pecan growers to better market their pecans. With these benefits in mind, the objective of this study was to determine differences in flavor profiles among 8 different cultivars in raw and roasted forms over 2 growing seasons using descriptive sensory analysis.

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Table 1–Flavor attributes, definitions, and references for descriptive analysis of pecans.

Attribute	Definition	Reference
Pecan ID	The aromatics commonly associated with pecans which include musty/earthy, piney, woody, brown, sweet, buttery, oily, astringent, and slightly acrid aromatics. Other aromatics may include musty/dusty, floral/fruity, and/or fruity-dark.	Ground Pecan pieces = 7.0 Preparation: Measure out 1 tbsp. of each of the 8 raw cultivars into a food processor and blend for 30 s. Pour into 1 oz. cups.
Overall nutty	A measurement that reflects the total of the nutty characteristics and the degree to which these characteristics fit together. These nutty characteristics are: sweet, oily, light brown, slightly musty and/or buttery, earthy, woody, astringent, bitter, and so on. Examples: nuts, wheat germ, certain whole grains.	Gold Medal Whole Wheat Flour = 4.5 Kretschmer Wheat Germ = 7.5 Mixture of Diamond Slivered Almonds and Kroger Chopped Hazelnuts = 7.5 Preparation: Puree the almonds and hazelnuts separately in blenders for 45 s on high speed. Combine equal amounts of the chopped nuts. Serve in individual 1 oz. cups. Serve pecans and walnuts in 1 oz cups. Diamond Shelled Walnuts = 8.0 Diamond Pecan Halves = 9.0
Nutty-woody	A nutty aromatic characterized by the presence of woodiness, increased musty/dustiness, brown, astringent and bitter.	Diamond Pecan Halves = 7.5 Diamond Shelled Walnuts = 7.5
Nutty-grain-like	A nutty aromatic characterized by the presence of a grainy aromatic, increased musty/dustiness and brown.	Gold Medal Whole Wheat Flour = 4.5 Kretschmer Wheat Germ = 7.5
Nutty-buttery	A nutty aromatic characterized by a buttery impression, and/or increased fatty aromatics and musty/earthy character.	HyVee Dry Roasted and Salted Macadamia Nuts = 5.0
Brown	A rich, full aromatic impression always characterized with some degree of darkness generally associated with attributes (that is, toasted, nutty, sweet).	Bush's Best Pinto Beans (Canned) = 5.0 Preparation: Drain beans and rinse with de-ionized water. Kretschmer Wheat Germ = 7.5
Caramelized	A round, full-bodied, medium brown aromatic.	C&H Golden Brown Sugar = 9.0
Acrid	The sharp/acrid, charred flavor note associated with something over baked or excessively browned in oil.	Alf's Natural Nutrition Puffed Red Wheat Cereal = 3.0
Burnt	A dark, brown, somewhat sharp, overbaked grain aromatic.	Alf's Natural Nutrition Puffed Red Wheat Cereal = 4.0
Musty/earthy	Humus-like aromatics that may or may not include damp soil, decaying vegetation, or cellar like characteristics.	Sliced Button mushroom = 10.5
Woody	The sweet, brown, musty, dark, dry aromatics associated with the bark of a tree.	Diamond Shelled Walnuts = 4.0
Roasted	Dark brown impression characteristic of products cooked to a high temperature by dry heat. Does not include bitter or burnt notes.	'Planters Dry Roasted Unsalted Peanuts = 5.0
Overall sweet	An aromatic associated with the impression of sweet substances.	Post Shredded Wheat = 1.5 General Mills Wheaties = 3.0 Lorna Doone Cookie = 4.5
Oily	The light aromatics associated with vegetable oil such as corn or soybean oil.	Kroger Slivered and Blanched Almonds = 4.0 HyVee Dry Roasted and Salted Macadamia Nuts = 9.0
Rancid	An aromatic commonly associated with oxidized fat and oils.	Wesson Vegetable Oil = 2.5 Preparation: Microwave 1/3 cup of oil on high power for 2 1/2 min. Let cool and serve in individual covered cups.
Oxidized	The aromatic associated with aged or highly used oil and fat.	Microwave Oven Heated Wesson Vegetable Oil = 6.0 Preparation: Add 300 mL of oil from a newly purchased and opened bottle of Wesson Vegetable Oil to a1000 mL glass beaker. Heat in the microwave oven on high power for 3 min. Remove from microwave and let sit at room temperature to cool for approximately 25 min. Then heat another 3 min, let cool another 25 min, and heat for 1 additional 3-min interval. Let beaker sit on counter uncovered overnight.
Astringent	A feeling of a puckering or a tingling sensation on the surface and/or edge of the tongue and mouth.	0.030% Alum solution = 1.5 0.050% Alum solution = 2.5 0.075% Alum solution = 3.5 0.10%Alum solution = 5.0
Bitter	A fundamental taste factor of which caffeine is typical.	0.010%CaffeineSolution = 2.0 0.020%CaffeineSolution = 3.5 0.035%CaffeineSolution = 5.0
Sour	A fundamental taste factor of which citric acid is typical.	0.015% Citric Acid Solution = 1.5 0.025% Citric Acid Solution = 2.5
Sweet	A fundamental taste factor of which sucrose is typical.	1% Sucrose Solution = 1.0

0 to 15 point numeric scale with 0.5 increments was used to rate the intensities of the attributes and references.

Materials and Methods

Samples

Eight pecan cultivars (~18.15 kg per cultivar, in shell) were collected from orchards located at Kansas State University's Pecan Experimental Fields in Chetopa, Kans., U.S.A. The cultivars included "Pawnee', "Witte," "Kanza," "Major," "Lakota," "Giles," "Maramec," and "Chetopa." The samples were kept under frozen conditions (–18 °C ± 1 °C) before and after the shelling process to maintain freshness and delay oil oxidation in the nuts (Reid 2011). The pecan shelling was completed over a 2-mo period from when the samples were received from each growing season, using a Duke Pecan Walnut Cracker (Duke Pecan Company, West Point, Miss., U.S.A.), a Davebilt Nutcracker (Davebilt Company, Lakeport Calif., U.S.A.), and Channel Lock model number 436, 15.24 cm cutting pliers (Channel Lock Inc., Meadville, Pa.,

Table 2–Initial moisture in pecans from the 2014 growing season.

Cultivar	Average percent moisture (%)	Standard deviation
Giles	3.20	0.11
Major	2.48	0.06
Chetopa	2.37	0.05
Lakota	3.59	0.16
Pawnee	2.45	0.07
Witte	2.97	0.09
Maramec	2.71	0.10
Kanza	3.01	0.10

U.S.A.) to remove the nutmeat from the shells. Samples were transferred to 3.79 L Food Saver vacuum seal bags and were vacuum sealed for storage using a FoodSaver Heat-Seal Vacuum Sealing System (Sunbeam Products Inc., Boca Raton, Fla., U.S.A.). The samples were stored frozen (–18 °C) until analysis. The initial percent moisture was measured using a Mettler Toledo HE 73/03 Moisture Analyzer (Mettler-Toledo AG, Greifensee, Switzerland) to ensure that each of the cultivars fell within industry standard for sale with a moisture content below 4.5% (Nelson and others 1992).

Two preparation methods were used in this experiment: raw and roasted. The pecans used for raw evaluation were removed from the freezer the afternoon prior to testing and allowed to thaw at room temperature (23 °C ± 1 °C) prior to evaluation. The pecans used for roasted evaluation were removed from the freezer 2 d prior to testing and allowed to thaw at room temperature (23 °C ± 1 °C). The pecans were roasted the afternoon before evaluation, following a method relatable to consumer use. Total of 100 g of each cultivar was placed on separate baking sheets and roasted at 176 °C for 10 min. The pecans were mixed after 5 min and after 8 min during roasting. After the roasting process the pecans were allowed to cool to ambient temperature (23 °C ± 1 °C) and stored in a sealed container overnight.

Descriptive analysis

Six panelists (5 female, 1 male) from the Sensory Analysis Center at Kansas State Univ. in Manhattan, Kans., U.S.A. were chosen for descriptive evaluation of the pecan samples from the 2013 growing season. Five of these panelists (4 female, 1 male) along with an additional 3 (2 female, 1 male) were selected to evaluate the samples from the 2014 growing season. All panelists had completed 120 h of general training in descriptive analysis methodology, and each panelist had over 2000 h of testing experience with a wide variety of food items. Five of the panelists had prior experience evaluating nut-related samples. Two days of orientation were used for the panel to familiarize itself with the products, attribute definitions, and references for each of the evaluation periods. Twenty flavor attributes were evaluated using a hybrid descriptive analysis method (Table 1).

Test design and sample evaluation

A series of modified William's Latin Square designs (Hunter 1996) were used to construct the test designs of this study. Computation of the Latin Squares for descriptive evaluation was completed with SAS® statistical software, version 9.3 (SAS Inst. Inc., Cary, N.C., U.S.A.) for the 2013 growing season evaluation. RedJade Sensory Software Suite (RedJade®, Redwood Shores, Calif., U.S.A.) was used for collecting sensory data and programming customizable balanced test designs, was used for the test design of the 2014 growing season evaluation.

The morning of evaluation each panelist was served 10 g of each cultivar in a plastic 3.25 ounce cup with plastic lid (Solo Cup Company, Lake Forest, Ill., U.S.A.). The cups were labeled with a 3-digit blinding code for the evaluation of the pecans from the 2013 growing season, and 4-digit blinding codes for the 2014 growing season evaluation. The evaluation was conducted under ambient lighting and temperature conditions. The panelists evaluated attribute intensities using a 0 to 15 point numerical scale with 0.5 increments, where 0.0 = none/not present and 15.0 = highest

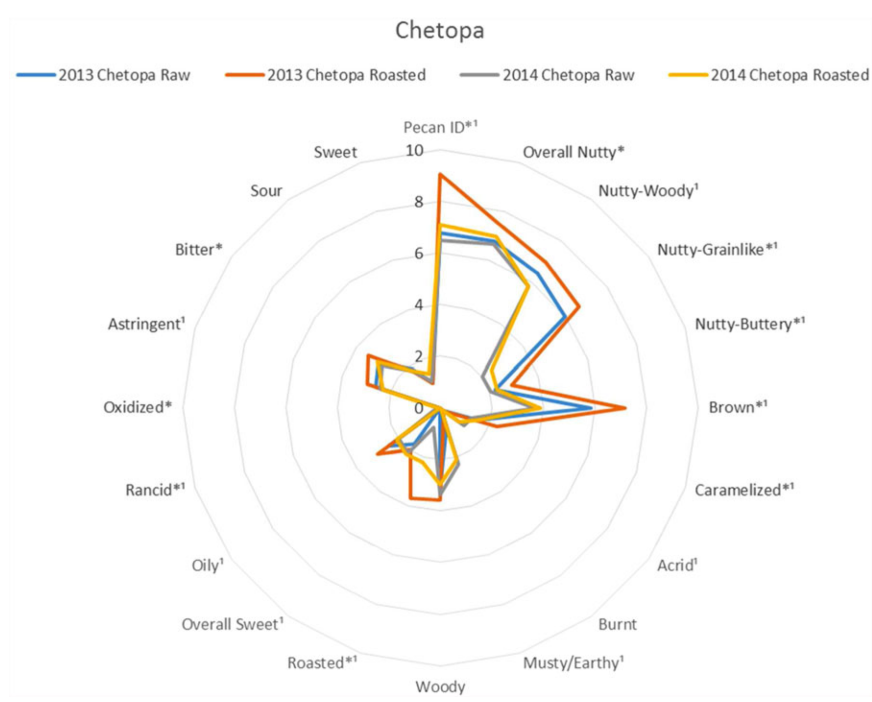

Figure 1–Spider plot of Chetopa cultivar. All attribute intensities were measured on a scale from 0 to 15 with 0.5 increments.
*Statistically significant difference between raw and roasted methods ($P < 0.05$).
[1]Statistically significant difference between 2013 and 2014 growing seasons ($P < 0.05$).

possible intensity. This evaluation procedure has been used in other recently published research (Suwonsichon and others 2012, Miller and Chambers 2013, Cherdchu and Chambers 2014). A tray with references for the flavor attributes (Table 1) was provided for each panelist along with definition/reference sheets. A quarter piece of pecan was determined appropriate to ensure approximately equal sampling amounts for attribute intensity scoring. Reverse osmosis de-ionized water (both at room temperature and heated), 0.5 cm peeled carrot slices, 1.27 cm Mozzarella cheese cubes (low moisture, part skim; Kroger Company, Cincinnati, Ohio, U.S.A.), and

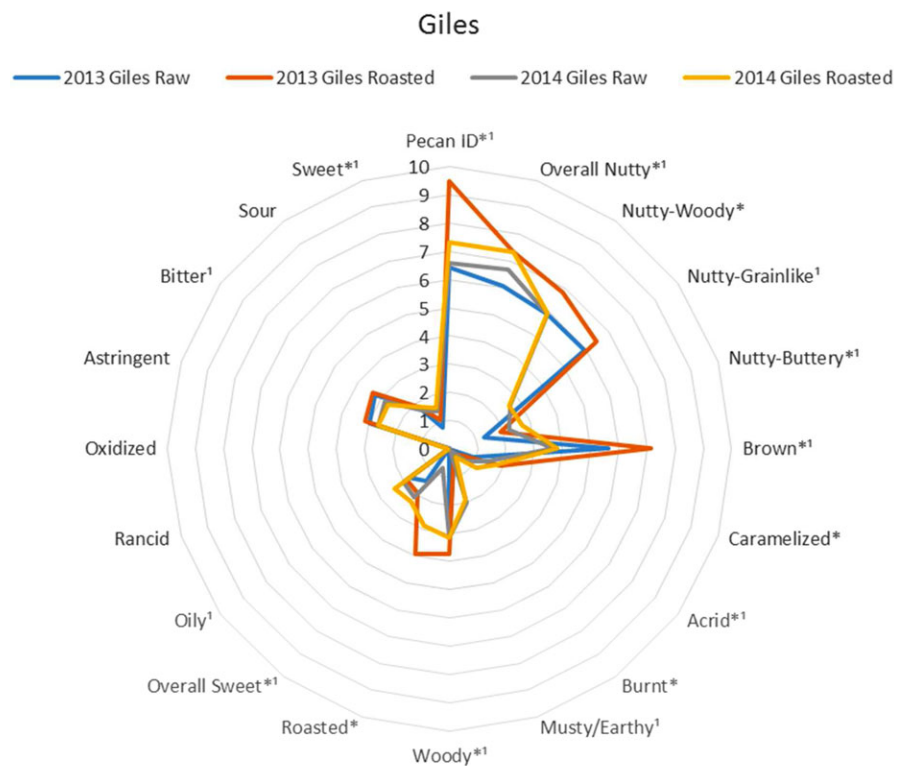

Figure 2–Spider plot of Giles cultivar. All attribute intensities were measured on a scale from 0 to 15 with 0.5 increments. *Statistically significant difference between raw and roasted methods ($P < 0.05$). [1]Statistically significant difference between 2013 and 2014 growing seasons ($P < 0.05$).

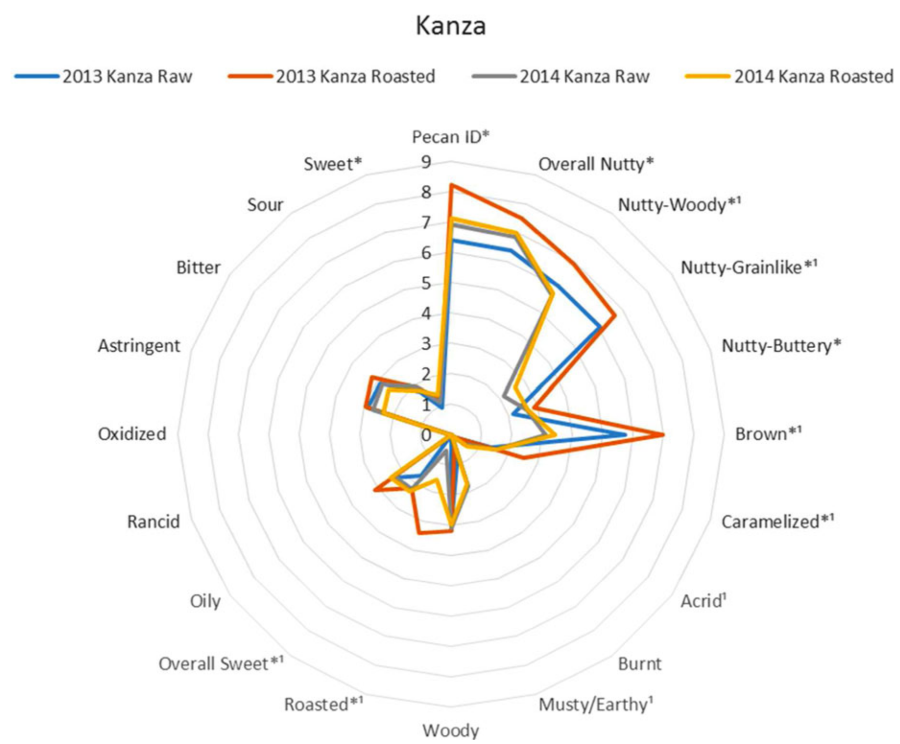

Figure 3–Spider plot of Kanza cultivar. All attribute intensities were measured on a scale from 0 to 15 with 0.5 increments.*Statistically significant difference between raw and roasted methods ($P < 0.05$). [1]Statistically significant difference between 2013 and 2014 growing seasons ($P < 0.05$).

0.32 cm skinless cucumber slices were used as palate cleansers. Sample evaluation took approximately 10 min per sample, and a 5-min rest period was used in addition to rinse agents to reduce flavor carryover. Panelists evaluated the 8 pecan samples with each preparation method, raw and roasted, in 3 replicates for each cultivar for the 2013 growing season, and in duplicate for the 2014 growing season.

Statistical analysis

Analysis of variance (ANOVA) was performed to test the significance of each flavor attribute across cultivars at the 5% level of significance for each year. Further, 2-way ANOVA was carried out to test the significance of sample variation, growing season, preparation method (roasted compared with raw), and the interaction of these factors at the 5% level of significance. Using a

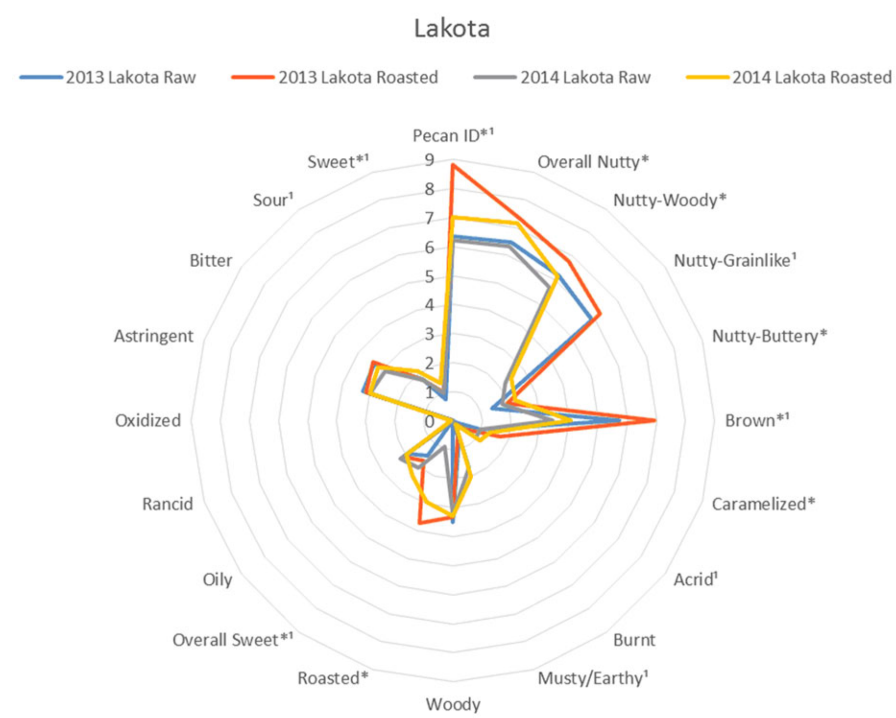

Figure 4–Spider plot of Lakota cultivar. All attribute intensities were measured on a scale from 0 to 15 with 0.5 increments. *Statistically significant difference between raw and roasted methods ($P < 0.05$). [1]Statistically significant difference between 2013 and 2014 growing seasons ($P < 0.05$).

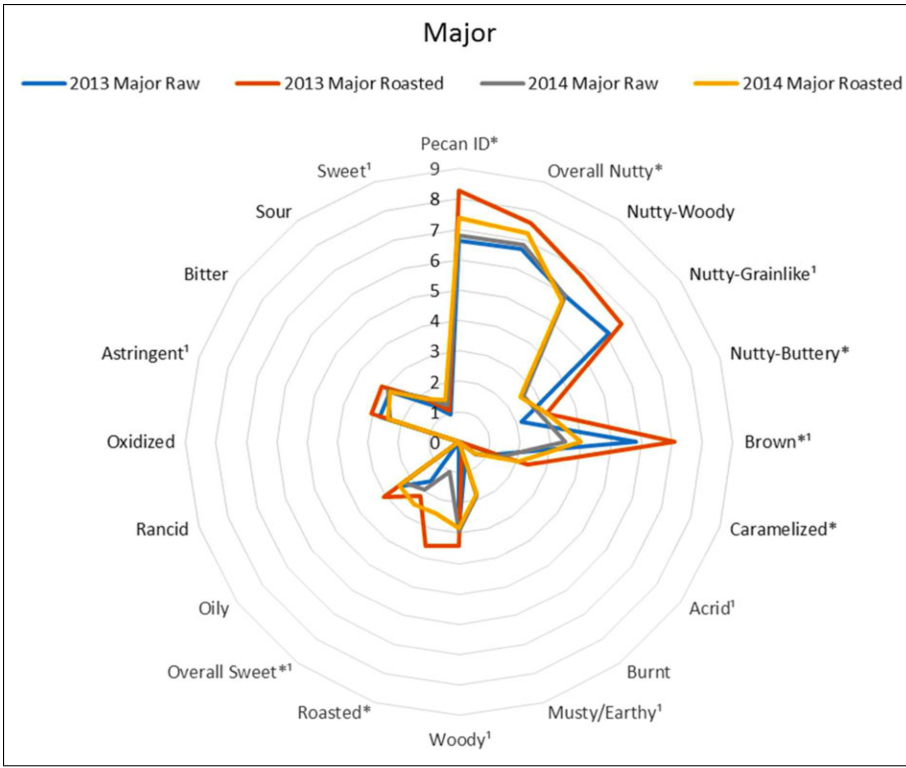

Figure 5–Spider plot of Major cultivar. All attribute intensities were measured on a scale from 0 to 15 with 0.5 increments. *Statistically significant difference between raw and roasted methods ($P < 0.05$). [1]Statistically significant difference between 2013 and 2014 growing seasons ($P < 0.05$).

Fisher's protected least significant difference (LSD) test, *post hoc* means separation was also analyzed at the 5% level of significance. Statistical analysis was performed with SAS® statistical software (SAS® version 9.3, SAS Institute Inc., Cary, N.C., U.S.A.) using PROC MIXED and PROC GLM.

Multiple factor analysis (MFA) was used to evaluate the relationship(s) among attributes and cultivars as well as to see the effect of growing season on flavor profiles. A MFA correlation circle visually depicts the inertia of individual attributes on cultivar differences for each of the growing seasons in order to draw conclusions on which attributes describe particular samples. The factor map reveals relationships between the cultivar profiles under the 2 different preparation means using cluster analysis and allows for the cultivars to be classified into uniquely defined sub groups. R software (R version 3.1.1, Ihaka R. and Gentleman, R., Auckland, New Zealand) was used to perform this analysis.

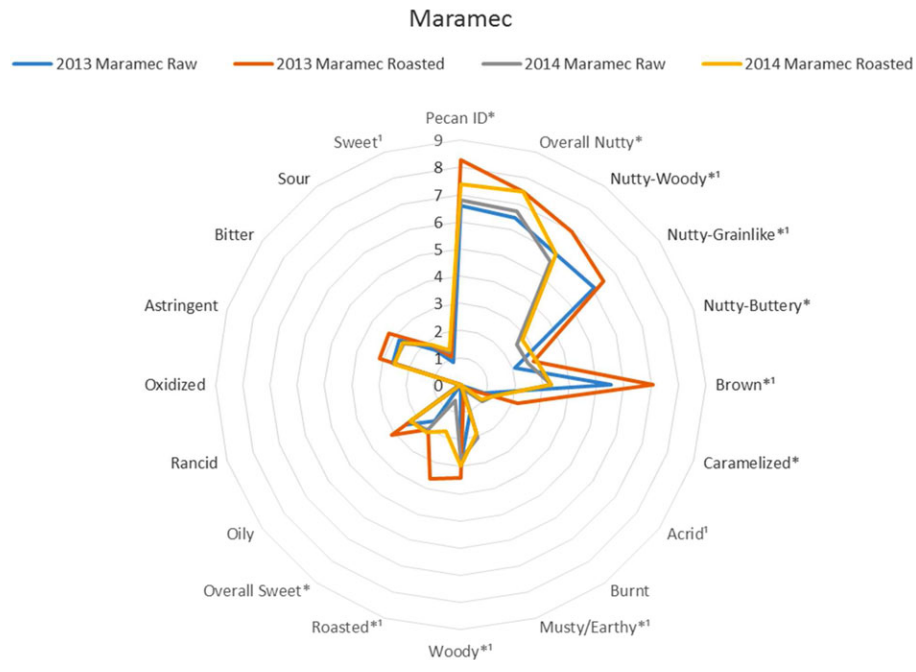

Figure 6–Spider plot of Maramec cultivar. All attribute intensities were measured on a scale from 0 to 15 with 0.5 increments. *Statistically significant difference between raw and roasted methods ($P < 0.05$). [1]Statistically significant difference between 2013 and 2014 growing seasons ($P < 0.05$).

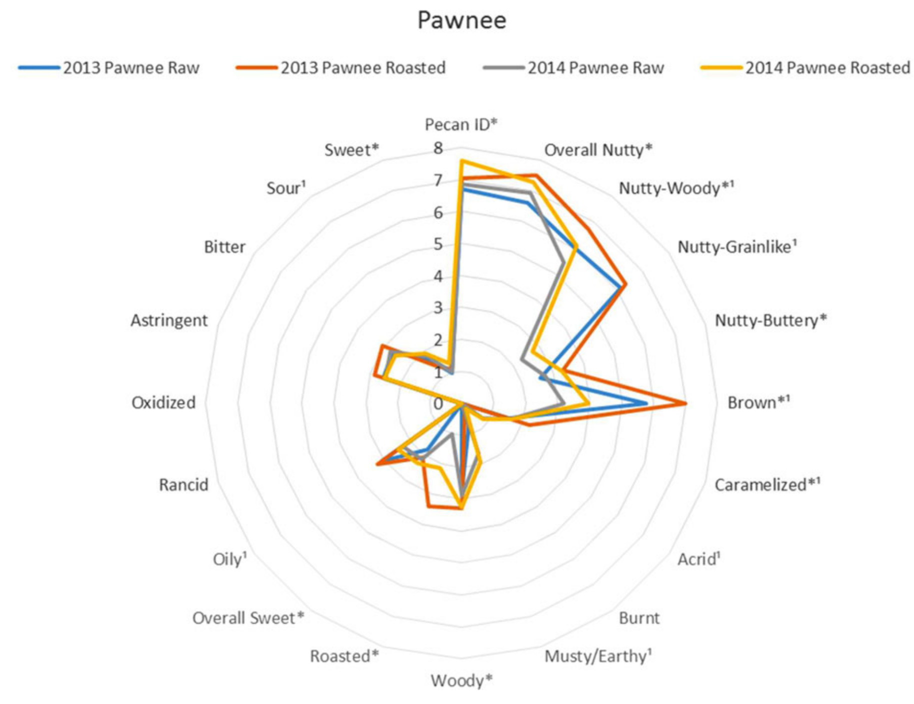

Figure 7–Spider plot of Pawnee cultivar. All attribute intensities were measured on a scale from 0 to 15 with 0.5 increments. *Statistically significant difference between raw and roasted methods ($P < 0.05$). [1]Statistically significant difference between 2013 and 2014 growing seasons ($P < 0.05$).

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Results and Discussion

Profile variations

While each of the cultivars is related to one another, being from the species *C. illinoinensis*, chemical composition differences and how the compounds that comprise each cultivar change in response to time and temperature can lead to very unique flavor profiles. Phenolic compounds and fatty acid composition can vary depending on the cultivar (Malik and others 2009). In research performed on hazelnut roasting flavors, it was determined that new volatiles were created and existing volatiles increased when the roasting process occurred (Alasalvar and others 2003). Seventy-one compounds were detected in roasted hazelnuts, including ketones, aldehydes, pyrazines, alcohols, aromatic hydrocarbons, furans, pyrroles, terpenes, and acids (Alasalvar and others 2003). Nutty, roasty, and fruity aromatics may be caused by ketones,

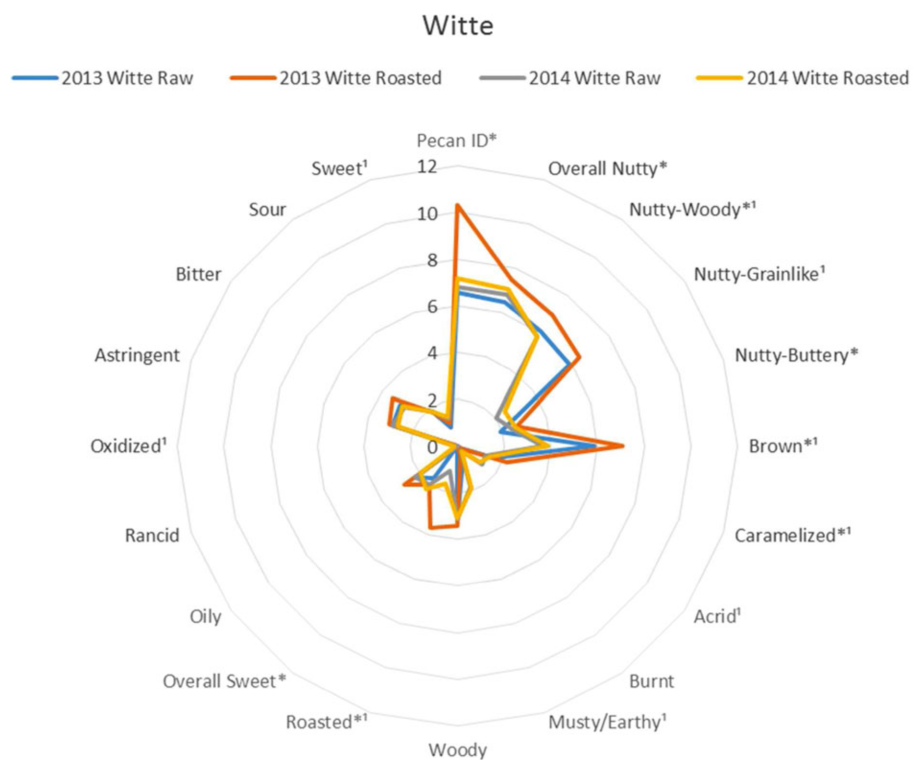

Figure 8–Spider plot of Witte cultivar. All attribute intensities were measured on a scale from 0 to 15 with 0.5 increments. *Statistically significant difference between raw and roasted methods ($P < 0.05$). [1]Statistically significant difference between 2013 and 2014 growing seasons ($P < 0.05$).

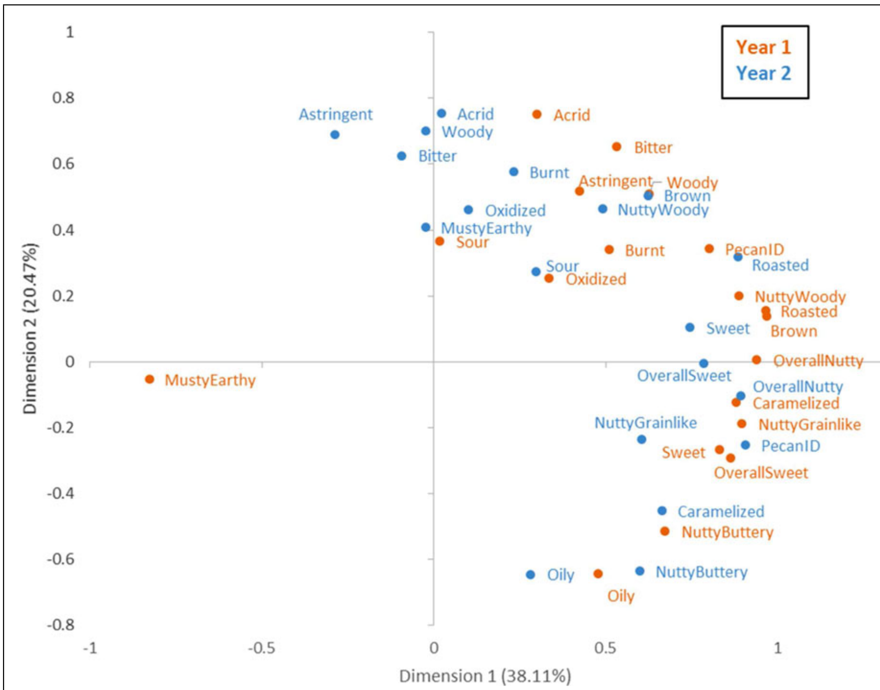

Figure 9–Multiple factor analysis correlation circle.

aldehydes, and pyrazines. Sweet aromatics are due to pyrazines, alcohols, and furans (Alasalvar and others 2003). Similar compounds can be expected from pecans, but further research is necessary to see how chemical composition can contribute to pecan flavor and flavor differences between cultivars.

Differences in initial moisture between the cultivars can furthermore lead to flavor variation. Although this is controlled to an extent in an industry setting, with requirements to be below 4.5% for quality and safety purposes, the moisture content of pecans can vary greatly. Seasonal variation in rainfall, storage conditions, and differences in chemical makeup of the pecans can all play a role in the amount of moisture in pecan nutmeat. Pecans in this experiment were examined under consumer-available conditions and therefore initial moisture in the pecans was not altered for specific cultivars and did not affect the roasting procedures. In pecans from the 2014 growing season, the initial moisture ranged from 2.37% in "Chetopa" to 3.58% in "Lakota" pecans (Table 2). This range could have contributed to some of the differences between the cultivars.

Spider plots gave a visual representation of the flavor profile for a selection of the cultivars (Figure 1 to 8). Although the general shapes of the plots were similar, there were clear differences within each cultivar between samples with different preparation methods and different growing seasons, many of these differences significant.

Three attributes showed negligible results across all cultivars, preparation methods, and growing seasons: rancid, oxidized, and burnt attributes were virtually undetected in the samples (Figure 1 to 8).

One cultivar that showed many attribute intensity differences when compared to the other cultivars for both growing seasons and preparation methods was "Lakota." The "Lakota" tree has an inclination to over-produce with age (Reid 2013b). The samples for this study originated from a tree over 30 years old. The kernel

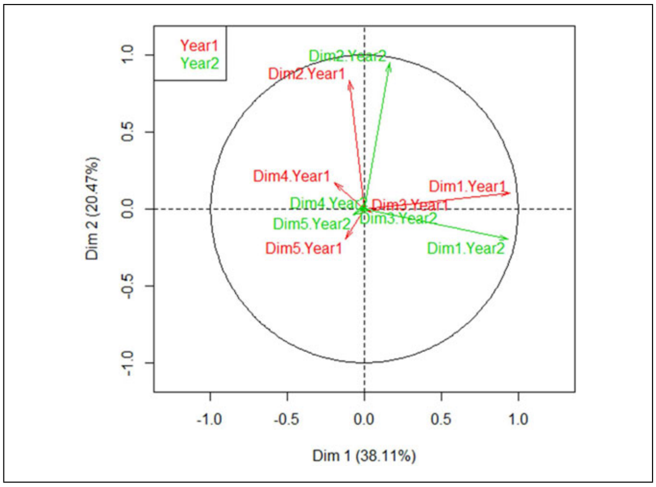

Figure 10–Multiple factor analysis partial axis plot.

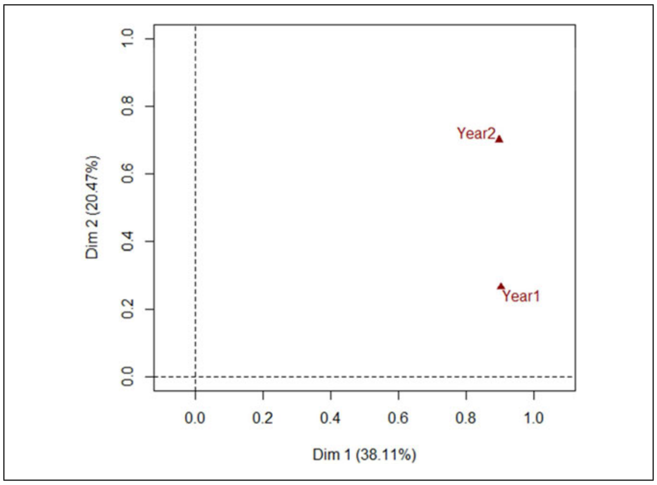

Figure 11–Multiple factor analysis groups representation plot.

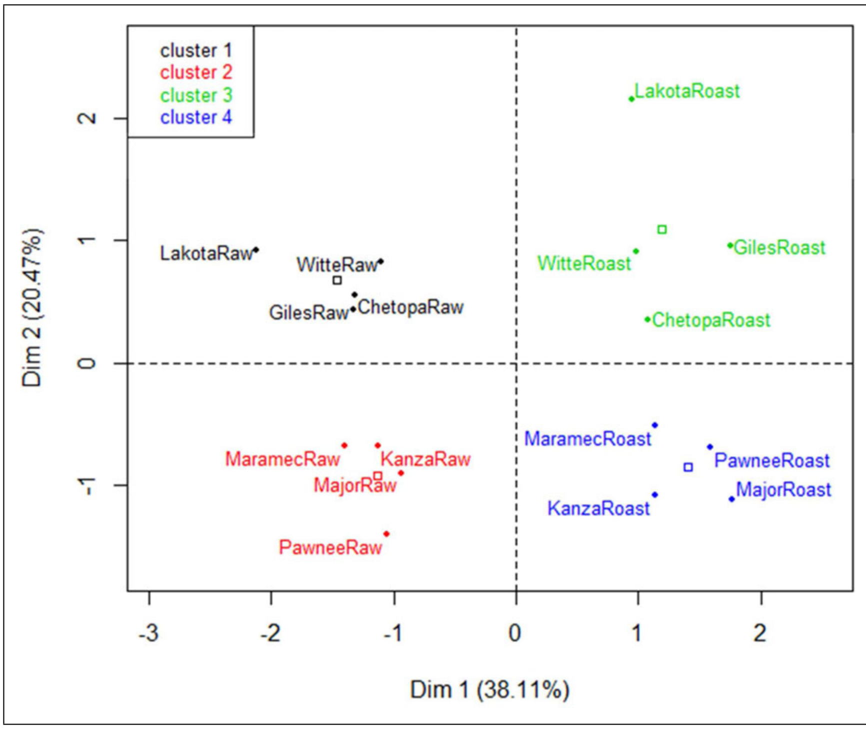

Figure 12–Multiple factor analysis factor map.

does not fill properly when large nut clusters are produced, which can have an effect on the quality of the kernel (Reid 2013b). This quality for the "Lakota" cultivar could have influenced the intensity of the flavor attributes and resulted in its rather unique profile.

Comparing cultivars

Because significant differences existed between both growing season and preparation method for many attributes within a cultivar, it is difficult to assess differences between the cultivars themselves. Since multiple factors are simultaneously significantly different within each cultivar, rather than using traditional ANOVA and principal component analysis (PCA) to analyze the data sets, MFA must be utilized.

MFA allows for comparison between cultivars, including both raw and roasted methods within each cultivar, by normalizing data sets from the 2 growing seasons and creating a compromise set. This analysis described the contribution of individual attributes to variation between cultivars as well as illustrated how these contributions differ between growing seasons. Dimension 1 and dimension 2 explained 38.11% and 20.47% of the variation between cultivars, respectively. The correlation circle plot (Figure 9) gave visual representation of individual attributes' contributions, or inertia, to each of the dimensions. Differences between samples in the first dimension were due to preparation method, raw compared with roasted, while differences in the second dimension were predominately related to association with astringency, bitterness, and musty/earthiness compared with oiliness, nutty-buttery intensity, and caramelized intensity. The partial axes plot (Figure 10) revealed that the factors of the separate analyses, 1 for each of the 2 separate growing seasons, were highly correlated to one another for the individual samples in terms of trends of attribute intensity differences between cultivars. The groups representation plot (Figure 11) further showed that the variation between cultivars for the 2 growing seasons was very similar in relation to dimension 1, and that the separation originated from differences related to dimension 2.

A factor map (Figure 12) pulled from MFA illustrated how the different samples related to one another, using normalized data sets from the 2 growing seasons; 4 distinct clusters were formed. Clusters 1 and 3 consisted of "Lakota," "Witte," "Giles," and "Chetopa" under raw and roasted preparation methods, respectively. "Maramec," "Kanza," "Major," and "Pawnee" comprised clusters 2 and 4, cluster 2 in raw form and cluster 4 in roasted form. Clusters 1 and 2, the raw samples, differed from clusters 3 and 4, their roasted counterparts, predominantly in dimension 1. This was expected, as dimension 1 explains variation in samples due to the presence of roasting. However, the correspondence of cultivars in clusters 1 and 2 with those in clusters 3 and 4 tell of the differences in the cultivars themselves and their transcendence across preparation methods. "Lakota," "Witte," "Giles," and "Chetopa" cultivars showed a higher correlation with astringent, bitter, and musty/earthy attributes and related attributes under both raw and roasted conditions. Conversely, "Maramec," "Kanza," "Major," and "Pawnee" cultivars were more correlated to characteristics relating to oily, nutty-buttery, and caramelized attributes. Interestingly, the cultivars had similar variation explained by dimension 2 across preparation methods as well; the cultivars' relationships to the other samples remained fairly consistent with the roasting process in relation to astringency, bitterness, and musty/earthiness compared with oiliness, nutty-buttery intensity, and caramelized intensity. However, 2 cultivars showed a large increase in variation

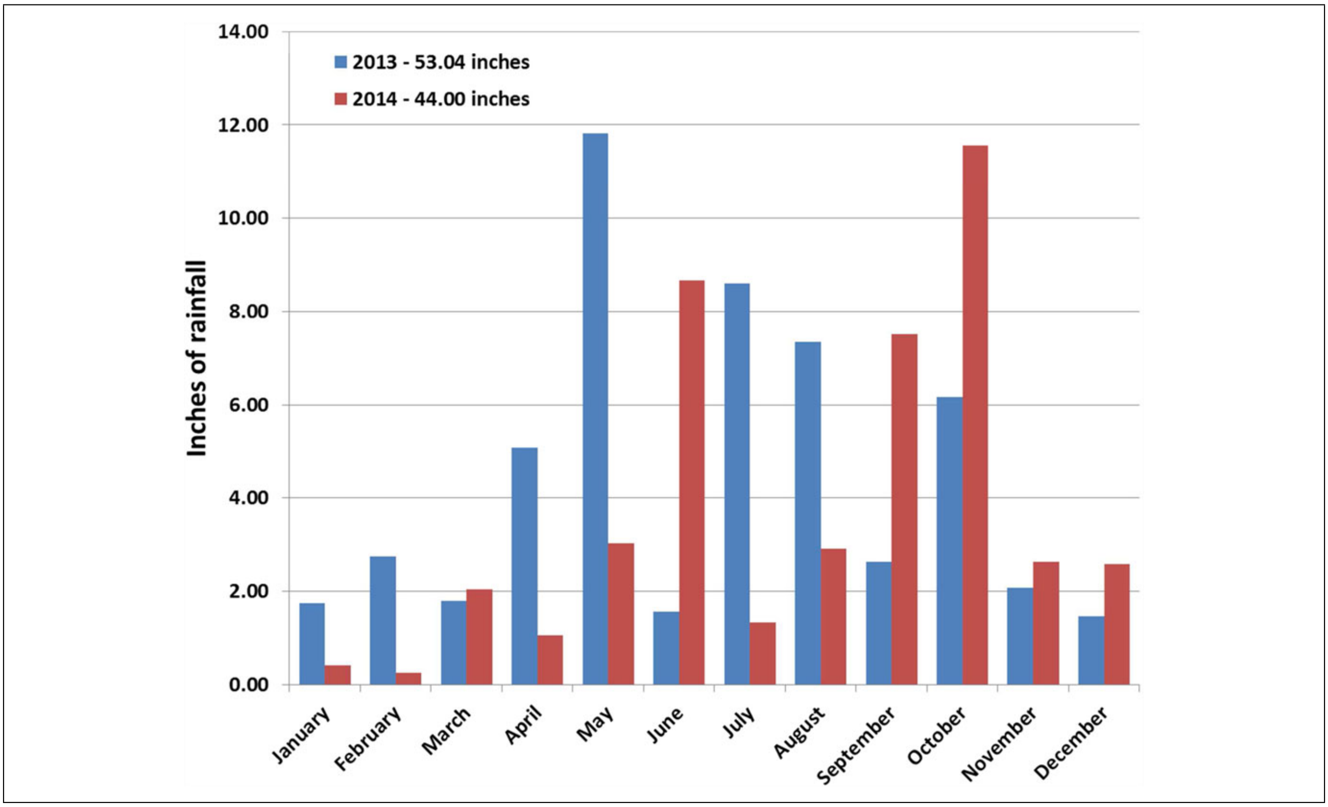

Figure 13–Monthly total rainfall at Kansas State University's Pecan Experimentation Fields in 2013 and 2014 (Chetopa, Kans.).

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Table 3–*P*-values of individual factors and factor interactions from ANOVA for flavor attributes.[a]

Flavor attribute	Sample	Year	Method	Sample*year	Sample*method
Pecan ID	**0.0036**[b]	**<0.0001**[b]	**<0.0001**[b]	**<0.0001**[b]	**<0.0001**[b]
Overall nutty	0.4061	0.2382	**<0.0001**[b]	0.4501	0.6565
Nutty-woody	0.8967	**<0.0001**[b]	**<0.0001**[b]	0.814	0.7549
Nutty-grainlike	0.1932	**<0.0001**[b]	**<0.0001**[b]	0.3861	0.6244
Nutty-buttery	**<0.0001**[b]	0.1281	**<0.0001**[b]	**0.0006**[b]	0.9923
Brown	0.5119	**<0.0001**[b]	**<0.0001**[b]	0.9075	0.9928
Caramelized	**<0.0001**[b]	**<0.0001**[b]	**<0.0001**[b]	**0.035**[b]	0.5334
Acrid	**0.0006**[b]	**<0.0001**[b]	0.2521	0.1639	0.3657
Burnt	0.4096	0.7933	**0.0386**[b]	0.4925	0.4481
Musty/earthy	0.5554	**<0.0001**[b]	**0.0055**[b]	0.7237	0.6871
Woody	**0.0006**[b]	**<0.0001**[b]	**<0.0001**[b]	0.9192	0.0895
Roasted	0.2908	**<0.0001**[b]	**<0.0001**[b]	0.657	0.4336
Overall sweet	0.1723	**<0.0001**[b]	**<0.0001**[b]	0.3506	0.3259
Oily	**<0.0001**[b]	**0.0172**[b]	**0.0026**[b]	**0.0008**[b]	0.9265
Rancid	0.3739	0.2244	0.9425	0.3739	0.0851
Oxidized	0.3344	**0.0307**[b]	0.1445	0.3705	0.5966
Astringent	**<0.0001**[b]	**0.0005**[b]	0.1524	0.7957	0.5446
Bitter	**0.0006**[b]	**0.0021**[b]	**0.0011**[b]	0.6114	0.5834
Sour	0.6885	**0.0023**[b]	0.4029	0.2587	0.4833
Sweet	0.2802	**<0.0001**[b]	**<0.0001**[b]	0.1167	0.8046

[a]Significance taken at $P \leq 0.05$.
[b]Significant factor or interaction for given attribute.

due to astringent, bitter, and musty/earthy characteristics with roasting, namely "Pawnee" and "Lakota."

Effects of roasting

Six attributes differed significantly ($P \leq 0.05$) between raw and roasted pecans for all 8 cultivars (Table 3). These were pecan ID, overall nutty, nutty-buttery, brown, caramelized, and roasted. For each cultivar, the roasted form was significantly higher in flavor intensity. In a similar study, sixteen flavor attributes were assessed for raw and roasted hazelnuts (aftertaste, bitter, burnt, coffee/chocolate-like, caramel-like, fruity, green/grassy, nutty, oily, painty, pungent, rancid, roasty, sour, sweet, and woody). There were no significant differences found for half of the attributes (Alasalvar and others 2003). In this study, however, only 3 attributes showed no significant differences between raw and roasted pecans: oily, astringent, and sour (Figure 1 to 8).

Including those attributes that were significantly higher for the roasted pecans, 10 of the attributes (pecan ID, overall nutty, nutty-woody, nutty-grainlike, nutty-buttery, brown, caramelized, roasted, overall sweet, and sweet) exhibited higher intensities for roasted pecans across the board (Figure 1 to 8). All but 5 of the attributes were affected by roasting from a statistical standpoint (Table 3). The attributes not affected by roasting were acrid, rancid, oxidized, astringent, and sour. One of the attributes, pecan ID, had a significant interaction ($P \leq 0.05$) between preparation method and cultivar, meaning that roasting did not affect all of the cultivars in the same way for pecan ID, albeit still significantly so across all cultivars (Table 3).

Nutty-woody, nutty-grainlike and nutty-buttery are subsets of the overall nutty attribute (Miller and others 2013). Although overall nutty and nutty-buttery attributes significantly increased in intensity with roasting, only 6 of the cultivars for nutty-woody and 3 for nutty-grainlike increased significantly (Figure 1 to 8). Between raw and roasted forms, only "Giles" cultivar showed a significant increase in burnt intensity, "Maramec" showed a significant decrease in musty/earthy intensity, and "Chetopa" showed a significant increase in bitter intensity ($P < 0.05$). Woody intensity was significantly increased for 3 cultivars and sweet intensity was significantly increased for 4 of the cultivars with roasting. Oiliness did not increase significantly for any of the cultivars, however roasting did have a significant affect as a whole on oiliness (Table 3). Roasting generally increased oiliness, with the exception of "Lakota" pecans which stayed at the same level of oiliness.

Trends in growing season

For 4 of the attributes, there were significant differences between the 2013 and 2014 growing seasons for all cultivars (Figure 1 to 8). Of these 4 attributes, 2 (nutty-grainlike and brown) were significantly higher in samples from 2013 and 2 (acrid and musty/earthy) were significantly higher in samples from 2014. Although 4 attributes were not significantly different between the 2 growing seasons as a whole (Table 3), only 1 attribute, burnt, did not show any significant differences between each season on the basis of individual cultivars.

A total of 4 attributes (nutty-woody, nutty-grainlike, brown, and roasted) were higher in samples from the 2013 growing season for all cultivars (Figure 1 to 8). Similarly, 4 attributes (acrid, musty/earthy, overall sweet, and sweet) were higher in all cultivars from the 2014 growing season. Overall nutty, nutty-buttery, burnt, and rancid intensity differences between the seasons were not significant collectively (Table 3). There was a significant interaction between cultivar and growing season for pecan ID, nutty-buttery, caramelized, and oily attributes. Although all of the cultivars were affected by growing season for these attributes, for 3 attributes significantly so, each cultivar was affected differently. For pecan ID, all of the samples from 2013 were higher with exception to "Pawnee," which exhibited a higher intensity in the 2014 growing season (Figure 1 to 8). "Chetopa" followed a similar trend for caramelized, being the only cultivar that did not have a higher caramelized intensity from the 2013 season. For nutty-buttery and oily attributes, there was no clear trend between the seasons.

For pecan ID, nutty-woody, woody, roasted, astringent, and bitter attributes, at least 1 cultivar displayed significantly higher intensities in the 2013 growing season while none from the 2014 season were significantly higher (Figure 1 to 8). Conversely, there were significantly higher attribute intensities in the 2014 season for overall sweet, oxidized, sour, and sweet for some of the cultivars, with none from the 2013 season being significantly higher.

Many of the differences between the 2 growing seasons may be related to the lack of summer heat in 2013. The shortage of heat can cause nut development to be delayed and the kernel filling process unable to be completed before the cooler temperatures of fall approach (Reid 2013a). "Giles" and "Maramec" specifically have later ripening times and may have been affected by this lack of heat (Reid 2013a). However, most of the variation between the 2 growing seasons can be attributed to the difference in timing and amount of rainfall between the 2 growing seasons. The most crucial time in pecan nutmeat development at Kansas State University's Pecan Experimentation Fields lies between July and September, following the facility's traditional growing schedule. During this time, the nut-size, nut-shape, and kernel filling are determined primarily on the amount of available water (Reid 2016). A lack of water can stunt the growth of the nutmeat and potentially be a contributor to flavor differences between growing seasons. Comparing rainfall between the 2 y, it is apparent that the 2014 pecan maturation season between July and September had much less total rainfall toward the beginning, but ended with a much higher amount of rain (Figure 13). Conversely, the 2013 maturation season began with a large amount of rain and ended with a much smaller amount. However, the soil in which the cultivars are grown at the Pecan Experimental Fields is primarily clay, which can retain water for up to 3 wk, effectively minimizing the problem of insufficient September rainfall (Reid 2016). Ultimately, the lower amount of rainfall in the crucial stages of the 2014 maturation period is likely the primary contributor to seasonal variation.

Conclusion

Roasting can greatly affect the flavor profile of pecans. Of the 20 attributes examined in this study, 10 showed an increase in intensity with roasting for all 8 of the cultivars, 6 increasing significantly. These attributes can be broadly categorized into nuttiness and sweetness. Although there were some differences in corresponding samples between growing seasons, most of these differences are not specific to certain cultivars and can be largely attributed to variation in environmental conditions. Similarities in flavor profiles for each of the cultivars exist, such as negligible rancid, oxidized, and burnt intensities, however sensory analysis has revealed that each of the cultivars has a unique profile. Some of these profiles are more unique than others, such as "Lakota's" higher affiliation with astringent, bitter, and woody characteristics and "Pawnee's" more oily nature. Future research will focus on chemical differences between the cultivars and the changes associated with preparation methods as well as consumer acceptance of each of the cultivars. This, in conjunction with flavor profiling, will allow for better marketing and increased application of pecans.

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Author Contributions

S. Magnuson and B. Kelly collectively conducted the studies, gathered data, interpreted results, and drafted the manuscript. K. Koppel and W. Reid acquired the samples, planned the study, and contributed to drafting and editing the manuscript.

References

Alasalvar C, Shahidi F, Cadwallader KR. 2003. Comparison of natural and roasted Turkish tombul hazelnut (*Corylus avellana* L.) volatiles and flavor by DHA/GC/MS and descriptive sensory analysis. J Agric Food Chem 51:5067–72.

Cherdchu P, Chambers E. 2014. Effect of carriers on descriptive sensory characteristics: a case study with soy sauce. J Sens Stud 29:272–84.

Erickson MC, Santerre CR, Malingre ME. 1994. Oxidative stability in raw and roasted pecans: chemical, physical and sensory measurements. J Food Sci 59:1234–8.

Grauke LJ, Thompson TE. Pecan breeding program: national collection of genetic resources for pecans and hickories. ARS-USDA. Available from: http://cgru.usda.gov/carya/. Accessed 2016 January 23.

Hunter EA. 1996. Experimental design. In: Naes T, Risvik E, editors. Multivariate analysis of data in sensory science. Amsterdam: Elsevier Science. p 37–70.

Lombardini L, Waliczek TM, Zajicek JM. 2008. Consumer knowledge of nutritional attributes of pecans and factors affecting purchasing behavior. HortTechnology 18: 481–8.

Malik NS, Perez JL, Lombardini L, Cornacchia R, Cisneros-Zevallos L, Braford J. 2009. Phenolic compounds and fatty acid composition of organic and conventional grown pecan kernels. J Sci Food Agric 89:2207–13.

Mertens-Talcott SU, Percival SS. 2005. Ellagic acid and quercetin interact synergistically with resveratrol in the induction of apoptosis and cause transient cell cycle arrest in human leukemia cells. Cancer Lett 218:141–51.

Miller AE, Chambers DH. 2013. Descriptive analysis of flavor characteristics for black walnut cultivars. J Food Sci 78:S887–93.

Miller AE, Chambers E, Jenkins A, Lee J, Chambers DH. 2013. Defining and characterizing the "nutty" attribute across food categories. Food Qual Pref 27:1–7.

NASS, United States Department of Agriculture. 2015. Noncitrus fruits and nuts: 2014 summary.

Nelson S, Lawrence K, Kandala C. 1992. Sensing moisture in peanut and pecan kernels by RF impedance measurements. JMPEE 27:171–4.

Rajaram S, Myint T, Connell B, Burke K, Sabaté J. 2000. Effect of pecan rich diet on serum lipids and lipoproteins in healthy men and women. FASEB J 14:A293–A293.

Rajaram S, Burke K, Connell B, Myint T, Sabaté J. 2001. A monounsaturated fatty acid–rich pecan-enriched diet favorably alters the serum lipid profile of healthy men and women. J Nutr 131:2275–9.

Reid W. 2011. Storage conditions for black walnut kernels. Personal Communication, August 2011.

Reid W. 2013a. Cultivars that ran out of time to fill kernel. 2 Dec 2013. Available from: www.northernpecans.blogspot.com. Accessed 2015 November 20.

Reid W. 2013b. What happens when Lakota over produces? 24 Dec 2013. Available from: www.northernpecans.blogspot.com. Accessed 2015 November 20.

Reid W. 2016. Northern pecans: observations on growing pecans in Kansas and across middle America. 16 January 2016. Available from: http://northernpecans.blogspot.com/. Accessed 2016 January 24.

Saklar S, Ungan S, Katnas S. 1999. Instrumental crispness and crunchiness of roasted hazelnuts and correlations with sensory assessment. J Food Sci 64:1015–9.

Suwonsichon S, Chambers E IV, Kongpensook V, Oupadissakoon C. 2012. Sensory lexicon for mango as affected by cultivars and stages of ripeness. J Sens Stud 27:148–60.

Tam NN, Nyska A, Maronpot RR, Kissling G, Lomnitski L, Suttie A, Bakshi S, Bergman M, Grossman S, Ho SM. 2006. Differential attenuation of oxidative/nitrosative injuries in early prostatic neoplastic lesions in TRAMP mice by dietary antioxidants. Prostate 66: 57–69.

Wood BW. 2001. Production unit trends and price characteristics within the United States pecan industry. HortTechnology 11:110–8.