Development of a model system to describe the flavor of grain varieties and a sensory lexicon to describe the flavor of sorghum

by

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Abstract

Sorghum (*Sorghum bicolor* [L.] Moench), is an ancient grain that possesses many health and economic values. Understanding the differences in the flavor profiles among cultivars is essential to increase the usage of the grain for food application purposes. The main objectives of this study were to 1) develop a model system to taste grain varieties and 2) develop a sensory lexicon to describe the flavor profile of sorghum grains. Fifty-seven sorghum cultivars including US commercially available samples as well as important breeding lines from around the world were included and investigated in the study.

After thorough investigations, this study developed a model which includes cooked grain and cookie applications to facilitate flavor characterization among different cultivars. The cooked grain and cookie recipes developed in this project are neutral and consistent. Therefore, they can serve as systems prototypes for identification of a grain's flavor profile and support descriptive analysis studies of flavor among grain cultivars. The developed model has been applied in sorghum and wheat to successfully characterize the flavor profile among different cultivars.

Moreover, a sensory lexicon with 28 descriptive terms was developed by the trained panel to describe the flavor of sorghum in grain form and in finished products. Some of the terms in the lexicon were starchy, beany, cardboard, oil-heated, brown-sweet, buttery, umami, overall green, musty dusty, woody, wheat like, sweet, salty, sour, bitter and metallic. Each attribute has a descriptive definition to describe the term and two to three descriptive references. The panel validated the effectiveness of the developed lexicon using a set of 20 sorghum cultivars, which were presented to the panelists in two forms: cookies and cooked grains. The descriptive analysis results were analyzed using PCA to produce sensory maps with key attributes associated with each sample. The generated maps for both cooked grain and cookies application showed clear

differentiation in flavors among sorghum cultivars indicating that the lexicon can be used to effectively characterize sorghum’s flavors in multiple applications. Such understanding will help to support researchers, food producers, food manufactures and contribute to promoting the use of sorghum grains in food applications.

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Chapter 1 - Literature Review

SORGHUM

Sorghum (*Sorghum bicolor* [L.] Moench) is an ancient grain; different sources have indicated different origins and domestication of sorghum. For instance, Vinall (1936) indicated that sorghum is indigenous to Egypt while Doggett (1970) indicates the West Africa origin for sorghum. Besides, the sorghum crops were said to be likely developed by the people of Caucasoid origin, specifically the Agau people who were the Cushites possessing the central and northern part of the Ethiopian plateau (Doggett, 1970). On the other hand, (Murdock, 1959) mentioned that sorghum may have been domesticated by the Mande people around the headwaters of the Niger River. Therefore, it is hard to determine the origins and domestication of sorghum. Sorghum is known by different names all around the world, such as *kafir* corn in South Africa, *mtama* on eastern Africa, *milo/guinea* corn in West Africa, *durra* in Sudan, *jowar* in India and kaoliang in China (Pummy Kumari, S.K. Pahuja, Satyawan Arya, & J.V. Patil, 2016). Nowadays, Sorghum is said to be the 5th most important cereal crop around the globe, coming after wheat, rice, maize and barley (Wall & Ross, 1970; Zhu, 2014). As a versatile crop that is grown as grain, forage or sweet crop, sorghum can be used in multiple applications such as in human foods, feed and fodder for livestock as well as fuel for bioethanol production. Moreover, sorghum is known for being heat, drought and insect resistant and thus, considered as one of the most efficient and environmentally friendly crops. Sorghum has been an essential crop in many parts of Africa and Asia; especially the arid and semi-arid parts where sorghum grain serves as a basic food (Wall & Ross, 1970). In the United States and other developed countries, sorghum is mostly known as a feed source for livestock or as a source for syrup production (Wall & Ross, 1970); however, sorghum has recently gained attention as a next important source of human food for its health benefits as well as natural environmentally friendly crops. Specifically, the grain is known to have multiple nutritional values such as containing abnormally high amounts of antioxidants compared to other grains. Moreover, sorghum grain is gluten free and non- GMO, which appeal to consumers seeking out healthier diets based on the current market trends. The grain is also known for its protein and starch resistant properties. Such capabilities have gained interests for the potential to prevent obesity, which remains as one of the most dangerous health problems that threaten people's lives in many developed countries.

Sorghum Category

There are four main categories of sorghum based on usage: grain sorghum, forage sorghum, biomass sorghum and sweet sorghum. Each group has different characteristics and usages. Grain sorghums have different shapes and sizes. The colors of grain sorghums range from white, tan to bronze, orange to burgundy and black representing varieties with different characteristics. For instances, the darker color sorghum varieties tend to be higher in phytochemical content than the lighter color varieties (Awika & Rooney, 2004). Grain sorghum is also characterized for having relatively large kernels that can be readily separated from the glumes compared to other groups of sorghum (Wall & Ross, 1970). Primarily, grain sorghum is grown for starch.

The second group of sorghum varieties is the forage sorghum, which can also be known as grass sorghum. Compared to the grain sorghum varieties, forage sorghums are taller, leafier and have less seeds/grains (Bean, Baumhardt, McCollum, & McCuistion, 2013). There are different utilizations of forage sorghums depending on specific varieties. Forage sorghums can be used for silage, green-chop, hay production and pasture; in the US, forage sorghums are most widely used for feedstock.

Figure 1-1 Sorghum Variety

From left to right, top to bottom: grain sorghum, forage sorghum, biomass sorghum and sweet sorghum.
Source: Sorghum Checkoff.

The next main group of sorghums are sweet sorghums – also known as sugar sorghums.. Its optimal growing region is in the tropical areas, but it can adapt to grow in areas of which winters are favored. Sweet sorghum is most grown for syrup production. Compared to grain sorghums, which are grown for the grains, sweet sorghum varieties are grown for the stalks, which are utilized for syrup production. Sweet sorghum syrup has a characteristic flavor, mild and is light in color (Freeman, 1973).

Another important group of sorghum is biomass sorghums. The main utilization for this group of sorghums is for energy production as suggested by the name. Ethanol production from lignocellulosic substrates is growing fast as the need for biofuel production in the US continue to increase (Rigdon, Jumpponen, Vadlani, & Maier, 2013). Approximately 33% of the

US sorghum crop is used for ethanol production purposes (Rooney, 2014). The biomass sorghum is bred from the sweet sorghum varieties to produce massive non-grain biomass; thus, it is the tallest among groups and can reach as tall as 20 feet in height.

Cultivation of sorghum grain

Sorghum has many agronomic characteristics that allow it to sustain multiple growing conditions. It is one of the rare crops that can survive in both wet and arid climates, as such sorghum enables production for food and feed purposes in the US and around the globe (Arkin, Vanderlip, & Ritchie, 1976). The optimal altitudes for cultivation of today's sorghum crops is in the belt between the sea level and 2700 meters (Doggett, 1970). Sorghum is known to be a warm season crop that has the ability to withstand heat much better than most crops; it has high resistance to desiccation thanks to the extensive fibrous root system, the effective transpiration rate and several xerophytic leaf characteristics that enable the plant to retard water lost (Wall & Ross, 1970). Besides, the plant is naturally drought, insect and disease resistant that can thrive even in growing conditions that have prolonged droughts. Thus, sorghum is primarily grown in arid and semi-arid regions where other crops are unable to grow (Pummy Kumari et al., 2016). Sorghum is suitable to grow in all soil; its fibrous root system helps to efficiently capture soil's nutrients and the optimal pH level for the growth of sorghum is between 6.5 and 7.5 (Rooney, 2014). Sorghum's characteristics to withstand drought are extremely important for the future of food insecurity in many places as the current climate continues to lead toward the scarcity of fresh water sources. Similar to other crops, timing is a critical factor in cultivation of sorghum to produce efficient crops. The timing can vary based on location, but ideally can be determined by soil temperature and moisture level. The optimal temperature of soil for growing sorghum is around 70^{o}F or 21 – 23^{o}C (Quinby, 1967; Wall & Ross, 1970). Early or late planting can be made as a solution for double cropping, prevention of chinch bugs and insect infestation; however, grains yield might be affected (Wall & Ross, 1970).

World's Sorghum Production, Consumption and Utilization

According to "USDA – Grain: World market and trade report of 2017", the World's total sorghum production for 2016/2017 is 63,207 metric tons while the total consumption is 63,383 metric tons. The United States is the largest producer and exporter of sorghum; in 2017/2018 the US produced 12,199 metric tons of sorghum. Most of the US exported sorghum is shipped to China for feed stock purposes. Other major producers of sorghum include Nigeria, Mexico, India, Sudan, China, Ethiopia and Argentina. In term of sorghum's consumption, China leads with 10,200 metric tons; other major countries that consume sorghums include Nigeria, Sudan, Mexico, India, Ethiopia, Argentina and the United States.

In the United States, sorghum is mainly grown in the Great Plains states. Traditionally, sorghum is grown in the Sorghum Belt between South Dakota and Southern Texas, though it is observed that acreages used for the growth of sorghum has been increasing in non-traditional areas like the Delta or Southeast regions (All about sorghum.). Also, according to the 2016 data from Sorghum Checkoff, the total number of acres for planting of sorghum is 6.7 million, which in turn produced 480 million bushels that were harvested. The main producers of sorghum by states are Kansas (3.1 million acres), Texas (1.9 million acres), Colorado (450,000 acres), Oklahoma (400,000 acres) and South Dakota (270,000 acres) (All about sorghum.)

Sorghum has been an important crop for many semi-arid and arid parts of Asia and Africa. Specifically, sorghum has been used in India for food and fodder (Ratnavathi CV, 2014; Wall & Ross, 1970) (Ratnavathi CV, 2014; Wall & Ross, 1970), and is also considered as a

Table 1-1 Word Sorghum Production, Consumption and Trade 2016-2017

Countries	Production	Consumption
Argentina	3,400	31,400
Australia	991	675
Brazil	1,865	1,700
Burkina	1,680	1,640
Cameroon	1,150	1,180
Chad	1,460	1,470
China	3,800	8,800
Ethiopia	3,600	3,750
India	4,570	4,500
Mali	1,394	1,394
Mexico	4,700	5,350
Niger	1,808	1,900
Nigeria	6,887	6,787
Sudan	5,864	760
Tanzania	800	5,814
Others	7,039	8,217
Subtotal	51,008	57,171
United States	12,199	6,212
World Total	63,207	63,383

Countries	TY Exports
Argentina	457
Australia	542
China	34
Ethiopia	15
India	24
Nigeria	100
Ukraine	164
Others	243
Subtotal	1579
United States	6090
World Total	7669

Countries	TY Imports
Chile	42
China	5,290
European Union	194
Japan	561
Kenya	130
Mexico	548
South Africa	100
South Sudan	50
Sudan	100
Others	463
Subtotal	7,397
Unaccounted	228
United States	44
World Total	7,669

October/September Year, Thousand Metric Tons.
*TY = Trade Year. (USDA, 2017)

vitally important crop for food security and a major source of protein in many parts of Africa (Belton & Taylor, 2004). There are differences in production and utilization of sorghum between developed and developing countries. In many developing countries (mainly in Asia and Africa), sorghum crops are most grown by the traditional farming methods without much of technology advancements; therefore, the yield is quite low. On the other hand, in the developed world such as in the United States, sorghum production is conducted on commercial basis with application of modern agricultural techniques, which produce much higher yields (Leder, 2004). The sorghum produced from traditional farms in developing countries is mostly used as food sources, while in developed countries such as the United States or many European countries, sorghum is mostly used for animal feed. Sorghum is used in food as porridges, cooked grains, popped grains as well as many traditional foods like bread, cakes and biscuits, especially in many African and Asian countries. In these areas, the sorghum grains are cooked in water as one part of grain boiled with two or three parts of water and are eaten instead of rice; this boiled sorghum grain is known as "Annam" or as "poor man's rice" (Doggett, 1970). Doggett also mentions other common ways for utilization of sorghum grains as food, such as "Rotti" which is a round, flat bread that can be made by forming dough between fine flour with hot water, carefully kneaded, flatten and baked on hot iron plate. Sorghum is also used by people in many savanna regions of Africa and Asia to make traditional alcoholic and non-alcoholic beverages like burukutu, tala, pito, sorghum wine, kaffir beer and kunu-zaki (asiedu, 1992; C. I. Owuama, 1997; C. Owuama, 1991). Dogget (1970) mentioned that the varieties used for brewing are usually the darker varieties since they can produce good bitter flavor that are essential in brewing. In addition to traditional brewing, sorghum is recognized for its potentials for larger beer brewing production since sorghum's malts have high diastatic power, amylases and starch content (C. I. Owuama, 1997). In the US, sorghum used to be used to make syrup, especially after World War I due to the shortage of sugarcane (Doggett, 1970). Unfortunately, the use of sorghum to make syrup is not as ubiquitous these days as it was in the past. Recently, there has been a lot of interest regarding potential usages of biomass sorghum for energy production. Especially, the use of biomass sorghum will not only help to prevent the potential shortage of fossil fuels but also potentially reduce US. dependence on foreign oil as well. There have been studies that explore the production of biomass sorghum in US southeastern states (Rocateli, Raper, Balkcom, Arriaga, & Bransby, 2012; Sharma et al., 2017).

Nutritional Characteristic and Chemical Compositions of Sorghum

As with other grains, the main composition of sorghum is starch, followed by proteins, non-starch polysaccharides and fat (Dicko, Gruppen, Traore, Voragen, & Berkel, 2006). Table 1-2 shows the proximate composition of sorghum grain. The proteins in sorghum are classified into four main groups: albumins, globulins, kafirins and cross-linked kafirins, and glutelins; the protein contents of whole grain sorghum were reported to be in the range of 7% to 15 % (FAO, 2005; (Dicko et al., 2006). Sorghum is rich in polyunsaturated fatty acids (Glew et al., 1997); the fat composition of sorghum is 49% linoleic acid, 31% oleic acid, 14% palmitic acid, 2.7% linolenic acid, 2.1% stearic acid and others (Dicko et al., 2006). Similar to other cereals, sorghum is a rich source of B vitamins such as thiamin, riboflavin, vitamin B6, biotin and niacin (Anglani, 1998), as well as the liposoluble vitamin A,D,E and K (Dicko et al., 2006). Sorghum is reported to contain various minerals including phosphorous, potassium, iron and zinc, while having low levels of calcium (Anglani, 1998; Dicko et al., 2006; Khalil, Sawaya, Safi, & Al-Mohammad, 1984).

The nutritional characteristics of grain sorghum that differentiates it from other grains and causes the current interest for utilizing in human food is the phytochemical composition. Sorghum possesses higher nutritional value in comparison to other cereal grains. Specifically, sorghum has been reported to be a rich source of numerous essential phytochemicals, such as tannins, anthocyanins, phenolic acids, phytosterols and policosanols (Awika & Rooney, 2004). These phytochemicals are considered to potentially provide positive impacts toward human health. The two major categories of phenols in sorghum are phenolic acids and flavonoids (Awika & Rooney, 2004). Tannins and anthocyanins are flavonoids that considered as the two most important components extracted from sorghum because of their potential health benefits. In particular, interest for tannin-containing sorghum is burgeoning, because tannins have been bred out of most other food crops.

Table 1-2 Proximate composition of sorghum grain.

Macro-components (g/ 100g f. m.)		Essential amino-acids		Vitamins (mg/100g d. m.)		Minerals (mg/ 100g d. m.)	
Carbohydrates	65 - 80	Leu	832 -	Vit.-A	21 RE**	Ca	21
Starch	60 - 75	Ile	215 -	Thiamin	0.35	Cl	57
Amylose	12 - 22	Met/Cys*	190 -	Riboflavin	0.14	Cu	1.8
Amylopectin	45 - 55	Lys	126 -	Niacin	2.8	I	0.029
Non starch	2 - 7	Phe/Tyr*	567 -	Pyridoxine	0.5	Fe	5.7
Low M_w carbohydrates	2 - 4	Thr	189 -	Biotin	0.007	Mg	140
Proteins	7 - 15	Trp	63 - 187	Pantothenat	1.0	P	368
α-Kafirins	4 - 8	Val	313 -	Vitamin C	<0.001	K	220
ß-Kafirins	0.2 - 0.5	Arg*	500 -			Na	19
γ-Kafirins	0.7 - 1.6	His*	200 -			Zn	2.5
Other proteins	2 - 5						
Fat	1.5 - 6						
Ash	1 - 4						
Moisture	8 - 12						

RE= retinol equivalent; f.m = fresh matter; d.m = dry matter; NSP = non starch polysaccharides**.**
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The chemical composition of sorghum can be varied based on different varieties. (Neucere & Sumrell, 1980) studied the chemical composition of five grain sorghum varieties and concluded that the fatty acid profiles for major acids such as palmitic, oleic and lenoleic did not vary considerably between the five sorghum varieties, while the minor components had more variation between the varieties. Moreover, the authors also mentioned that despite the fact that the five varieties were grown in similar conditions, they were considerably different in mineral uptake, amount of free sugar, as well as in the level of tannin content. The variation in extractable tannin content of sorghum has been used to classify sorghum. Awika & Rooney (2004) mentioned a broad method for classification of sorghum based on its appearance: white/tan sorghums with very low to no total extractable phenol levels and no tannins or anthocyanins detected; the red varieties have significant levels of extractable phenols in the red pericarp but do not contain tannins; black sorghums do not contain tannins but possess very high level of anthocyanins in the black pericarp;

last but not least, brown sorghums have pigmented testa and high level of tannins (Awika & Rooney, 2004).

Tannin in Sorghum

Tannins are a unique phytochemical constituent found in sorghum cultivars, since these compounds have been bred out of many other food crops. In sorghum, tannins are present within a pigmented testa, which lies beneath the pericarp. Sorghum tannins mostly belong to the "condensed" type, which is also known as proanthocyanidin. They are large polymers that are formed by oxidative polymerization of flavan-3-ols and/or flavan-3,4-diols (Awika & Rooney, 2004). Sorghum varieties that contain tannins have dominant B_1 and B_2 genes, which control the presence of the pigmented testa layer (Awika & Rooney, 2004; Han, D.H., Rooney, L.W., 1986). Based on testa genes and the spreader gene (S), sorghums are divided into 3 different groups. Sorghums that do not contain a pigmented testa belong to group I, group II's sorghums have a pigmented testa but lack of the spreader gene, while sorghums that have a pigmented testa and spreader gene belong to group III (Han, D.H., Rooney, L.W., 1986; Kaufman, 2005; Rooney, 2000; Salunkhe, 1990). More than 99% of sorghum produced in the US is tannin free while in other parts of the world, where more conventional farming techniques are applied and often have to deal with pets or disease problems, sorghums containing tannin are grown in large quantities since they are more tolerant to such conditions (Awika and Rooney, 2004).

Sorghum tannins are increasingly studied for their potential health benefits. Tannins have widely been known as antinutrients because of their ability to bind proteins, carbohydrates and other nutrients and thus preventing their digestibility and limiting the nutritional values of food or feed products (Kaufman, Herald, Bean, Wilson, & Tuinstra, 2013). However, there are positive sides to tannins being antinutrients even though they hinder the digestibility process. According to

(Awika & Rooney, 2004), sorghum containing tannin may potentially be utilized for prevention of obesity in humans since it has been widely reported for the abilities to hinder weight gain in animals. Additionally, tannins are an excellent source of antioxidants, containing up to 30 times more antioxidants than grapes (Awika & Rooney, 2004), and are 15-30 times more effective in radical scavenging ability than other simple phenolic compounds (Hagerman et al., 1998; Kaufman et al., 2013). Tannin functionalities and biological activities such as protein digestibility and antioxidant activity can be different based on content and composition. Therefore, depending on specific purpose and application, particular sorghum cultivars or traits can be selected.

Sorghum's potential use as a food source in the United States

Even though they are the number one producer of sorghum, unfortunately, sorghum is still uncommon to the US general population as a human food source. Specifically, a huge portion of U.S. consumers do not know sorghum can be used for human consumption or have never heard of sorghum; sorghum is most likely associated with feed stocks or something related to molasses as in the southern United States (Medeiros, Vázquez Araújo, & Chambers, 2011). Sorghum as a food source has huge potential for commercial utilization for many reasons, including promoting human heath, being environmental friendly and being grown locally in the US. Sorghum flour can be a healthier replacement or substitution for wheat and maize in multiple traditional and widely appealing food products. Sorghum can be used alone or in-blend with maize for tortilla production (Bedolla, et al., 1983). Moreover, sorghum can also be used as main ingredients in making of gluten free bread, cookies, couscous and porridges (Anglani, 1998; Carson, Setser, & Sun, 2000).

Especially, sorghum fits in the current healthy diet trend as being gluten free, non-GMO, containing high antioxidant levels and having starch resistant properties; still the grain is being ignored as a food source by large manufactures (Medeiros et al., 2011). In addition, according to Lee et al., a gluten free diet can cause economic burden because the gluten-free products are often more expensive and has poorer availability than the gluten-containing counterparts (Lee, Ng, Zivin, & Green, 2007). Utilization of sorghum as a food source can be a solution for such problem. In specific, sorghum is seen as a potential for the gluten free market segment to substitute for rice, corn and other gluten-free flours as it is cheaper than corn and even wheat flour (McCann, Krause, & Sanguansri, 2015).

Regardless of multiple benefits in the use of sorghum grain as a food source in the United States, lack of consumer interest remains to be the main reasons for ignorance of sorghum grains utilization as human food. As such, education and promotion campaigns are necessary to enhance consumer understanding and awareness about sorghum. Characteristics that can be used to engage consumer interests in sorghum grain include grains grown from the US, which create the local connection, as well as having health benefits such as high anti-oxidants (Vázquez-Araújo, Chambers, & Cherdchu, 2012). The above researchers also suggest based on results from focus group studies to provide the information on food packaging since it is the main source for communication with consumers about the food product.

SENSORY ANALYSIS AND ITS ROLE IN TESTING BETWEEN MULTIPLE CULTIVARS

Sensory analysis is a science that measure, evoke, analyze and interpret human perceptions and responses to products as perceived through the five senses: sight, smell, touch, taste and hearing. Sensory characteristic has been proven to be one of the pivotal factors for determinations of product success. As the food market is increasing rapidly, thousands of new food products are introduced to a certain market every year whether through innovation, emulation of products from other cultures or through selective breeding process. Unfortunately, new product success rates remains very low and one of the main reasons behind product failure is misalignment with consumer perceptions and expectations. Little et al., (2015) reported that the product failure rate is between 72% to 88%, and based on certain markets that such rates can be even higher. Product can not be successful in the market without acceptable sensory properties that meet consumer's liking. Specifically, sensory was determined to be the most important aspect from a recent conjoint analysis that evaluated level of importance between three categories -- health, production and sensory -- toward consumer perception of potential sorghum based products (Vázquez-Araújo et al., 2012). Moreover, results from a study about pecan conducted by Gold et al (2004) showed that taste and quality are the most important factors that affect consumer purchase intention. Those factors are even more important than price when it comes to decision making factors for purchasing of products. Human perception of food results from complex sensory and interpretation processes that instruments cannot measure. Chambers and Koppel (2013) indicate that the association between sensory analysis and instrumental measurement are difficult to interpret or weak in nature due to the complex characters of flavors. Specifically, combinations of volatiles yield different flavors than those expected from individual compounds that are responsible for a specific sensation (E. Chambers IV & Koppel, 2013). As a result, characterizing sensory data through human perception provides the best model to predict how consumers will perceive and react to food products in real life (Lawless, 2010).

Sensory testing is an essential part of product innovation, development, optimization and improvement. Also, sensory testing is often applied to ensure product quality as a form of shelf-life testing in many cases. Moreover, as the world is emerging and becoming more open, newer generations are more interested in and willing to try new food products whether they are innovative products or products of other cultures. Thus, there is a need for importing and exporting of food products and ingredients from one culture or country to another. At the same time, it is necessary to determine and select product's traits that match consumer's likings of target markets. Different cultivars of food products can vary in their sensory profiles and have different characteristics or behaviors. For example, fruits of different cultivars can have different flavor and aroma characteristics. They are also different from each other in physical characteristics as well as in mature stages, ripeness and may behave differently to the same storage conditions or cultivation approach. Therefore, sensory testing is often utilized to characterize perceptions of product between different cultivars.

Cultivars are defined as plants that are selected based on desirable characteristics that can be maintained by propagation (Bhattacharya, 2016). Selection of such characteristics can help to support selective breeding efforts, product development, as well as product's storage, transportation and cultivation efforts. There are many studies that have been done to explore sensory perception of products between different cultivars, especially fruits and vegetable. For example, Suwonsichon, et al. (2012) explored differences in flavor and texture characteristics among mango cultivars and determined how those characteristics changed during ripening of the products. Such information could be used to help mango producers and exporters in selecting desirable traits for targeting market as well as ensuring the quality of products during transportation (Suwonsichon, Chambers, Kongpensook, & Oupadissakoon, 2012). Other studies have been done to investigate the relationship between different cultivars of fruit products and sensory quality, including studies on differences among Spanish and Latin-American banana cultivars (Cano et al., 1997), pineapple fruit of Red Spanish and Smooth Cayenne cultivars (Bartolomé, Rupérez, & Fúster, 1995), aroma components between nectarine cultivars (Engel et al., 1988a), apples (Aprea et al., 2012), breadfruit (Ragone & Cavaletto, 2006), and blueberry (Saftner, Polashock, Ehlenfeldt, & Vinyard, 2008a). Besides, there are also extensive studies that have been done to uncover how different cultivars impact the sensory quality of vegetable products such as flavor and texture profiles of fresh and processed tomatoes (Hongsoongnern & Chambers, 2008), dry beans (Koehler, Chang, Scheier, & Burke, 1987a) and potatoes (Thybo, Christiansen, Kaack, & Petersen, 2006). Moreover, vegetables are an essential part of human diets and transportation or storage condition are often critical to maintain the freshness and quality of vegetable. Therefore, researchers are also interested in how storage conditions and transportation may affect differently on vegetables of different cultivars. Some studies that have been done to investigate such effects, including studies about sweet potatoes (van Oirschot, Quirien E A, Rees, & Aked, 2003), melon (Hoberg, Ulrich, Schulz, Tuvia-Alkali, & Fallik, 2003) and butter-but squash (Hurst, Corrigan, Hannan, & Lill, 1995).

Compared to fruits and vegetables, studies that explore the differences in products cultivars and sensory characteristic of grains remain very limited even though grains are a major and essential part of the human diet. There are some studies that have been conducted on how different cultivars may affect sensory perceptions of rice and wheat cultivars, but besides that there have not been much work done on the topic. In specific, there has been very little to no studies investigating the relationship between different cultivars and sensory characteristic of other grains such as quinoa, barley, lentil, rye or sorghum. Those studies that were conducted remain limited in many ways. The lack of sufficient sensory studies, especially on descriptive analysis of grain's characteristic, can be explained by the lack of sufficient sensory lexicons to facilitate the evaluation and characterization of products. Without essential sensory studies, it is hard for food manufactures and processors to understand characteristics of products as well as measuring consumer perceptions to determine potential utilization of products. As a result, large food manufactures can overlook and ignore the use of certain food products regardless of the huge potentials associated with applications of the products. Specifically, sorghum is largely ignored by many food manufactures (Medeiros et al., 2011) and thus, applications of sorghum grains remain very limited in the current market; such factors also greatly contribute to the lack of consumer knowledge of sorghum as a food source, especially in many developed countries.

Sensory works that have been done in sorghum

There are some works that have been done to explore potential use of sorghum in finished food products. Specifically, researchers conducted studies to understand the potential substitutions and sensory characteristic of food products made from sorghum. For example, many studies explored the possibilities of replacing sorghum flour for wheat flour in baked goods. Unfortunately, sorghum flour does not have the ideal characteristics for making bread due to the lack of the gluten network to create elastic dough. As such, in terms of appearances and texture, sorghum bread tends to be smaller, drier and have darker color than regular wheat bread (Anglani, 1998). Moreover, the phenolic compounds in sorghum, either alone or combined with other components, affect the sensory characteristic of finished products by imparting astringency, bitter and sour tastes (Brannan, Setser, Kemp, Seib, & Roozeboom, 2001; Maga, J.A & Lorenz, K., 1973). As mentioned, sorghum flour has huge potential for gluten free baked goods market; however; regarding the textural limitation, sorghum can't be used alone to make acceptable breads. It has been reported that bread made with up to 30% of sorghum flour replacement of wheat flour has good to excellent acceptability ratings (Perten, 1983). Rose and others (2014) studied the characteristic of fried bread made from different sorghum varieties and interesting results were found. The above authors indicated that red color - tannin containing sorghum may decrease oil uptake and there is no significant difference detected by panelists between fried breads made from up to 50% white, tannin-free sorghum flour substitution and regular refined wheat flour fried breads (Rose, Williams, Mkandawire, Weller, & Jackson, 2014). Results from studies of sorghum flours tortilla showed that sorghum can be used to produce acceptable tortillas and the best replacement level for maize by sorghum flour is 25 % (Winger, Khouryieh, Aramouni, & Herald, 2014). However, most of these studies are similar with each other in the fact that they hardly explore differences in the flavor profiles of sorghum between different cultivars even though differences clearly exist. There are very few studies that have been done to investigate the sensory differences between different cultivars of sorghum. Brannan et al. (2001) have previously studied the sensory profile of sorghums between different cultivars and developed a sensory lexicon to differentiate the flavors between the samples. However, the selected samples for testing contained only commercial feed grains and commercial seeds that were locally grown in Kansas and Texas. In addition, the developed lexicon only contains 3 aroma attributes and 8 flavor attributes while supposedly there are many more flavor terms that associate with the flavors of sorghum grains and finished sorghum products.

RESEARCH OBJECTIVES.

Sorghum grain has multiple potentials for application as food sources. Unfortunately, the grain has not been widely utilized as food in many developed countries including the United States. Many large food manufactures still ignore the use of sorghum grains and, as such, consumer knowledge and awareness about sorghum remain very low. Essential research is necessary for understanding and enhancing the use of sorghum grain. There are multiple studies that have been done to explore nutritional factors as well as characteristics of sorghum grains or sorghum flours but have been predominantly focus on the health aspects. Sensory studies on application of sorghum focus mostly on potential substitution of sorghum flours with regular wheat flour or acceptance of sorghum finished products in general; however, there are huge variations in characteristics and flavors between sorghum of different cultivars. Therefore, this research focuses on identifying the sensory profiles of sorghum cultivars.

The main goal of this study is to determine which sensory attributes are present in sorghum cultivars and their correlative intensities. There are two mains objectives that help to achieve such goal: 1) Developing a model system to successfully describe the flavor of grains between different cultivars as both in grain form and in finish products, and 2) developing a sensory lexicon to describe the flavor of sorghum grains and validating of the lexicon. Sensory understandings of sorghum between different cultivars will help researchers with specific application purposes, encourage food manufactures to utilize sorghum grains as well as allow breeders and those that cultivate sorghum to pick the cultivars with particular traits for selective breeding purposes. Specifically, the results will help to determine the cultivars with favorable sensory profiles that potentially will be more successful in the market as well as be suitable for specific application.

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Chapter 2 - Developing a Model System to Taste Grain Varieties

ABSTRACT

This research investigated suitable approaches and effective applications for evaluation of grain flavors and the differences among cultivars. Therefore, a model system that helps to facilitate characterization of flavors in grain varieties was developed using sorghum grain as a tool. Five different applications were initially used including cooked grain, porridge, cookies, muffins and extruded puffed snacks. Six highly trained panelists from the Center for Sensory and Consumer Behavior participated in the project. The effectiveness of each application was determined based on results of the attribute generation process as well as from panelist feedback. The results indicate that the combination of a cooked whole grain procedure and the use of flour made into cookies provides an effective and potent model for flavor characterization in both their grain form and as finished products. Both the recipes for the cooked grain and cookie applications effectively brought out the flavor characteristics of the grains as well as differentiated the flavor differences between grain cultivars. The developed model can be applied for flavor evaluation of multiple grain types and can help researchers understand the flavor differences among grain cultivars. As a result, such knowledge will help to facilitate selection of suitable products with favorable characteristics for specific applications as well as for selective breeding purposes.

BACKGROUND

Grain is an important part of the human diet. According to the current report from the USDA, the total world consumption of wheat, rice/millet and corn is 742.9 MMT (million metric ton), 475.5 MMT, and 1063.2.9 MMT, respectively (USDA, 2018). Intake of whole grains has recently gained considerable attention due to their potential health benefits. For instance, the phytochemicals and antioxidants in whole grains have positive impacts on human health.

According to (Liu, 2007), whole grains are rich sources of phytochemicals, vitamins, minerals, inulin, resistant starch, and beta-glucans, a class of soluble fibers that the FDA has approved to lower blood cholesterol levels. Many studies also have reported an association between intake of whole grains and reduction of risk for cardiovascular disease, cancer, respiratory diseases, infectious diseases, diabetes, as well as non-cancer and non-cardiovascular diseases (Aune et al., 2016; Lang & Jebb, 2003; Okarter & Liu, 2010).

Each type of grain has a gene pool with a large amount of genetic variability. The huge genetic variability is responsible for numerous varieties that are vital for specific applications or cultivation purposes. Bhattacharya (2016) defines cultivars as plants that are selected based on desirable characteristics that can be maintained for propagation purposes. The variability in genetic, nutritional, physical characteristics and growing conditions can yield differences in flavor profiles of grains among cultivars. Understanding the flavor profiles of grain variety can help scientists, researchers, and industry professionals to select and develop favorable food solutions. Such understanding also enables selective breeding efforts and supports product development, storage, and cultivation purposes. There have been various studies conducted to investigate flavor differences among products of different cultivars, as well as how storage conditions and importation might have different impacts on sensory characteristics among cultivars. In particular, multiple studies investigated flavor differences of fruit cultivars, such as apples (Mehinagic et al., 2003), nectarines (Engel et al., 1988b), blueberries (Saftner, Polashock, Ehlenfeldt, & Vinyard, 2008b), and cherries (Díaz-Mula et al., 2009). Moreover, other studies were conducted on the topic of multiple types of vegetables, including tomatoes (Pagliarini, Monteleone, & Ratti, 2001), *Perilla frutescens* (Laureati, Buratti, Bassoli, Borgonovo, & Pagliarini, 2010), carrots, (Alasalvar, Grigor, Zhang, Quantick, & Shahidi, 2001), capsicum (Chitwood, Pangborn, & Jennings, 1983), and pumpkins (Marek, Jadwiga, Honorata, Elvyra, & Judita, 2008). In addition, Koehler and others also looked at a total of 36 cultivars representing dry beans and determined the cultivar effects on nutrient composition, protein quality, and especially on sensory properties (Koehler, Chang, Scheier, & Burke, 1987b).

Unlike the extensive work that has been conducted on fruits and vegetables to identify the effects of cultivars on sensory properties of products, studies of this sort on grain varieties remain limited. Some studies have been conducted to investigate the sensory aspects of rice and wheat varieties; however, there has not been many studies conducted for most other grains and cereals, such as barley, quinoa, buckwheat, millet, sorghum, or rye, where differences in flavor among cultivars clearly exists. The number of studies conducted for those grain types is very rare and if conducted, these studies are limited either in application methods or in selection of samples. For example, Kobue-Lekalake and others studied the effects of the phenolic compounds in sorghum grains on its bitterness, astringency and other sensory properties, but they only looked at the cooked grain applications for six African grown sorghum cultivars (Kobue-Lekalake, Taylor, & de Kock, 2007). Studies on genetically diverse varieties are needed in order to capture the full spectrum of flavor profiles within a grain crop Therefore, the aim of this study is to develop a model system to characterize the flavor profile of grain varieties in order to support differentiation among different cultivars in both grain form and in finished products. The study was conducted using sorghum grain as a model. Sorghum was chosen because there are enough differences and variations among the commercially available sorghum samples that allow sorghum to effectively serve as a model for the scope of this project.

MATERIALS AND METHOD

Grains were evaluated in both their whole grain and milled forms. Different cooking methods and procedures were applied to determine their effectiveness in evaluating the flavors. After a careful selection and consideration process, the five cooking methods that were chosen for the study included cooked grains, porridge, cookies, muffins, and extruded puff snacks. Adjustments to the cooking process, recipe, and serving of samples were made by the panelists during the process.

Investigation of cooking methods

The cooking methods were determined based on available literature on common applications and cooking methods of grains as well as whether or not the applications were initially applied for flavor characterization of grains. The cooked grain method was chosen because cooked grain is a common application for many grains; in addition, many studies that investigated flavor differences among different cultivars of rice utilized this procedure (Champagne, Bett-Garber, Mcclung, & Bergman, 2004; Lyon, Champagne, Vinyard, & Windham, 2000). Kobue-Lekalake, Taylor, and de Kock (2007) also characterized flavor differences among sorghum grains based on the cooked grains method. Porridge is another popular application of grains and thus was chosen as an application for investigation of this study. Specifically, cooked porridges were applied for tolerance testing made from sorghum-based fortified blended food to ensure sensory qualities of the products under multiples modifications of cooking procedure (Chanadang, Chambers, & Alavi, 2016). Furthermore, results from literature investigations suggest that cookies and muffins can serve as effective models to characterize the flavors of grains. Many studies on sensory properties among wheat varieties use cookie application to investigate difference (Mcwatters, Ouedraogo, Resurreccion, Hung, & Phillips, 2003; Mohsen, Fadel, Bekhit, Edris, & Ahmed, 2009). In addition, muffins were also used as tools to study nutritional composition, texture, appearances and sensory acceptance among barley cultivars (Newman, McGuire, & Newman, 1990). Finally, an extrusion application was chosen for the study in the form of puffed snacks to represent extruded snack applications of grain varieties.

Samples

Nine commercially available sorghum samples were chosen for the study. All samples are available for food application purposes in the US market. The samples were provided by Nu Life Market (Scott City, Kansas) and Archer Daniels Midland (Chicago, IL). Eight samples were provided by Nu-Life Market and one sample was provided by ADM in whole grain and milled flour forms. Of the eight varieties from Nu-Life, there were 4 tan varieties, 3 burgundy and one black. These samples are different from each other not only in color but they also have different functionalities and genetic makeups. For instance, these varieties were classified by their tannin content, as waxy or non-waxy, and by functionality such as specified for baking, specified for extrusion and specified for popping. The specifications and information regarding the

Table 2-1 Commercial available sorghum samples..

<table>
<tr><th>Company</th><th>Color</th><th>Specification</th></tr>
<tr><td rowspan="11">Nu-Life</td><td rowspan="4">Tan</td><td>Specified for Baking</td></tr>
<tr><td>Specified for Extrusion</td></tr>
<tr><td>Specified for popping of grain</td></tr>
<tr><td>Waxy</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td rowspan="3">Burgundy</td><td>Tannin-free</td></tr>
<tr><td>Tannin-containing</td></tr>
<tr><td>Waxy</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Black</td><td></td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>ADM</td><td>Tan</td><td>Whole grain</td></tr>
</table>

samples were provided by each company. The sample from ADM is tan in color and has no information regarding specific applications of the variety. Samples were stored at room temperature until utilized. Specific information regarding the sample's color and applications is provided in Table 2-1.

Samples preparations and serving

To prepare the cooked grain samples, sorghum grains were cooked in deionized water using the ratio of 1 cup of grains to 3 cups of deionized water. The detailed procedure includes measuring the appropriate quantity of grains, rinsing of sorghum grains, bringing the approximate amount of grains and water to boil, turning the heat down to medium-low and cooking for approximately 45 minutes (Table 2-2). Samples were occasionally stirred and additional water was added as necessary. Any excess water was strained and samples were served to the panelists while still warm in 120 ml Styrofoam cups covered with lids and labeled with 3-digits codes.

To prepare the porridge samples, the ratio of 1 part of flour to 9 parts of deionized water was used. The flours were measured in a large bowl and were mixed with 4 parts of water to dissolve. The purpose of this step was to prevent samples from clumping during cooking and to maintain texture consistency among samples. Then, the previously mixed blend was put into a cooking pot and mixed with the remaining amount of water (5 parts). The sample was brought to boil before simmering on low heat for 8 minutes while continuously stirring with a wooden spoon. Samples were served to each panelist approximately 10 minutes after cooking, while still warm, in a 120 ml Styrofoam cup covered with a lid and labeled with 3-digits codes.

The cookie samples were prepared according to the recipe and procedure listed in Table 2-3. The cookie recipe was developed particularly for this project. Initially, the AACC's regular cookie recipe (Baking Quality Cookie Flour-Micro Wire-cut Formulation, AACC International

Table 2-2 Preparation of cooked grain samples.

Ingredients	Amount (g)	Procedure
Grain	1 cups	1. Measure the amount of grains. 2. Wash grain. 3. Drain and put in the pot. 4. Measure the amount of water, add in and bring the pot to boil. 5. Lower the heat and let simmer for 45-50 minutes. 6. Drains the excess water and serve.
Water	3 cups	

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Method 10-54.01) was used. However, according to the panelist feedbacks it was hard to characterize the flavor profile of samples because the samples were quite sweet and the leavening attribute's intensity was too strong, overwhelming the grain's characteristic flavor notes. Therefore, the recipe was modified until a consensus was reached among the panelists that the cookie samples could successfully bring out the different flavor characteristics of sorghum grains in a baked grain product. After the cookie samples were baked, they were allowed to cool for around 1 hour, then were vacuum sealed in bags (Food Savers, Newell Brands, NJ) and kept at room temperature until serving. The samples were opened 1 hour before serving and were presented in 3.25 oz. cups with lids and labeled with 3-digits binding codes. Each panelist received 1 cookie and additional samples were served to panelists as requested.

For the muffin samples, a standard muffin recipe and procedure were used (Table 2-4). All samples were prepared approximately 1.5 hours before serving. After baking, the samples were allowed to cool for about 30 minutes, cut into quarters, and were served in 3.25 oz. plastic cups with lids, coded with 3-digit codes. Each panelist received one muffin and additional samples were served upon request.

Table 2-3 Cookie's recipe and procedure.

<table>
<tr><th>Ingredients</th><th>Amount per 100 g flour</th><th>Procedure</th></tr>
<tr><td>C&H Granulated White Sugar</td><td>10</td><td rowspan="9">1. Measure shortening and corn syrup into a mixer bowl.
2. Measure all dry ingredients in a separate bowl, mix all the dry ingredients together until incorporated.
3. Place the mixing bowl into the mixer, turn on speed 2 and let mix for around 2 minutes.
4. Slowly add the dry ingredients mix to the mixing bowl while mixing (small portion at a time) and scrape down in between.
5. Turn to speed four and mix for 2-3 minutes until nice crumbs are formed.
6. The amount of water can be varied based on grain variety. Start with a lower amount and add more as needed. Slowly add water to the mixture (this step need to be monitored carefully, add water enough to form the dough but do not go over or the dough will get too wet and hard to work with)
7. Slower the speed to two and let mix for 2 minutes.
8. Take out a nice size of dough at the time and form into a ball.
9. Neat the dough a little more and roll out the thickness of 0.4-0.5 cm.
10. Cut into 2 inches diameter cookies and bake at 400 F for 11 minutes.</td></tr>
<tr><td>Carnation Instant Nonfat Dry Milk</td><td>1</td></tr>
<tr><td>Morton Salt</td><td>1.25</td></tr>
<tr><td>Arm&Harmer Baking Soda</td><td>0.5</td></tr>
<tr><td>Crisco All-purpose shortening</td><td>40</td></tr>
<tr><td>Caro Light Corn Syrup</td><td>1.5</td></tr>
<tr><td>Deionized water</td><td>Vary (20 ml – 40 ml)</td></tr>
<tr><td>Sorghum Flour</td><td>98.75</td></tr>
<tr><td>Total</td><td>176.5</td></tr>
</table>

For the extruded puffs samples, sorghum flours (moisture contents range from 8% - 10%) were pre-mixed in a Hobart planetary mixer with water to reach a moisture content of 15% - 16%. The pre-moistened flours were transferred into sealed plastic bags (Ziploc, S.C.Johnson & Son, WI) and were left to hydrate overnight in a refrigerator. The sorghum puffs samples were extruded using a lab scale co-rotating twin screw extruder (American Leistritz, Somerville, NJ) with a circular die of 3.2 mm diameter. The screw speed was kept constant at 400 rpm and the extruded products were cut into approximately 20 -25 cm strands using a stainless steel kitchen knife. The products dried in the oven at 60^{o}C for approximately 2 hours. After the drying step, products were stored in

Table 2-4 Muffin's recipe and baking procedure

Muffin Recipe	Amount (g) for approx. 6 muffins	Procedure
Sorghum Flour	112 (1cup)	1. Preheat the oven to 370^{o}F
C&H granulated white sugar	12	2. Grease two 6-cup muffin pans or line with paper cups.
Clabber Girl Baking Powder	5.4	3. In a medium-large bowl, stir together the flour, sugar, baking powder and salt. In a separate bowl, mix oil, egg beater and milk
Morton Salt	3	4. Make a well in the dry ingredients. Immediately add the mixed liquid ingredients, stir with a rubber spatula until well blended, do not over mix.
Egg Beaters Original	24	5. Spoon the batter into the prepared cups, filling around half full of the muffin tins.
Dillon's Milk 2%	125	6. Bake until the tops of the muffins spring back when lightly pressed, about 20-25 minutes. Cool in the pans for at least 10 minutes before removing
Oil	21	7. Cut the muffin in half and serve in a 3.25 oz. cup.

Ziploc bags at room temperature. All extruded samples were served within one week after being processed. Samples were served to panelists in 3.25 oz. cup labeled with 3-digit binding codes.

Panelists

Six highly trained panelists from the Center for Sensory and Consumer Behavior, Kansas State University (Manhattan, Kansas) participated in the study. All of the panelists completed 120 hours of panel training for descriptive analysis on a variety of food and non-food products. Specifically, the panelists received training and practice in attribute identification, terminology development, and intensity scoring. Moreover, the panelists have extensive experience on descriptive analysis with more than 1,000 hours of testing and evaluation of a variety of food products and received orientation specific for this project.

Evaluation procedure

Ten 1.5-hour sessions were held for term generation and assessment of all samples prepared from the 5 cooking applications used to develop the model system. Panelists were served 4-5 samples per session and were asked to come up with terms to describe the flavors associated with each product. The panelists also were asked to provide feedback and suggestions regarding the served samples on their effectiveness for flavor characterizations. Then, modifications to sample preparation were made to reflect panelist feedback. For instance, panelists discussed attributes that they thought were related to processing instead of cultivar variations. Besides, the panel also indicated if there were any inconsistencies among samples that might be a result of preparation efforts that need to be addressed. Therefore, modifications of sample preparation such as cooking procedures or recipes were made based on panelist feedback to enhance the effectiveness of the evaluation process. This process continued until consensus was reached among panelists. Panelists evaluated samples using the consensus method, because it is convenient for any necessary modifications or adjustments to be made during the process. Results were gathered and comparisons on the effectiveness of each cooking application were made to identify their effectiveness in characterizing the grain flavors.

RESULTS AND DISCUSSIONS

Table 2-5 summarizes results from the term generation process for all five cooking applications: cooked grains, porridge, cookies, muffins and extruded puffed snacks. The cookie application has the highest number of generated terms with a total of 37 terms identified from nine sorghum cookie samples. Some of the terms include acrid, bran, brown, leather, burnt, buttery, beany, corn-like, fruity, heated oil, leavening, metallic, salty, toasted, wheat-like and woody. For the cooked grains procedure, there were 27 terms generated such as astringent, beany, bitter, bran, cardboard, earthy, nutty, petroleum, sour, wheat-like and woody. The panel generated 23 descriptive terms to describe the flavor of 9 sorghum porridge samples, while the number of terms generated from 9 muffin samples was 21. There were only 18 descriptive flavor attributes identified by panelists based on the 9 extruded puffed snack samples.

Panelists' feedback includes that it is best to identify and characterize the flavor characteristics of sorghum varieties based on the samples from two of the cooking applications: cooked grains and cookies. The cooked grain samples greatly bring out the distinct flavor attributes of the grains to provide clear differentiation among sample profiles. In addition, the cookie samples that were made using the recipe and procedure listed in Table 2-3, are neutral but emphasize the clear differences in the grain's flavor profiles between different cultivars after use in a product that is cooked with a dry heat method. The porridge samples were described by the panelists as having a texture that hindered the ability to focus on the flavor identification process. Specifically, the samples were mouth coating and drying as well as gummy, adhesive, lumpy, and having an overall inconsistency in texture that sometimes left residue in the mouth that was hard to clean out. Modifications to the cooking procedure and recipe were attempted to enhance the textural aspects of the porridge samples but the result was not successful. In addition, there were huge differences in the functional characteristics among the various sorghum flour samples that resulted in overall textural inconsistency between samples prepared from the same cooking procedure. Because no unique or distinct flavor terms other than those identified using the cooked whole grains procedure were found using the porridge samples, they provided no benefit.

Table 2-5 Generated terms from 5 cooking applications.

Cooking Methods	Terms generated			
Cooked Grains	Astringent	Cooked	Floral	Sour
	Beany	Corn like	Green	Starchy
	Bitter	Dark Green	Heated Oil	Sweet
	Bran	Dusty	Musty	Umami
	Brown	Earthy	Nutty	Wheat Like
	Buttery	Eggy	Petroleum	Woody
	Cardboard	Ferment	Raw	
Porridge	Animalic (leather)*	Cooked* ®	Heated Oil* ®	Starchy* ®
	Astringent * ®	Dark Green* ®	Metallic* ®	Sweet* ®
	Beany* ®	Dusty* ®	Musty* ®	Umami* ®
	Brown* ®	Earthy* ®	Nutty* ®	Wheat Like* ®
	Cardboard* ®	Floral* ®	Oily*	Woody* ®
	Chalky*	Fruity*	Salt*	
Cookies	Acrid	Chalky	Fruity	Raw
	Animalic (leather)	Cooked	Green	Salt
	Astringent	Corn like	Heated Oil	Sour
	Beany	Dark Green	Leavening	Starchy
	Bitter	Dusty	Metallic	Sweet
	Bran	Earthy	Musty	Toasted
	Brown	Eggy	Nutty	Umami
	Burnt	Fermented	Oily	Wheat Like
	Buttery	Floral	Petroleum	Woody
	Cardboard			
Muffins	Baked	Eggy* ®	Metallic* ®	Starchy* ®
	Bran * ®	Floral* ®	Musty* ®	Sweet* ®
	Brown * ®	Fruity*	Nutty* ®	Toasted*
	Cardboard* ®	Heated Oil* ®	Salt* ®	Woody* ®
	Doughy	Leavening*	Sour* ®	
	Dusty* ®			
Extruded Puffed Snacks	Animalic (leather)*	Cardboard* ®	Oily®	Wheat like* ®
	Bitter* ®	Dusty* ®	Sour* ®	Woody* ®
	Bran* ®	Floral* ®	Starchy* ®	
	Brown* ®	Fruity*	Sweet* ®	
	Burnt *	Nutty* ®	Toasted*	

Notes: (*) Terms included in Cookies. (®) Terms included in Cooked Grains. (*®) Terms included in Cookies and Cooked Grains

Thus, as an application to develop a model system to characterise the flavor profiles of grain varieties, the porridge approach was eliminated from the model.

All identified terms from the muffin samples were included in the identified list of terms for the cookie samples. The textural inconsistency between muffin samples also affected the flavor characterization process. Some samples appeared to be gummier while others were grittier and had strong mouth drying effects. In addition, the intensity level of the leavening attribute was so strong in the muffin samples that it overwhelmed the distinct flavor notes of the grain. Attempts to reduce the amount of leavening and the lack of an elastic gluten network in sorghum flour resulted in an unacceptable muffin product. As a result, muffin application was eliminated from the model. Finally, the panelists mentioned that the extruded puffed snack samples were highly associated with many processing attributes such as toasted and burnt. There were not many attributes identified and none of the attributes were unique to the extrusion application. Thus, the extrusion application was also eliminated from the model.

Together, the cookies and cooked grain applications cover all the identified attributes from all five cooking approaches and thus, can serve as great representations to establish the flavor profile of grain varieties in both the raw grain form and in the finished product. The sorghum cookies made using the above recipe and procedure provide an effective model to facilitate characterization of grain flavors.

This approach also was applied for flavor characterization of wheat varieties and results confirmed the effectiveness of the model (Data not shown).

There were some limitations associated with the study. The first limitation is tied to the limited number of sorghum varieties used for the project. The model was developed using only 9 commercially available sorghum samples, while literature has indicated much more genetic variations of sorghum grain. Additionally, more application of the model for other grain types such as rice, barley, rye, quinoa or millet, is necessary to confirm the effectiveness of the model for grain flavor characterization. Finally, descriptive sensory testing of samples made using this developed model is necessary to provide grain's flavor map as well as to further confirm the practicality of the model.

CONCLUSION

Understanding the flavor profiles of grains and how they might differ among cultivars will help researchers, food producers and those who cultivate grains in many ways. This research develops a model system to facilitate characterization of flavor among grain cultivars. The model was developed using nine commercial sorghum samples that are different from each other in physical appearance, nutritional composition as well as functional characteristics. A total of 5 cooking applications were examined and the results indicated that cooked grains and cookie applications established an effective model for flavor characterization of grains between different cultivars. This project developed a cookie recipe that creates consistent and neutral samples that successfully facilitate the identification of grain's character notes. Therefore, the model can be used in future applications for demonstration purposes as well as in combination with descriptive analysis to characterize the flavor of grains and their differences among multiple cultivars.

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Chapter 3 - Development of a sensory lexicon for descriptive analysis of sorghum flavor

ABSTRACT

This study aims to develop a sensory lexicon to describe the flavor profiles of sorghum grains in both whole grain form and in finished products. The study used a total of 57 sorghum samples, which included nine commercially available samples as well as samples chosen from a genetically diverse sorghum set. The initial lexicon was developed using the nine commercially available US samples in two forms: whole grain and whole sorghum flour. The lexicon was further developed using a set of 48 representative sorghum cultivars that were chosen based on their genetic variability. In total, a sensory lexicon consisting of 28 sensory attributes, and their associated definitions and references were identified. The reference scale developed in this project is a product-specific scale, which means that it was developed to specifically describe and characterize the flavor of sorghum grains and sorghum products. Then, 20 sorghum cultivars were chosen to validate the lexicon in two forms: cooked grains and cookies. A modified flavor profile method with a 15-point intensity scale was used during the validation study. The results from the validation of the lexicon were analyzed using principal component analysis (PCA) to identify main attributes that differentiate the samples as well as provide sensory maps for characterizing samples based on their sensory profiles. The trained panel successfully used the developed lexicon to assess a broad range of sorghum cultivars. At this stage, the lexicon provides panelists a tool to successfully describe the flavor characteristics of sorghum products in various applications.

PRACTICAL APPLICATION

A sensory lexicon with appropriate terminologies, their definitions, references, and preparation instructions was fully developed to describe the flavor profiles of sorghum grains as well as to characterize the flavor differences among sorghum cultivars. The information is clear and easy to reproduce for further research on sorghum and sorghum applications. This allows researchers to better understand differences in sorghum flavors and thus, such knowledge can be used to select appropriate varieties with traits that are suitable for certain applications as well as to select certain characteristics for selective breeding purposes.

INTRODUCTION

Sorghum (*Sorghum bicolor* [L.] Moench) is an ancient grain that originated from Africa. It is one of the most important cereal crops worldwide. There are many varieties of sorghum that are classified into 4 main groups including grain sorghum, forage sorghum, biomass sorghum, and sweet sorghum (Sorghum Checkoff) Sorghum grains have been widely utilized as human food in many parts of the world especially in many African and Asian countries. The sorghum crops are widely known for being environmentally friendly as they are drought, heat, and insect resistant. Therefore, it is an important crop worldwide and serves as the dietary staple for over 500 million people in more than 30 countries, especially in many arid and semi-arid parts of the world (Wu et al., 2012). Ratnavathi and Patil (2013) discuss that sorghum is widely utilized for various applications in many African and Asian countries to make traditional foods as well as bakery products such as bread, cakes, and biscuits. In addition, many semi-arid parts of India consider sorghum grain as an important crop for food and fodder purposes (Ratnavathi CV, 2014).

Although the United States is the world's largest producer and exporter of sorghum grains and accounted for the production of 480 million bushels in 2016 (Sorghum Checkoff), it barely utilizes or considers sorghum as a food source. In the developed parts of the world, sorghum is mostly known and utilized as feedstock while its applications in human foods have largely been ignored. Recently, however, developed countries have begun to recognize sorghum as the next essential food source. Specifically, manufacturers, researchers, and consumers have noticed its potential health benefits and that it is an environmentally friendly crop. Moreover, sorghum grain is gluten-free and non-GMO; therefore, the grain can satisfy the modern consumer's criteria for healthy diet. In fact, many studies have shown that certain varieties of sorghum are rich sources of micronutrients, such as minerals and vitamins as well as macronutrients, such as carbohydrates, proteins, and fat (Dicko et al., 2006). The above authors also mention that sorghum has resistant starch properties, which can potentially solve diabetic and obesity problems in many developed countries.

Moreover, sorghum as a drought-resistant crop has huge potential and can serve as a solution for the global food crisis, since the world is becoming drier. However, the lack of necessary research goes along with other limitations that limit application of sorghum in food products. Particularly, research conducted to investigate the flavor properties of sorghum grains has been limited in many ways. Noticeable limitations include the lack of an appropriate sensory vocabulary and its associated properties, preventing researchers from understanding the flavor characteristics of sorghum grain and possibly leading to the abandonment of sorghum applications in food. Another limitation is lack of consumer knowledge and awareness about sorghum grains. In addition, there are many varieties of sorghum which vary in their physical characteristics, nutritional contents as well as sensory properties. Such variations can cause huge differences in the applications of the grain. In total, there are more than 40,000 sorghum varieties that have been identified. Sorghum cultivars vary in their origin, genetic group, appearance, nutritional characteristics, and race. Understanding the differences in sensory characteristics, especially the flavor profile between cultivars, will help researchers, food producers and manufacturers to select the appropriate varieties that are suitable for specific applications as well as to help breeders for selective breeding purposes.

The use of descriptive sensory analysis will help to provide information and support flavor characterizations between different sorghum cultivars. However, it is necessary to have an appropriate sensory language tool to facilitate the flavor characterization process in conducting descriptive sensory studies of sorghum's flavor profiles. There have been some studies conducted to explore the descriptive profiles of sorghum but the results remain limited due to the lack of appropriate terms and references to fully describe the versatile sorghum flavors. In addition, the samples selected in previous studies were not representive of the genetic variations of sorghum. Therefore, the main purpose of this study is to develop a sensory lexicon to describe and characterize the flavor profiles of sorghum grains that can potentially be applied for many sorghum cultivars under different applications.

MATERIALS AND METHODS

Sorghum Samples

In total, 57 sorghum samples were used in the study. The samples were divided into 2 sets depending on which stage of the study in which they were used. The first set of samples, which includes a total of 9 US commercial available sorghum samples (Table 2-1), was used in stage I to develop the initial lexicon. These samples are currently available in the US market and are mainly used for food application purposes. They were donated by Nulife Market (Scott City, Kansas) and ADM (Chicago, IL) to be used in this study. All samples came in both forms: whole grains and whole sorghum flours.

Additional sorghum samples were chosen to further develop the lexicon as well as for validation of the lexicon. For stages II and III, which aimed to further develop and validate the lexicon, the sorghum samples were chosen from the sorghum association panel created by Casa and others (2008). The sorghum association panel was created to represent a collection of genetically diverse sorghum varieties that are cultivated in different areas of the world, as well as some important US breeding lines (Casa et al., 2008). The previous authors also mention that the panel was created to be used for identifying genes that control traits of interest such as yield, height, and nutrient content. The data contains a total of more than 300 sorghum varieties that represented of the world's sorghum. Based on the available information regarding the above samples, a subset of 48 representative samples was chosen for this study based on their genetic information, color, race and nutritional contents. Table 3-1 provides specific information regarding the samples. The selected samples were grown specifically for the research purposes of this study. They were planted in late May 2017 in Manhattan, Kansas. Then, 20 out of the 48 sorghum samples that were chosen from the second stage were chosen for validation of the lexicon after it was fully established. There was huge variation in the arrived amount of these samples, approximately 50g to 1000g of grains collected per samples, which also influenced samples selection process. Researchers selected samples with sufficient amounts that last throughout the study. Each chosen sample was divided into 2 parts: one was kept as grain forms and the other was milled into flours. Sorghum grains were milled using the Wiley's model 4 lab-

Table 3-1 A subset of sorghums samples chosen for the project from the sorghum associated panel that consists of breeding lines and cultivars.

PI Number	Starch (%)	Pro (%)	Fat (%)	Phenols	Tannins	3-Deoxyanthocyanidin	Grain Color	Genetic Groups	Country of Origin	Morphological Race
PI48770	68.9	9.9	2.2	7.0	10.7	21.3	white	C	South Africa	kafir
PI565121	66.6	11.2	3.0	2.8	0.8	15.8	white	E	Zimbabwe	caudatum
PI655988	69.2	8.7	2.6	3.8	3.4	8.9	white	C	United States	kafir
PI656032	68.7	10.4	3.4	1.6	0.0	0.0	white	C	Senegal	
PI533839								B		
PI534037	68.7	8.7	2.2	10.4	21.6	3.1	brown	D	Chad	guineacaudatum
PI576399	67.5	10.4	2.4	9.3	15.3	30.7	white	D	Sudan	caudatum
PI533965	63.9	17.8	4.2	15.1	20.6	4.0	red	E	Uganda	bicolorcaudatum
PI656090	68.3	9.7	2.8	6.2	5.7	43.6	white	E		
PI534092	65.5	13.1	3.3	1.5	0.0	37.2	yellow	D	Nigeria	caudatum
PI576428	65.3	11.5	2.9	2.7	0.0	20.6	yellow	E	Ethiopia	caudatum
PI655996	66.4	11.5	3.4	2.6	0.1	24.5	brown	D	United States	
PI597957	67.0	11.4	3.0	2.0	0.0	30.9	red	A	Ethiopia	bicolordurra
PI656098	68.2	8.8	2.1	6.0	9.5	10.4	brown			
PI534163	69.2	8.3	1.6	8.8	18.6	12.4	white	E	United States	caudatum
PI576426	66.5	11.8	2.5	2.2	0.0	52.1	red	A	Ethiopia	bicolordurra
PI576340	67.6	11.9	3.2	0.8	0.0	1.9	red	C	South Africa	caudatumkafir
PI533752	64.5	16.2	3.6	11.2	13.9	27.5	brown	E	South Africa	caudatum
PI534070	65.1	14.4	3.4	0.6	0.0	22.1	red	D	Nigeria	guinea
PI597973	67.7	10.4	2.5	6.1	4.4	47.0	white	A	Sudan	bicolordurra
PI655984	67.8	10.1	2.6	7.3	10.7	13.9	white		United States	
PI655990	67.9	10.3	2.3	3.7	0.0	19.1	red	A	United States	
PI576373	67.7	10.4	2.7	6.2	5.5	18.8	white	E	Japan	
PI656115								B		

PI576418	66.9	13.3	3.5	0.0	0.0	70.1	red	D	Nigeria	guinea
PI533807	68.1	9.3	1.7	7.5	11.7	16.1	white	E	Nigeria	
PI561073	67.1	11.2	3.1	3.4	1.7	32.4	white	E	United States	caudatumkafir
PI576391	61.7	17.3	4.3	29.8	57.9	150.9	brown	A	India	bicolor
PI656015	69.0	10.4	2.3	8.7	13.0	22.1	white	E	Sudan	
PI656046	66.1	11.9	3.1	12.4	26.1	18.5	brown	A	China	
PI576364	66.3	13.7	3.2	17.0	31.8	14.7	red	C	India	caudatum
PI533938	65.8	14.4	3.1	16.6	31.1	27.3	brown	C	Zaire	caudatum
PI656023	69.9	9.2	2.7	1.7	0.0	10.2	yellow	C		
PI656107	68.8	8.8	2.2	9.9	21.4	0.8	brown	E		
PI656095	67.5	11.9	3.1	4.0	2.7	35.8	yellow	D		
PI533957	65.0	15.6	3.6	18.1	34.0	65.4	brown	E	United States	caudatum
PI656056	66.4	12.3	2.5	-0.8	-7.0	17.4	white	E	United States	
PI533766	68.9	9.6	3.0	3.6	1.0	18.3	white	D	West Volta	guinea
PI533948	66.8	12.1	3.2	2.5	0.0	16.6	brown	C	United States	guineakafir
PI533754	65.6	11.1	3.1	6.7	7.7	0.0	brown	A	Sudan	bicolor
PI656081								B		
PI534137	70.2	9.0	3.0	3.5	1.5	21.2	yellow	E	Sudan	caudatum
PI656086	65.9	13.3	3.0	10.9	21.1	41.4	red	E		
PI656049	68.0	9.4	2.6	3.9	3.9	16.7	white	C	Botswana	
PI534021	67.0	11.6	3.0	0.3	0.0	2.7	white	A	India	durra
PI629040	67.6	11.6	2.5	1.3	0.0	25.2	brown	E	United States	
PI576380	65.7	12.7	3.0	0.7	0.0	20.5	white	E	Ethiopia	caudatum
PI655974	68.9	9.3	2.1	3.5	5.0	10.3	brown	C	United States	kafir

Source: (Rhodes et al., 2014; Rhodes et al., 2017).

mill (Thomas Scientific, NJ) with a 0.5mm screen. The milling procedure included feeding samples into the mill and let run for 15 minutes. The next steps was brushing out the mill, colleting all the remaining products and blending the collected products back into flours.

Sample Preparation

Based on the results from stage I (Chapter 2) of the study on the effectiveness and necessity of each cooking application on characterizing sorghum grain flavors, cookies and cooked grains were chosen for use in flavor characterization projects. Therefore, for lexicon development and validation, sorghum samples were provided both as cooked grains and cookies.

Panel

Six highly trained panelists from the Center for Sensory and Consumer Behavior at Kansas State University (Manhattan, Kansas) participated in the project. All of the panelists completed 120 hours of panel training in the general descriptive analysis of a variety of food and non-food products. Specifically, the panelists were trained for both technique and practice in attribute identification, terminology development, and intensity scoring. Moreover, the panelists have extensive experience on descriptive analysis with more than 2,000 hours of product testing and evaluation. For this project, panelists received further orientation sessions to familiarize themselves with sorghum samples and identify potential attributes and references.

Development and Testing

Lexicon Development

A consensus method (Chambers, 2017) based on a modification of the flavor profile method (Caul, 1957; Keane, 1992) was used in this study; the general procedure is similar to what has been used in other lexicon development studies such as smoke flavor (Jaffe, 2017), medical beverages (Chambers et al., 2017), and coffee (E. Chambers et al., 2016). The consensus method was used throughout the process of lexicon development for generating terms, defining attribute definitions and references, and determining the intensity of attributes. Because of the nature of lexicon development projects, where new attributes may be added, defined and referenced during the process, the consensus approach is useful since it helps to simplify the process (Koppel & Chambers IV, 2010; Maughan, Chambers, & Godwin, 2016). The reference scale that was developed in this project is a product-specific scale, which means that the scale is applied specifically for characterization of sorghum grain and its applications. The use of such a scale was to ensure appropriate differentiation among samples. The used scale is a 0-15 point scale with 0.5 increments in which 0 means none and 15 means extremely strong for that characteristics within the expected range for sorghum grain.

In the first stage of the study, which included the nine commercially available sorghum samples, an initial lexicon developed by Brannan et al. (2001) was given to the panelists as a starting point to build on. The panelists were instructed to modify the current attributes and references as needed. At this point, additional terms, references and definitions were proposed by the panel based on their knowledge and descriptive research experiences. Additional help, input, and suggestions were provided to the panelists, as necessary, from the researchers involved in the project. For example, literature was consulted and researchers proposed attribute definitions and references from existing lexicons (E. Chambers, Smith, Seitz, & Sauer, 1998; E. Chambers et al., 2016; Hongsoongnern & Chambers Iv, 2008) to facilitate the process and address panelists concerns. In total, 20 daily sessions of 1.5 hours per session were devoted to the initial establishment of the lexicon. This is an overly large number of sessions, but included time for the panelists to provide feedback on other aspects of the research such as various cooking procedures and alternative product forms that were not included in the lexicon development. Generally, each session was structured to establish, discuss and/or refine attributes, their terms and descriptive references to capture necessary information while at the same time, avoiding redundancy and overlapping of descriptive terms.

Panelists tasted the samples and noted all perceived attributes. Then, proper definitions and references were introduced to help define the attributes. Appropriate modifications to term definitions and references were made until an agreement was reached among the panelists. Panelists cleaned their palate in between samples and as needed with water, crackers, cucumbers, and cheese.

For stage II of the study, a wider range of samples was used to broaden understanding of the sorghum grain category and expand the lexicon by incorporating additional attributes, if applicable. Having a broader range of samples also helps the panel to examine potential redundancy, overlapping of attributes or problems of the initially developed lexicon. The second set of samples included 48 sorghum cultivars chosen for this phase of the study. A set of 300 samples grown annually by USDA that represents a wide range of cultivated and wild samples was further reduced to 48 samples by examining prior data and information on the samples as well as determining availability of enough grain for testing. The final set was intended to provide as wide a range as possible of the sorghum grain genetics to ensure a wide range of flavor profiles. The panelists evaluated all 48 cultivars as cooked grains to identify if there were any additional terms that needed to be added to the lexicon. The panel also confirmed information associated with the developed lexicon to make sure that the lexicon can fully represent the flavor profiles of sorghum samples. Additionally, 10 representative samples within the 48 samples set were selected and cookies samples of those cultivars were also served during this stage. This step helped to potentially capture any descriptive terms that are specific to based product (e.g. cookie applications), that could not be identified based on the cooked grain samples and to make sure that panelists captured all represented flavor attributes of sorghum grain.

Validation of the lexicon by descriptive analysis of some sorghum cultivars

For the last phase of the study, the validation phase, 20 sorghum cultivars were chosen and evaluated by the panel in two forms: cooked grains and cookies. A total of seven 1.5 hour daily sessions were held to evaluate the 40 sorghum samples. Again, highly trained panelists from the Center for Sensory and Consumer Behavior (Manhattan, Kansas) participated in the sessions to evaluate the samples using a consensus approach. The data was collected and XLSTAT 2017 software (Addinsoft, Paris, France) was used to run Principal Component Analysis (PCA) to provide descriptive maps with key sensory attributes and how they correlated to the samples. . Principal Component analysis was run on the correlation matrix using Pearson (n-1). Attributes present in fewer than 4 samples were excluded from the analysis since the inclusion of those attributes might force the data to create a separate factor and, thus, do not represent the overall pattern of the data. The presented results helped to determine the usefulness of the developed lexicon in discriminating the diverse flavor characteristics of sorghum grains and their applications among differences cultivars.

RESULTS AND DISCUSSION

Lexicon

In total, 57 sorghum cultivars were used to develop the sensory lexicon to describe the flavor of sorghum grains. Table 3-2 lists the initially generated terms from samples of the 9 commercially available sorghum samples. The descriptive panel generated a total of 37 descriptive terms to describe the flavor of sorghum samples. Terms highly associated with processing such as burnt, acrid, toasted, cooked and raw were later eliminated from the lexicon. After multiple reviews and thorough discussions, the panel reached this decision because those terms were only associated with processing, and thus did not contribute to characterizing the actual grains' flavor profiles.

Table 3-2 Initial list of lexicon terms generated by the descriptive panel from 9 commercial sorghum samples.

Attributes			
Acrid	Corn like	Heated Oil	Toasted
Astringent	Dark Green	Leather	Umami
Beany	Dusty	Leavening	Wheat Like
Bran	Earthy	Musty	Woody
Brown	Eggy	Nutty	Sweet
Burnt	Fermented	Oily	Bitter
Buttery	Floral	Petroleum	Sour
Cardboard	Fruity	Raw	Salt
Cooked	Green	Starchy	Metallic

The panel mentioned that the terms such as fermented, floral and dark green need further investigation because such terms were hardly noticed by all panelists. However, it was decided that it was best to keep them at this point to capture all attributes present in the samples. Therefore, the initial lexicon was developed with 32 descriptive terms, each term with a definition to describe the term and two to three descriptive references.

In the second stage of the study, the panel worked on further development of the lexicon. For this stage, the panel evaluated a total of 48 sorghum cultivars (Table 3-1) in two forms: cooked grains and cookies. The lexicon went through several modifications to make sure the flavor terms, their definition, and references fully represent the flavor profile of sorghum grains and sorghum products. For instance, panelists re-examined definitions and descriptive references during the process and they discussed questionable terms that were initially developed in Stage I, such as fermented, floral, fruity and earthy; attributes perceived by one panelist and at a very low level. At this point, the panelists could confidently make decisions to confirm the initial concerns since there was a great variety of samples presented in this stage and that the chosen samples were very representative of the world's sorghum. After thorough discussions, panelists decided to eliminate floral, fruity, fermented, musty earthy and earthy. The term dusty was also eliminated because it was a redundancy of the term musty-dusty. Musty dusty was defined as musty, dusty and papery and thus contained the term dusty within it. Panelists also agreed that musty-dusty was a better term to describe the musty flavor notes in sorghum grains that are associated with an "old library book". The panel also eliminated the term dark green because it was a redundant term. Panelists agreed that the term overall green can fully represent the green flavor note of sorghum grains. Oily was eliminated from the lexicon since oil-heated described the oil characteristic notes in sorghum products. The panel added three descriptive terms to the lexicon including sweet aromatics, spice brown and brown sweet. These three terms were specific to the cookie samples. The panel added sweet aromatics because they indicated that it was necessary to have a flavor term that describes the sweet flavor of the cookie samples. The panel also came up with definitions and descriptive references to describe those attributes. As a result, a sensory lexicon with 28 flavor terms, their definitions and descriptive references to describe the flavor of sorghum grains and sorghum products were developed (table 3-3).

Table 3-3 Sorghum Sensory Attributes, Definitions, references and intensities on a 15-point scale.

Attributes	Definition	References and Intensity
Starchy	The flat flavor note associated with raw or processed starch based grain products such as wheat, rice, oats, and other grains.	Mix of 2g corn Starch in 200 mL water = 3.5 Microwaved potato meat = 7.0 Prep: Microwave a raw potato for 8 minutes. Remove skin, cut the meat into 0.1" square cubes and serve in 1 oz cup. Cooked American Beauty Elbow Macaroni = 12.0 Prep: Boil 3 oz. pasta in 1 quart of water and cook for 7 min with occasionally stirring. Drain & serve.
Beany	A slightly brown, musty, nutty, and starchy flavor associated with cooked beans.	Kroger Great Northern Beans= 6.0 Bush's Best Pinto Beans = 12.0
Cardboard	A flat flavor note associated with cardboard or paper packaging that may be associated with a stale characteristic.	Mission Flour Tortilla = 6.0 Baked Mama Mary's Pizza Crust = 12 Bake the crust for 4 minutes at 425 F. Serve in cups
Brown	A part of the grain complex that presents a flavor impression associated with characteristics such as toasted, nutty, caramelized and sweet.	Kretschmer Wheat Germ = 5.0 (f) Wheat Chex Cereal = 12.0 (f)
Spice brown	A blend of sweet, slightly pungent, brown, spicy aromatics.	McCormick Spice blend in water (1/8 tsp in 16c water) = 7.0 McCormick Spice blend in water (1/8 tsp in 8c water) = 13.0 Mix 0.25 g cinnamon powder, 0.25 g all spice powder, 0.25 nutmeg powder, 0.06 g cloves powder. Take 1/8 tsp of the blend and dilute with the corresponding amount of boiling deionized water. Let cool, filter and serve.
Sweet Aromatics	Aromatics associated with the impression of sweet substances.	Kellogg's Special K = 8.0 Lorna Doone Cookies = 12.0
Brown-Sweet	A rich, full-bodied, light brown, sweet aromatic, which may include the character notes of vanilla and caramelized.	Nabisco Graham Original = 13.0
Leavening	The flat, metallic, somewhat sour, bitter and salty aromatics associated with baking soda and/or baking powder in baked flour products.	Pancake = 7.0 Prep: Combine ½ cup Aunt Jemima's Buttermilk Pancake Mix, 1 1/2-tsp. Clabber Girl Baking Powder, and ½ cup water. Cook on electric griddle. Do not brown. Cut edges and discard. Cut remainder into 1/2" square and serve Pillsbury Original Biscuit Dough (raw) = 15.0 (f)

Oil-Heated	The aromatics/flavors associated with heated cooking oils that may include olive oil, vegetable oils such as corn or soybean, and other common cooking oils. Characteristics include a lack of freshness, accompanied by slight brown and musty notes.	Heated Spectrum Safflower Oil = 6.0 (f) Heated Wesson Vegetable Oil = 12.0 (f) Prep: Heat 1/3 cup oil for 2 minutes on high power in the microwave oven. Let cool and serve in 1 oz. cup.
Buttery	Dairy aromatics/flavors associated with sweet cream. May also include a slightly salty note and occur in both natural and non-natural products.	2 drops of Kroger Imitation Butter Flavor in 200 ml water = 6.0 3 drops of Kroger Imitation Butter Flavor in 200 ml water =12.0
Petroleum	Specific chemical aromatics/flavors associated with crude oil and its refined products that have heavy oil characteristics.	2 drops of Briggs & Stratton SAE 30 Small Engine Oil = 7.0 (Character Reference) 4 drops of Briggs & Stratton SAE 30 Small Engine Oil = 12.0 (Character Reference) Prep: drop oil on a cotton ball in a large 24 oz. snifter, covered.
Eggy	Aromatics/flavors associated with cooked whole chicken eggs, with savory, earthy, salty, buttery, and sulfur overtones. May also include sweet, metallic, and cardboard notes.	Sara Lee Pound Cake = 6.0 (f) Prep: remove crust, cut into ½ " slice and serve Chopped Egg White = 13.0 (f) Prep: Boil egg for 15 minutes, cut egg white into cubes and serve.
Umami	Savory, salty, and somewhat flat, brothy aromatics/flavors associated with juices from cooked seafood, meat, and/or vegetables.	2 Button Mushrooms Broth = 3.0 2 Button Mushrooms + 2 Shrimps Broth = 6.0 4 Button Mushrooms + 4 Shrimps Broth = 12.0 Prep: to make the broth, brings 2 cups of water and the according amount of ingredients to boil. Cook for 5 minutes, let cool, filter and serve.
Overall Green	Aromatic characteristics of plant-based materials. A measurement of total green characteristics and the degree to which they fit together. Green attributes include one or more of the following: green-unripe, green-peapod, green-grassy/leafy, green-viney and green-fruity. These may be accompanied by musty/earthy, pungent, astringent, bitter, sweet, sour, floral, beany, minty and piney.	Diluted Fresh Parsley water (1:6 dilution) = 6.0 Diluted Fresh Parsley water (1:3 dilution) = 12.0 Prep: Rinse and chop 50 g of fresh parsley. Add 600 ml of water. Let sit for 15 min. Filter. Mix 1 part of filtered parsley water to the according parts of water and serve in 1.0 oz. cups.
Nutty	A combination of slightly sweet, brown, woody, oily, musty, bitter and astringent aromatics commonly associated with nuts, seeds, beans, and grains.	Quaker Quick Oats (uncooked) = 6.0 Kretschmer Wheat Germ= 12.0
Woody	The sweet, brown, musty, dark aromatics/flavor associated with dry, freshly cut wood.	Dry Hickory Smoker Wood Chips = 8.0 Prep: Place 50g wood chips in a large snifter, cover Wet Apple Wood Smoker Chips = 15.0

		Prep: Place 50g wood chips + ¼ cup of water in a large snifter, cover.
Musty Dusty	Dusty, musty, papery.	Diluted Brewed Lipton decaffeinated tea = 6.0 Prep: Brew 1 tea bag in 1c of water for 5 minutes. Diluted with ½ c of hot water, let cool and serve. Brewed Lipton decaffeinated tea = 13.0 Prep: Brew 1 tea bag in 1c of water for 5 minutes.
Cocoa	A brown, sweet, dusty, musty, often bitter aromatic associated with cocoa bean, powdered cocoa and chocolate bars.	Hershey's Cocoa Powder in water (1/16 tsp in 200 ml water) = 6.0 Hershey's Cocoa Powder in water (1/8 tsp in 200 ml water) = 12.0
Leather	Warm, sweet, aromatics associated with tanned animal hides. Characteristics may include musky perfumery, honey, woody, tobacco, resinous, and smoky notes.	Brewed Harney & Sons PU-ERH Tea diluted = 4.0 Prep: Brew 1tsp tea in 1c boiling water for 5 min, dilute with 1 c hot water, let cool and serve. Brewed Harney & Sons PU-ERH Tea = 14.0 Prep: Brew 1tsp tea in 1c boiling water for 5 min.
Bran	Light dusty brown grain-like aromatic/flavor impression that may include characteristics such as slightly raw, sweet, or bitter.	Bob's Oat Bran=4.0 Kretschmer Wheat Germ= 7.0 Bob's Wheat Bran = 12.0
Corn-Like	Sweet, musty, light brown, and slightly sour aromatics/flavors, accompanied by earthy and starchy characteristics.	Quaker Yellow Corn Meal =7.0 Prep: use 0.25 c corn meal+1c water+1/4tsp salt and prepare according to package instructions Corn Chex=13.0
Wheat Like	Dusty brown, nutty aromatics/flavors that may include light raw or caramelized notes, as well as a slight metallic note.	Wheat Chex = 4.0 Baked Whole Wheat Flour = 8.0 Prep: Bake 1 cup flour at 350 F for 5 minutes.
Sweet	A fundamental taste factor of which sucrose is typical.	0.25% Sucrose Solution = 3.0 0.50% Sucrose Solution = 7.0 1.0% Sucrose Solution = 12.0
Sour	The fundamental taste factor associated with a citric acid solution.	0.015% Citric Acid Solution = 8.0 0.025% Citric Acid Solution = 15.0
Bitter	The fundamental taste factor associated with a caffeine solution.	0.01% Caffeine Solution = 6.0 0.02% Caffeine Solution = 12.0
Salty	The fundamental taste factor of which sodium chloride is typical.	0.15% NaCl Solution = 8.0 0.20% NaCl Solution = 14.0
Metallic	The impression of slightly oxidized metal such as iron, copper, and silver spoons.	0.10% Potassium Chloride Solution = 8.0 0.15% Potassium Chloride Solution = 14.0
Astringent	The drying, puckering sensation on the tongue and other mouth surfaces.	0.03% Alum Solution = 3.0 0.07 % Alum Solution = 8.0 0.10% Alum Solution = 12.0

Validation of the sorghum sensory lexicon

The lexicon was validated using a set of 20 sorghum samples chosen from the 48 samples in Stage II. The goal of this stage was to examine the effectiveness of the developed lexicon in characterizing the flavor profiles and discriminating among sorghum cultivars. The sorghum samples were validated using two forms: cookies and cooked grains. The PCA for both cooked grain and cookies showed from 4 to 9 (cooked grain) or 7-10 (cookies) key principal components (depending on how "key" is defined). Figures 1 and 2 show a bi-plot mapping of the first two principal components for each grain preparation method. Based on the results, there are differences in flavor among sorghum cultivars and the attributes successfully separate the sorghum samples in various applications. Exclusion of attributes that presented in less than 4 samples does not indicate that those attributes are not important. They may be characterizing for a grain – but merely shows that even without such attributes, distinctions among varieties can be shown.

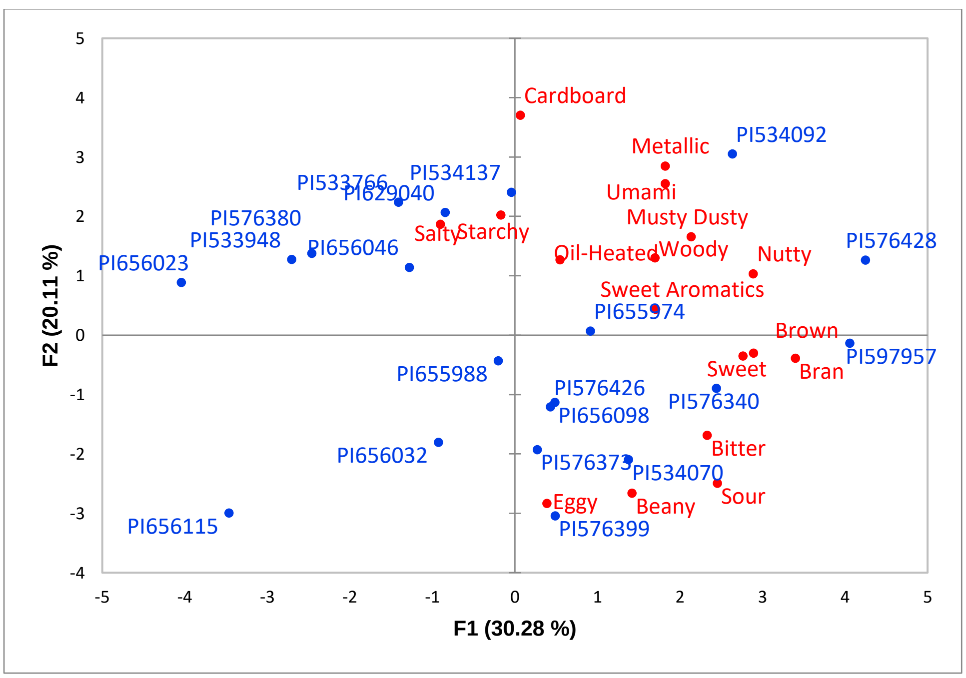

Figure 3-1 Principal Component Analysis (PCA) of the trained panel evaluations for flavor attributes of multiple cooked grains sorghum samples.

The map in Figure 1 shows clear differences among cooked grain sorghum samples. Even though attributes might seem to be grouped close together, the map demonstrated flavor variations among samples. Specifically, samples PI576428 and PI597957 were highly correlated with factor 1 and thus, were perceived as more pronounced in bran, nutty and sweet compared to samples PI656023 and PI656115. Samples PI534092 were stretched in the area of metallic, umami and cardboard while still on the side of sweet, bran and nutty attributes. The three samples PI576399, PI534070, and PI576373 were characterized as being more pronounced in eggy, beany and sour than other samples. In addition, samples PI533766, PI534137, and PI629040 were grouped close to salty, starchy and cardboard compared to other samples.

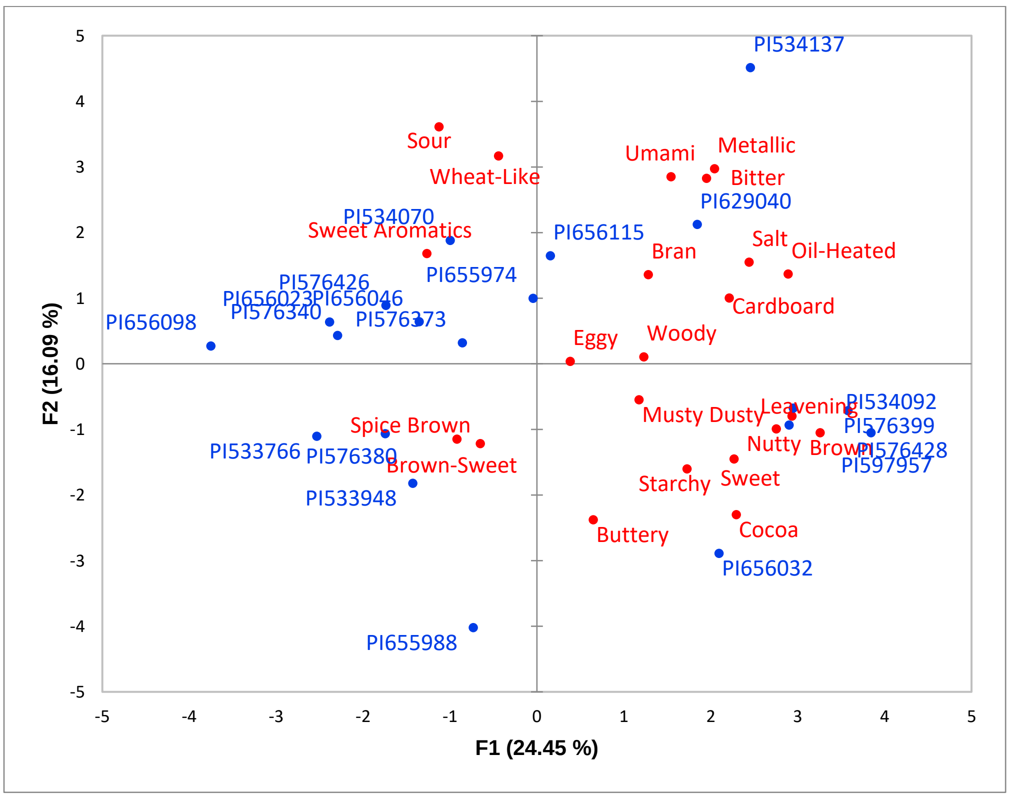

Figure 3-2 Principal Component Analysis (PCA) of the trained panel evaluations for flavor attributes of multiple sorghum cookies samples.

As seen in Figure 2, sorghum cookie samples were greatly differentiated from each other. Attributes, and samples spread out evenly across the map, which indicated that the sensory lexicon can effectively characterize and differentiate among sorghum samples. Moreover, the results also proved that the cookie application use in this study provides a potent model for characterization of flavor among multiple sorghum cultivars. In particular, sample PI534137 and PI629040 were more pronounced in umami, metallic and bitter than other samples. The four samples PI534092, PI576399, PI576428, and PI597957 were grouped close together with attributes that are highly correlated with factor 1 such as brown, leavening and nutty. The panel characterized samples PI533766, PI576380 and PI533948 to be more related to the brown attributes, spice brown and brown sweet, compared to other sorghum varieties. Some samples were identified to be unique in their flavor profiles such as sample PI655988 as well as sample PI656032 which characterized to be higher in cocoa and butter than most samples.

It must be noted that samples that appear close to each other on the bi-plots for the first two principal components may not be close to each other on other PCs and, thus, likely are clearly different in other characteristics. The results in both Figure 1 and Figure 2 indicated that the lexicon can be effectively utilized to identify the differences in flavor among sorghum cultivars under multiple applications.

With a total of 28 descriptive terms, the sorghum lexicon developed from this study has been expanded tremendously compared to previous studies (Brannan et al., 2001; Winger et al., 2014). These studies were surprisingly successful regardless of the limitations in which they were devised. The lists of terms developed by Brannan and others (2001) was used as landmarks for this process. Except for doughy, all of the terms from the starting list were included in the newly developed lexicon. Another difference is that the previous lexicon have dusty instead of musty-dusty. As mentioned above, dusty is included in the definition of musty-dusty and, thus, musty-dusty is a more suitable term for describing the flavor combination of musty, dusty and papery in sorghum grains. Winger and others (2014) also generated a lexicon based on the list from Brannan and others (2001) to characterize the flavor profiles of sorghum flour tortillas. Surprisingly in this list the authors eliminated dusty and have musty as one of the terms in the lexicon and, therefore, helps to support our finding that musty-dusty is sufficient term for flavor characterization of sorghum grains. Another term from the attribute list developed by Winger et al. (2014) that the current lexicon does not included is rancid. This lexicon included 2 attributes that encompass the character of rancidity: cardboard and heated-oil. Specifically, the above author used stale saltine crackers as a reference for rancid, while in the newly developed lexicon, cardboard was defined as a flat flavor note associated with cardboard or paper packaging that may be associated with a stale characteristic. Moreover, the new lexicon also includes heated –oil that can potentially cover the rancid definition, as an aromatic associated with decomposed fat or oil. There are also limited descriptive flavor terms developed by Winger and others (2014); this limitation can be explained by the lack of samples used in their study since there were only 4 samples evaluated. Hence, the lexicon devised in this study built upon these previously developed lexicons. The representative set of sorghum samples used in this study helped the panel to not only generate terms that are commonly associated with sorghum grains but also terms that are more unique to certain varieties. Researchers, food producers, and farmers can use the information to further study sorghum flavor profiles, to select varieties with advantageous traits suitable for specific applications as well as to support selective breeding efforts

CONCLUSION

The study developed a sensory lexicon for sorghum including attributes, definitions and descriptive references with intensities, anchored on a 0-15 scale to support the characterization of sorghum flavor both in plain cooked grain form and in baked finished products. Validation of the lexicon with sorghum samples presented in cooked grains and cookie form shows that the lexicon can successfully characterize and differentiate the flavor profiles among sorghum cultivars. This lexicon can provide researchers with a much needed tool to help provide flavor information related to breeding and selection of varieties for specific types of products. Further steps to follow up this study can include comparisons of the sensory profiles of sorghum cultivars with their genetic or other information to possibly uncover trends in the genetic traits that might influence the grain's flavor characteristics. Specifically, it would be interesting to match sorghum sensory descriptive data with nutritional factors in the varieties to determine how they may be correlated. Testing additional sorghum cultivars and breeding can potentially help to expand the current lexicon and be more representative of flavor profiles of the world's sorghum.

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Appendix A - Evaluation Ballot

Attribute						
Starchy						
Beany						
Cardboard						
Brown						
Spice Brown						
Sweet Aromatics						
Brown-Sweet						
Leavening						
Oil-Heated						
Buttery						
Petroleum						
Eggy						
Umami						
Overall Green						
Nutty						
Woody						
Musty Dusty						
Cocoa						
Leather						
Bran						
Corn-Like						
Wheat-Like						
Sweet						
Sour						
Bitter						
Salt						
Metallic						
Astringent						

Appendix B - Sample Serving Codes for Validation of the Lexicon

Samples	Cooked grains	Cookies
PI655988	536	275
PI656032	241	496
PI576399	863	068
PI534092	772	926
PI576428	586	717
PI597957	983	504
PI656098	458	679
PI576426	256	233
PI576340	732	415
PI534070	286	335
PI576373	947	571
PI656115	158	641
PI656046	896	089
PI656023	224	172
PI533766	379	298
PI533948	465	316
PI534137	078	854
PI629040	823	109
PI576380	191	665
PI655974	380	240

Appendix C - Commercial Sorghum Samples (Grain Form)

NL-Tan specified for Baking

NL-Tan specified for Popping

NL-Tan specified for Extrusion

ADM-Whole Grain

NL-Tan Waxy

NL-Burgundy Regular

NL-Burgundy Sumac

NL-Burgundy Waxy

NL-Black