INCORPORATING FLAVOR INTO A

WHEAT BREEDING PROGRAM

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WHEAT BREEDING PROGRAM

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Nothing left to do but smile, smile, smile

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Abstract:

Wheat is a major cash crop in Oklahoma, accounting for nearly 2.6 million harvested acres in 2020. Many farmers rely on wheat varieties developed at Oklahoma State University (OSU), as these varieties have proven capable of producing robust yields despite Oklahoma's unique climatic characteristics and disease pressures. Flavor is not a formal consideration in the breeding program; this is perhaps unfortunate, as milling entrepreneurs are developing a local market for flour produced from specific OSU varieties. Thus, the objective of this research is to assess the ability to document variety-specific flavors in bread by having food professionals sample breads made from different wheat varieties. First, a qualitative study is conducted to identify the range of flavor attributes bread made from different wheat varieties can possess. Then a quantitative analysis is performed to measure the extent to which similar flavors are manifested in the same wheat variety grown in different Oklahoma regions. Both analyses use professionals in the food industry as sensory analysts.

The first study compares nine different OSU and three different heirloom wheat varieties. Fourteen food professionals sampled the breads, describing flavor characteristics and likeability. A Napping-Ultra Flash Profile exercise is also performed, providing data for measuring differences in flavor, allowing millers to identify which varieties can be blended while still preserving a common flavor profile. The OSU varieties provided a distinct and largely superior eating experience compared to the heirlooms, suggesting recent genetic changes to promote disease resistance, yield increases, and baking quality have not sacrificed flavor. The results of this exploratory analysis are then used to identify a more quantitative instrument for analyzing flavor differences in wheat varieties by food professionals.

If Oklahoma is to associate specific wheat varieties with specific flavors it is important those flavors be present in bread regardless of where in Oklahoma it is grown. The second study asks a similar sample of food professionals to sample breads made from five different OSU varieties and two different regions. By sampling the same variety grown in both the northern and southern region, and using a more quantitative instrument, it is possible to measure the extent to which the same flavor emerges regardless of the region. Twelve food professionals rated the intensity of nine flavor attributes, selected the presence of other attributes from a word bank, and completed a napping ultra-flash profile exercise. Overall, the same wheat variety can impart considerably different flavors when grown in different regions of Oklahoma, suggesting it is difficult to associate a wheat variety with a specific flavor profile without knowing where in Oklahoma it is grown.

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CHAPTER I

DEVELOPING FLAVOR PROFILES FOR WHEAT VARIETIES IN A BREEDING PROGRAM

Introduction

Wheat is an important cash crop for Oklahoma producers, with roughly 2.6 million acres harvested annually (USDA-NASS, 2020). Oklahoma specializes in Hard Red Winter Wheat (HRWW), a type used mostly for bread and all-purpose flour. The state ranks fourth in the US for commercial production (Statista, 2022). However, commercial production of HRWW is also susceptible to pest infestations and diseases (Marburger et al., 2018). As such, producers often to rely on wheat varieties developed at Oklahoma State University (OSU) that demonstrate resistance to certain pests and diseases endemic to the state. In fact, the top six varieties of wheat planted in Oklahoma for the 2018 growing season were all developed by the OSU Wheat Breeding Program (WIT, 2018).

The OSU Wheat Breeding Program began in 1987 with the goal of developing wheat varieties that both thrive in the Oklahoma climate and are highly marketable to millers (WIT, 2022). One to five new cultivars are released annually in response to the changing climate, pests, and disease. Prototype varieties are evaluated based on specific traits like grazeability, Rust/Septoria resistance, Hessian fly resistance, acidic soils,

functionality, and baking quality (WIT, 2022). However, the program does not have any formal mechanism for evaluating the flavor a variety imparts to bread.

Incorporating flavor into breeding considerations for wheat varieties has been largely left unexplored, and protocols for standard sensory evaluations of bread were only recently developed (Callejo, 2011). However, there is evidence that untrained assessors can perceive a difference among breads baked from different wheat varieties (Norwood and Albers-Nelson, 2018). OSU's breeding program does measure certain attributes of its varieties that relate to baking quality, such as protein percentage, loaf volume, and baking absorption, but these attributes have more to do with appearance than taste. The program evaluates wheat on almost every aspect except for taste, and given that the purpose of wheat is to be eaten, expanding the breeding program to include flavor is an obvious next step.

Adopting taste as a variety attribute could improve the marketability of Oklahoma wheat. Certain wheat characteristics like protein percentage for baking are already considered when selecting wheat cultivars and these features are already used to help price wheat (Cato and Mullan, 2020). Protein percentage typically relates to the characteristics the flour will impart to baked goods. Characteristics determined by protein percentage are the flavor, rising, and volume of the baked good (Parcell and Stiegert, 2003). Thus, there is a demand for different protein percentages in flour depending on goals of individuals such as the baker who wishes to bake cookies versus bread, both of which have different protein percentage requirements. Most millers select wheat to purchase based on attributes like protein percentage, and they will blend the different wheat cultivars to achieve their desired consistency in flour and baking properties.

However, if cultivars impart different flavors, then they are not necessarily achieving consistency in taste. To achieve flavor consistency—or better yet, superiority—companies may need to focus on producing flours derived from varieties proven to impart similar tastes.

Entrepreneurs in Oklahoma, such as Chisolm Trail Milling, have begun sourcing locally grown wheat varieties and milling them into variety-specific flour to achieve this very goal. By sourcing locally grown varieties directly from the producer, such mills aim to create a market based on personal preferences of wheat variety flavor. Small bakeries have begun sourcing this product because they know the specific variety and flavor it may impart to a baked good. With an emerging demand for variety-specific flour, having a consideration for flavor in the breeding process will help producers discover and profit from such niche markets. Also, understanding the similarity in flavor of different varieties can help millers understand which varieties they can combine while keeping the flavor profile similar.

The objective of this study is to develop a flavor profile for nine popular OSU cultivars and to measure the similarities in flavor between them. This objective is achieved by having 14 food professionals taste bread made from nine OSU and three heirloom cultivars. The subjects describe the flavors in their own words and complete an Ultra-Flash Napping exercise whereby the similarity in the breads' flavors is measured.

Background on Sensory Analysis of Bread

Bread is a food whose flavors can take on myriad properties, depending on the ingredients used and the baking process. Sensory analysis has long been employed to document these properties. Studies have evaluated the relationship between bread flavor

and the type of grain used (Callejo et al., 2015), the genetics of the yeast used (Heitmann et al., 2017), the fermentation and baking procedure (Katina et. al., 2006), and the agricultural production system used (Kihlberg et al., 2004).

Much of this work has been performed by professional sensory analysts who are trained to rate the intensity of specific flavors that possess objective definitions. For example, the intensity of a "wheaty" flavor may be measured, where "wheaty" is defined as the flavor of wheat kernels treated with boiling water and left to steep for hours (Callejo, 2011). For researchers wanting a complete and objective profile of a bread's flavors using trained sensory analysts, Callejo (2011) provides a comprehensive list of possible flavors with specific directions on the meaning of those flavors.

Employing a trained sensory panel is ideal for a thorough and objective assessment of a bread's sensory properties, but is expensive and time consuming (Frøst et al., 2015). For example, Heenan et al. (2008) trained a panel over eight two hour sessions before they gauged 28 different sensory properties of twenty different bread products. Kihlberg et al. (2004) spent seven hours training eight assessors to evaluate 48 bread samples for 35 different sensory properties over seven days.

The perspectives of trained assessors may not reflect the language and preferences of ordinary consumers or those in the food industry (Faye et al., 2006). Assessors go through extensive training to see food through a particular lens that differs from how ordinary consumers interact with food. This cues them to view foods like bread as an aggregate of human constructs like 'malty aroma' and 'rye flavors', when most consumers may not know how malt really smells or rye really tastes. Plus, there is uncertainty of how well trained assessors can adapt to new food products. Some studies

find trained assessors considerably better than their untrained counterparts, while other studies find small differences. Overall it seems trained assessors are indeed better at detecting differences than untrained individuals but their superiority is often modest (Chollet et al., 2005).

While trained assessors are essential for developing a scientific vocabulary and objective measures for differentiating breads, food development and marketing typically takes place without these definitions and measures. When researchers are interested in the perspectives of bread from those who consume and sell it, there are advantages to using untrained assessors. Small groups of food industry representatives are sometimes used to develop sensory profiles of food products. Frøst et al. (2014) conducted a sensory analysis of beers using eight professional brewers; for evaluating spices they used 26 chefs, foodies, and culinary professionals. Rocha et. al. (2012) used ten chefs to evaluate tomatoes and generate a list of sensory descriptors that was used to develop a questionnaire for 110 consumers. Pagès (2005) used wine growers, oenologists, wine waiters, and similar individuals to evaluate different wines.

When using untrained sensory assessors, it is important to use methods that require little training and are easy to understand. One method is to use traditional focus groups that involve tasting bread, as Crucean et al. (2019) used to evaluate salt substitutes in bread and Gellynck et al. (2009) used to document consumers' overall perceptions of bread. Likert scales to measure constructs such as "likeability" have also been employed (Teuber et al., 2016). To evaluate the extent to which breads are similar, simple discrimination tests like the duo-trio test have proven effective with untrained subjects (Norwood and Albers-Nelson, 2018), as have the Ultra-Flash Napping method, where

subjects arrange the identification numbers of food samples on a grid, placing samples similar to one another closer and samples that are distinct more distant (Frøst et al., 2015; Giacalone et al., 2016; and Mayhew et al., 2016).

Methods

Subjects

The sensory analysts consists of 14 individuals. Thirteen are professionals in the food industry whose job consists of designing recipes in some form; the non-professional cooks as a hobby but has the reputation as a gourmet. Of the thirteen professionals, ten are professional cooks at restaurants, one owns and runs a business creating bakery edibles, one is a brewer, and one owns and manages a tea shop. Each participant is identified by a local search and recruited personally. Each participant is compensated $590 to participate in two separate two-hour sessions. The fourteen analysts are split into two seven-person groups. Group A attended the sessions on July 27 and 29 and Group B attended sessions August 3 and 5, both in 2021 and from 3 – 5 PM.

Materials

The major objective of the research is to identify flavor profiles of breads made from popular OSU wheat varieties. Nine OSU varieties (Table 1.1) were chosen based on the recommendation of the program's head breeder. All are hard red winter wheat varieties, except for Big Country which is a hard winter white variety. All are officially released to the public and raised throughout the state. For comparison, three heirloom varieties currently marketed as possessing superior flavors are also included.

Each of the nine OSU varieties were milled into both white and whole wheat flour at the Hal Ross Flour Mill at Kansas State University, using standard milling for white flour

and fine granulation for whole wheat flour. White and whole wheat flour for the three heirloom varieties were purchased online from Barton Springs Mill. It should be noted that the “white” flour for the heirloom varieties was produced using a stone mill and contained a small percentage of germ and bran (about 15%). Also, all whole wheat flour used for OSU and heirlooms varieties meets the whole-grain rich criteria set forth by the USDA of 50% all whole wheat and 50% white flour (USDA, 2012).

Each flour was then baked into small loaves using an identical recipe for white bread, following the AACC International Method 10-10.03 recipe. For the first session with seven of the subjects, the same recipe was used for whole wheat bread, but the subjects found the bread to be of relatively low quality. For the second session with the other seven subjects, the recipe was modified by doubling the added yeast. All breads were baked the morning before the experiment and were cut into half-inch slices using the Mini-Supreme Bread Slicer 709.

Group A performed their sensory analysis in a standard ISO sensory room (ISO 8589:2007). Group B expressed concern about COVID-19, so a larger classroom was sought where greater distances between the subjects was possible. While not an ISO sensory room, it possessed a similar level of neutrality in the use of white colors, no pictures, and neutral odors.

Table 1.1 Wheat Varieties

Group A		Group B	
07/27/2021	07/29/2021	08/03/2021	08/05/2021
Green Hammer	Skydance	Turkey Red	Butler's Gold
Baker's Ann	Showdown Red	Strad CL+	Big Country
Rouge de Bordeaux	Yecore Red	Smith's Gold	OK Corral
OK Corral	Smith's Gold	Yecore Red	Rouge de Bordeaux
Big Country	Strad CL+	Showdown Red	Baker's Ann
Butler's Gold	Turkey Red	Skydance	Green Hammer
Turkey Red	Butler's Gold	Green Hammer	Skydance
Strad CL+	Big Country	Baker's Ann	Showdown Red
Smith's Gold	OK Corral	Rouge de Bordeaux	Yecore Red
Yecore Red	Rouge de Bordeaux	OK Corral	Smith's Gold
Showdown Red	Baker's Ann	Big Country	Strad CL+
Skydance	Green Hammer	Butler's Gold	Turkey Red

Note: Wheat varieties are presented in the order subjects tasted them in each session.

Recall that the breads used in the sensory analysis were made from 9 OSU (Green Hammer, Baker's Ann, OK Corral, Big Country, Butler's Gold, Strad CL+, Smith's Gold, Showdown Red, and Skydance) and 3 heirloom varieties (Rouge de Bordeaux, Turkey Red, Yecore Red). Table 1.1 presents the varieties in the order they were provided to subjects in each group session. An heirloom variety is one that has been in commercial production for a long duration and are conventionally believed to have superior genetics for yield and flavor. The heirloom varieties are only included in the study for comparison purposes.

Sensory Experiment

The experiment was approved by OSU's Institutional Review Board under application IRB-21-246. The first session for each group focused on white breads (July 27 and August 3) and the second session focused on whole wheat breads (July 29 and August 5). During each session, twelve samples of bread were sampled corresponding to the twelve

varieties, with each sample represented by a random three-digit number. Within each session each subject sampled the breads in the same order, but across sessions the order varied as shown in Table 1.1.

At the beginning of each session, subjects were informed that the only difference in each bread sample was the wheat used in the baking process and that we seek their honest opinion as to the breads' flavors. At each subject's seat was a bottle of water, a covered container containing coffee grounds, a questionnaire, and a Napping grid. Each session involved tasting individual samples of bread. Before each sample, subjects were asked to drink water and smell the container with coffee grounds to cleanse their palette.

The questionnaire consisted of 13 pages of questions: one page of questions for each of the 12 varieties and one page of questions regarding the overall sensory experience. For each sample the subject was asked to answer four questions. First, subjects were asked to write a description of the bread's flavors in their own words, and then to write a description of what might pair well with the bread or how the bread might be consumed, given its unique flavors[1]. The third question consisted of a nine-item Likert-type scale question to gauge the bread's overall likeability, with the options: dislike extremely, dislike very much, dislike moderately, dislike slightly, neither like nor dislike, like slightly, like moderately, like very much, and like extremely. The last questionnaire item for each sample requested them to perform a Napping Ultra-Flash exercise, discussed below. After these four questions and before the next sample was evaluated, a group discussion was held where subjects discussed the bread's flavor profile. This group

[1] This question did not provide useful information and is thus not a focus of the analysis. Major focus was played to other questions of likeability and bread description.

discussion was necessary to provide further elaboration on how the words in their written narratives should be interpreted.

After the last sample, subjects were asked to indicate (1) the extent to which they agreed with the statement "I am surprised how much influence the wheat variety has in the flavor of bread" (2) as well as the statement "The breads tasted mostly the same to me" (3) at what point, if any, did the subject's palate become weary and (4) if the breads were more distinguishable by their taste, aroma, or both? These questions were provided to highlight areas where the focus sessions could be improved and locate the point at which results of the tastings could be skewed due to palate fatigue. An example of the questionnaire is provided in Figure A.1 in Appendix A.

Napping Ultra-Flash Exercise

Recall that each bread sample had its own page of questions in the session questionnaire, and the last question on each page asked them to perform a Napping Ultra-Flash exercise, following procedures outlined by Frøst et al. (2015); Giacalone et al. (2016); and Mayhew et al. (2016). This exercise aims to capture similarities between samples quickly and without the need for laborious sensory training.

Each subject was provided with 60 cm x 40 cm blank grid and 12 tags containing the identification number of each bread sample. The grid contained no labels on the x- or y-axes, as they only represent distance in terms of differences in flavor. After a subject tasted a sample, they were asked to place the related id-tag somewhere on the grid, such that breads which have a similar flavor are placed close to one another, and breads with different flavors are placed further apart. The greater the distance between the bread samples, the greater the difference in perceived flavor. Subjects were allowed to

continually alter the placement of each sample id-tag on the grid as the session ensued. Figure A.2 in Appendix A highlights an example of how one subject constructed a grid.

Data collection

After each session the questionnaires were scanned and saved electronically, and the ultra-flash exercise grids were photographed and the coordinates for each subject and bread sample were recorded. All sessions were video recorded in their entirety, re-watched, and annotated. The annotations provide clarification as to the meaning behind written responses and as additional sensory data. Keywords used in written responses by each subject were tabulated in an Excel spreadsheet and aggregated across each session to categorize responses for white and whole wheat breads. This tabulation was used to create a narrative of each variety's flavor and to help understand the justification for distances between each sample on the Napping grid.

Analysis methods

The experimental method produced three types of data (1) qualitative verbal data from the open-ended questions and focus group discussion of the bread sample flavors (2) quantitative scale data on the likeability of the bread and (3) quantitative data on the coordinates of each bread sample in the Napping exercise. The method by which each data type is analyzed is described below, where separate analyses are conducted for the white bread and whole wheat bread samples.

The qualitative verbal data are analyzed by manually tabulating each subject's responses into an Excel spreadsheet by group (A & B) and by session date. Keywords describing the attributes of each bread are the responses obtained from our subjects. Short answer written responses from each subject in both of their sessions are recorded. For

example, if a subject wrote “The crumb of this bread tastes burnt to me” then “burnt” is the keyword. Special treatment is given to responses where the subject specifies a specific section of the bread. For example, the sentence “the crust for this sample is chewy” is recorded as “chewy” under the crust category. For each group and session, keywords are divided if the descriptor refers to a specific part of the bread sample. The keyword groupings are texture/flavor, crust, aftertaste, color, and aroma. Keywords are treated as descriptors for texture/flavor of a sample unless stated otherwise. Some keywords may contrast one another, i.e., “dry” and “moist”, and are treated as opposites.

Likert scale data on bread likeability is analyzed by the simple average likeability rating for each variety, where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely. In addition to likeability related data, recall the last page in each questionnaire asked our subjects if they 1 = strongly disagreed, 4 = neither agreed nor disagreed, and 7 = strongly agreed with statements relating to bread samples and palate fatigue. These responses are also analyzed by simply taking an average of total responses over all sessions, white bread sessions, and whole wheat bread sessions. Since there are only twelve subjects in the experiment no hypothesis tests of these data are performed.

The Ultra-Flash Napping data are analyzed using cluster analysis. Varieties are placed into different classes, where each class contains varieties with similar flavors. This involves first calculating, for each subject, the Euclidean distance between each bread sample on the Napping grid. The average distance between each sample is then calculated across all fourteen subjects, providing a distance matrix D_{ij}, which denotes the average Euclidean distance between samples i and j. Separate distance matrices are calculated for white and whole wheat bread.

This distance matrix is used to (a) obtain a representative grid using multidimensional scaling (MDS) (Torgerson,1952) and (b) a dendrogram for categorizing the wheat varieties into classes. Recall that subjects are asked to place the first sample in the middle of the Napping grid and place every sample thereafter close if it's similar and further away if it imparts a different taste; subjects are also allowed to update their grid at any time during the sessions. We can call the first sample, "first choice" for subjects. Bias could arise from having subjects compare each bread to the first choice; however, since we are only interested in relative distance between samples, this bias gets removed by 1) randomizing each variety across each session and 2) when Euclidean distance is calculated between each bread sample.

The MDS algorithm generates a set of coordinates for all twelve varieties on a grid that best reflects the fourteen grids created by the subjects in the experiment. It thus creates a representative grid for all subjects. Consider any hypothetical representative grid, containing twelve coordinates for each of twelve wheat varieties. A distance matrix can be calculated for this representative grid; let this distance matrix be denoted δ_{ij}. The goal of the algorithm is to identify a representative grid that results in a distance matrix δ_{ij} similar to D_{ij} (Torgerson, 1952), where D_{ij} is considered the "master distance matrix". The calculation of δ_{ij} is accomplished by minimizing a loss function. A variety of loss functions are available that increase in value the more δ_{ij} and D_{ij} differ. The algorithm used here minimizes the loss function shown in (1.1), often referred to as a stress function. Since we are interested in the proximities of each variety in relation to another, we adopted a non-metric MDS that only highlights the distance between each point (Togerson, 1952). The representative grid was generated using the function

isoMDS in the MASS package in R (R Core Team (2022)). If the algorithm successfully converges, the stress function is said to be minimized and the projection represents the true distances between varieties.

$$Stress = \sqrt{\frac{\sum_{i,j}(D_{ij} - \delta_{ij})^2}{\sum_{i,j} D_{ij}^2}} \tag{1.1}$$

The representative grid only provides a visual representation of similarities between wheat varieties. It does not indicate which varieties belong in the same class. To determine classes, a bottom-up clustering algorithm is used. At the beginning of the algorithm, each variety is assumed to be in its own unique class. Then, for each iteration the algorithm merges the two classes that are most similar to one another. At the first iteration "most similar" is defined as the two varieties with the shortest Euclidean distance in the distance matrix D_{ij}. In the second iteration there is one class that contains two varieties and ten classes that contain only one variety. The algorithm proceeds to then merge the next two classes with the smallest distance, where the distance between the class A with two varieties and class B with one variety is the average distance between each variety in class A and the variety in class B. At each iteration more classes are created and varieties are increasingly grouped into a class with other varieties. At any iteration the distance between two classes, one with K varieties and one with L varieties, is calculated as shown in (1.2). At the last iteration all varieties are placed in the same class.

$$d_{jt} = \frac{1}{KL} \sum_{k=1}^{K} \sum_{l=1}^{L} d(X_{jk}, Y_{lt}) \quad (1.2)$$

Note that this clustering algorithm only provides an objective measure to help the research identify classes of similar varieties; it does not explicitly say which variety belongs to which class. Instead, at each iteration it provides information on the "distance" one has to go to combine varieties. The shorter (longer) the distance the more (less) the researcher should consider combining the two classes. The output is a dendrogram, which the researcher uses to determine the number of classes and class memberships. Total within sum of squares is chosen as a metric to determine optimal clustering assignments for both groups. An explanation of the use of the metric is given in Appendix B, accompanied with Tables B.1.1 and B.1.2 showing the variance at each cluster assignment.

Results and Discussion

The sensory experiment provides three types of data that are used to identify the flavor properties of breads made from different wheat varieties. One type of data are written and verbal descriptions of the flavors, another is a quantitative score of each bread's likeability, and the third is the output of a clustering algorithm to classify which wheat varieties impart similar flavors. The results are described by first detailing the clustering results, and then using the likeability score and qualitative descriptors of the varieties to better understand the reasons for the clustering results. The results for white and whole wheat breads are discussed separately.

White Breads

The dendrogram of white breads created by the hierarchical clustering algorithm is shown in Figure 1.1. The x-axis scale has no meaning, other than just the location of the varieties (as in a bar graph). Starting from the bottom of the y-axis and traveling upwards, lines for each variety are connected to lines for other varieties, indicating they are placed in the same class at that point. The vertical length of the line before it is joined with another indicates the "distance" one must go to place two varieties (or two classes of varieties) in the same class. To go a large distance to join two varieties in the same class is akin to saying "it's a stretch" to saying they are alike in terms of flavor.

Class assignments are typically made by inserting a horizontal slice of the dendrogram at a location decided by the researcher, where all varieties underneath this line connected to one another are in the same group. Where should this slice take place on the y-axis? Starting from a y-axis value of zero, the higher the value chosen to place the slice the greater the dissimilarity in the varieties within each group, where dissimilarity is indicated by the y-axis value. One typically chooses a slice location based on the price they are willing to pay for clustering varieties together (with price determined by the y-axis value), the aesthetics of the dendrogram with the slice, and what is deemed to be a reasonable number of groups given the sample size.

The slice location chosen was below 16, as indicated by the red line in Figure 1.1, resulting in four classifications. Observations joined together below the decision line are said to be in a cluster, resulting in the following four classifications:

- Group A consists of varieties Green Hammer, OK Corral, Baker's Ann, Butler's Gold, and Big Country.

- Group B: Smith's Gold, Strad CL+, Showdown Red, and Skydance.
- Group C: Rouge de Bordeaux.
- Group D: Turkey Red and Yecore Rojo.

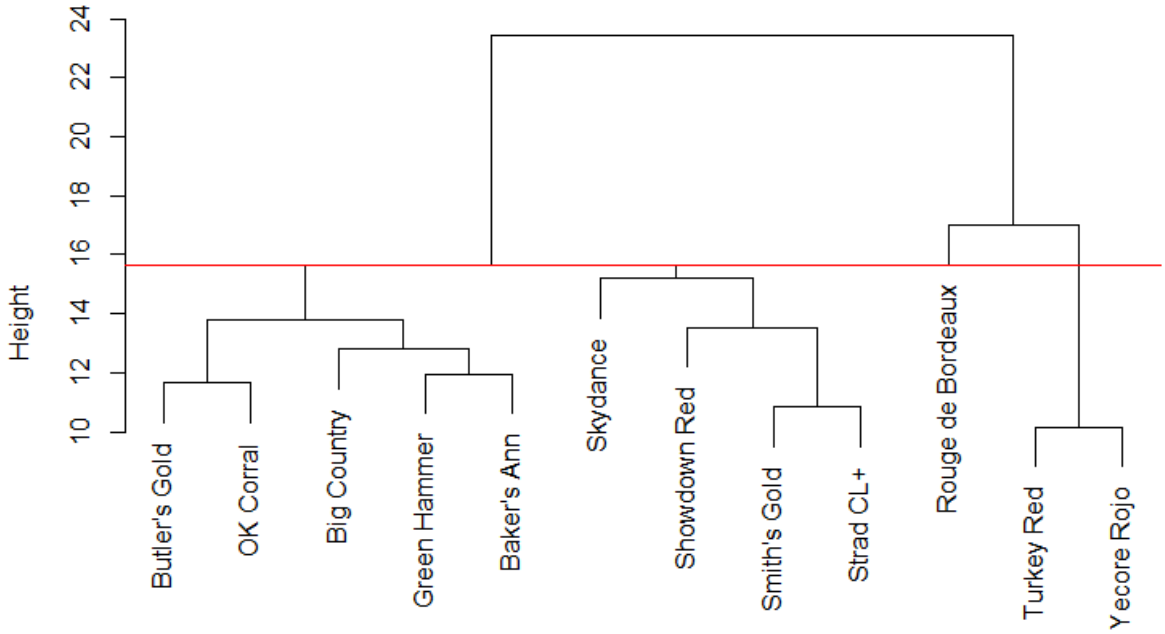

Figure 1.1. White Bread Sampling Dendrogram

Figure 1.2 provides a representative grid (or MDS plot) demonstrating the patterns subjects displayed in their own individual grid for white breads. For convenience, the clustering groups defined in Figure 1.1 are superimposed over the MDS plot. (The representative grid uses a different algorithm than that used to create Figure 1.1 so, while they should have similarities, there is no reason for them to reflect identical phenomenon.) Since the stress function for each bread groups are minimized, we can say the MDS plotting represents how the subjects constructed their grids across both white bread sampling sessions. The grid demonstrates a clear separation in the nine OSU and

the three heirloom varieties. It is important to remember the x- and y-axes have no meaning other than being a measure of flavor differences between varieties.

Although the OSU varieties are separated into two distinct groups, it would also be a reasonable interpretation of the dendrogram to place them into one single group. (There is no reason there should always be one set of class assignments that is unambiguously superior to all possible sets, and so in some circumstances it is helpful to identify alternative plausible sets.) Figure 1.1 also shows that a small increase in the horizontal line slice from clustering could easily show all nine OSU varieties could belong in the same group. The close proximity between Butler's Gold and Smith's Gold in Figure 1.2, and the small increase in distance needed to group all OSU varieties into one class as opposed to two, suggests that one can use a single group or two groups to describe the OSU varieties. Treating the two as one group for all OSU varieties shows 1) a strong dividing line between the perceived sensory properties of heirloom and OSU varieties (which partially reflects the presence of some germ and bran in the heirloom white flour) and 2) the flavor properties of sampled OSU varieties are perceived to be similar. The ultimate conclusion, then, is that all OSU varieties have similar flavor properties, but there are two subsets that display some differences.

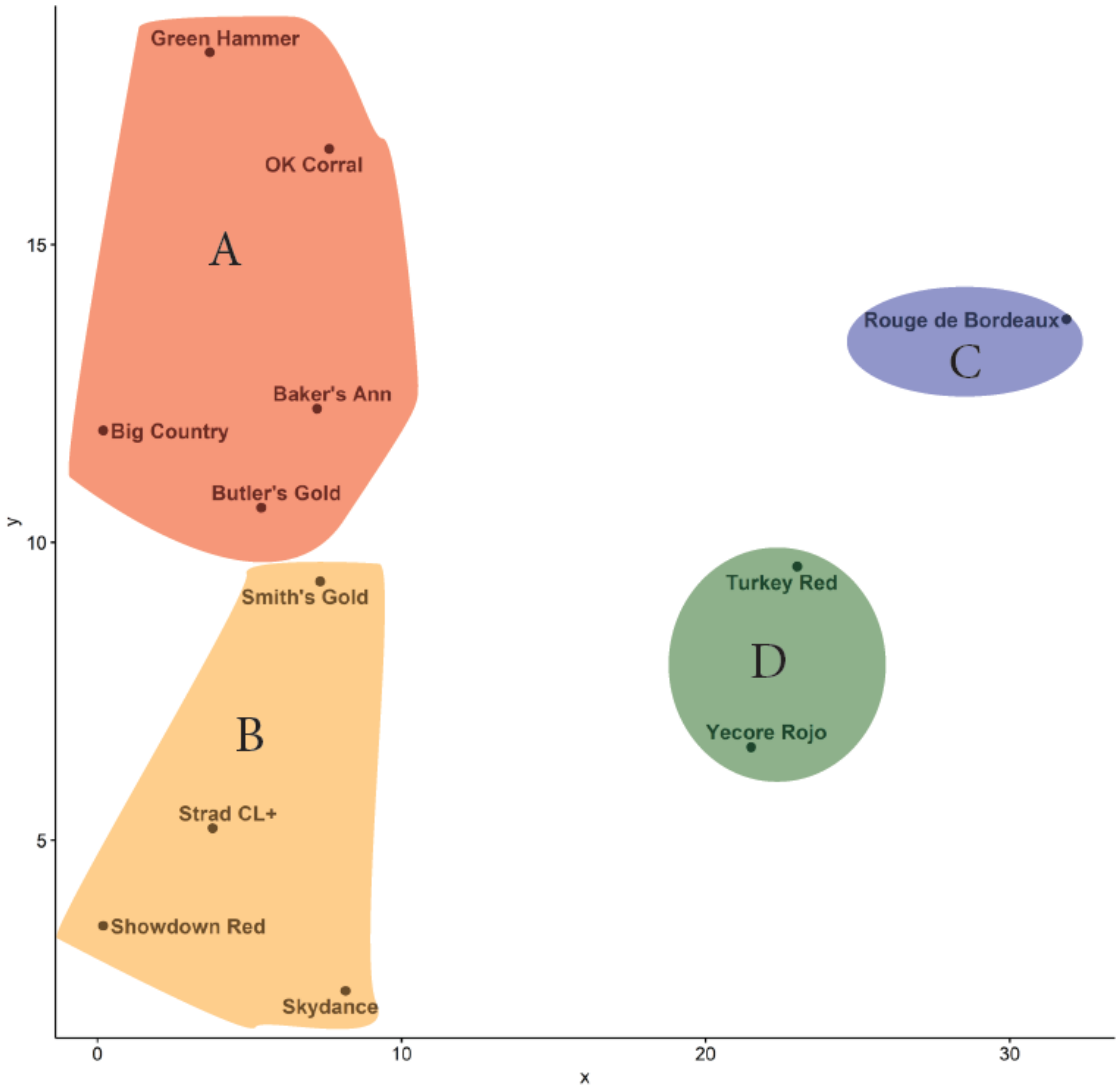

Figure 1.2. Ordinal MDS Plot of White Bread Samples

To better understand why these varieties are sorted into the four groups, consider the likeability scores shown in Table 1.2 and the keywords documented in the qualitative bread descriptions. Table 1.2 represents the total responses for both white bread session relating to the likeability of a variety. The values in parenthesis correspond to the assigned groupings from the clustering algorithm and holds no value other than to easily relate the groupings and likeability. Both average likeability scores and the number of times a variety was rated highest by a subject are shown. Two measures of likeability are

used to demonstrate that it is impossible to crown one variety as unambiguously superior, and to reinforce the idea that the highest average in likeability may not relate to the "best bread" for all occasions and all people. Because of this, the likable qualities of varieties are also highlighted through the qualitative bread descriptions given later. The last column is a count of the number of comments made for each variety. A response is counted regardless of if they are positive or negative.

Table 1.2. Likeability of White Bread Varieties

ID (Group B)	Variety (Class)	Average Likeability	Number of Times Variety was Rated Highest	Number of Descriptors Provided
226	Big Country (A)	6.79	3	53
696	Showdown Red (B)	6.67	3	58
562	Skydance (B)	6.64	4	57
851	OK Corral (A)	6.48	3	50
369	Smith's Gold (B)	6.36	1	61
509	Butler's Gold (A)	6.00	0	50
427	Turkey Red (D)	5.92	2	58
431	Strad CL+ (B)	5.79	0	58
713	Baker's Ann (A)	5.76	0	53
857	Yecore Rojo (D)	5.71	3	71
381	Green Hammer (A)	5.71	0	57
181	Rouge de Bordeaux (C)	4.93	1	59

Notes: Two subjects did not provide a likeability score. They are removed from average likability but included in the number of times a variety was rated the highest. Multiple varieties could be rated the highest by the same subject since the totals are aggregated across both white bread sessions.

There exists a clear distinction between heirloom and OSU varieties both from the clustering algorithm and MDS plot. For example, the heirloom variety Rouge de Bordeaux is placed in cluster C by itself. This grouping suggests the perception of this variety was more unique than other sampled varieties. Referring to Table 2, Rouge de Bordeaux was the least likeable (4.93 on a scale Likert-scale of 1-9) by a sizeable margin compared to other varieties. However, Rouge de Bordeaux was rated the highest by one

individual and while, on average, the variety was placed last in likeability, there are some quality characteristics that individuals enjoy. Rouge de Bordeaux's low average likeability rating helps explain why the clustering algorithm places it in a separate class from the other two heirlooms.

Interesting to note is the case of Butler's Gold, Strad CL+, Baker's Ann, and Green Hammer. These varieties were never rated the highest for any subject over both white bread sessions. One could assume these varieties would be the bottom four in average likeability. However, we see Butler's Gold, a variety that is never ranked highest, places higher for average likeability than some varieties (*e.g.*, Turkey Red and Yecore Rojo) that are ranked highest for. The average likeability ratings for the group is thus not representative of the ratings for any one subject.

A new variety developed by OSU, Big Country, had the highest likeability rating and was also the highest rating three times over the course of both focus group sessions. For this variety, we see a relationship between the average likeability and the number of times it was regarded as the top variety. Namely, the pattern exists for the top four varieties, Big Country, Showdown Red, Skydance, and OK Corral, where the large amount of highest ratings for individuals occur. Big Country was assigned to cluster A with four other similarly perceived varieties, Green Hammer, OK Corral, Baker's Ann, and Butler's Gold. Big County does differ from the other varieties in that it is a hard white variety, not hard red.

There is no correlation between number of descriptors and likeability score, as one might expect. Varieties assigned to cluster A along with Big Country do not all have superior average ratings. In fact, only the OK Corral variety reached the top five, coming

in fourth place among all varieties. Showdown Red, assigned to cluster B, only had the Skydance variety similarly placed for likeability. Furthermore, one could say that cluster D is related to its' likeability responses since Turkey Red and Yecore Rojo both are in the lower six varieties for likeability. Considering the range of likeability scores within assigned clusters, we now turn our focus to keywords used by our subjects in order to further understand perceptions of the varieties.

Whole Wheat Breads

As with the white bread samples, hierarchical clustering and MDS are conducted on the whole wheat bread responses. Before analyzing each subject's responses, it is worth noting that it is commonly thought that flavor differences due to the choice of wheat variety are more pronounced in whole wheat bread compared to white bread. This assumption may stem from the fact that whole wheat flour is made from all components of the wheat grain, i.e., the bran, germ, and endosperm (FDA, 2006), whereas white bread uses only endosperm. However, the results of the whole wheat bread analysis show the opposite. Figure 1.3 below shows the dendrogram created from the hierarchical clustering algorithm on the whole wheat bread sessions. A horizontal line cut is made at 15.7 on the y-axis line, identical to the white bread analysis. Distinguishing the dendrogram at this point and adopting the same hierarchical clustering algorithm gives us two significant groupings for the whole wheat bread samples:

- Group A consisting of Green Hammer, Baker's Ann, OK Corral, Yecore Rojo, Showdown Red, Strad CL+, Smith's Gold, and Skydance.
- Group B: Big Country, Butler's Gold, Rouge De Bordeaux, and Turkey Red.

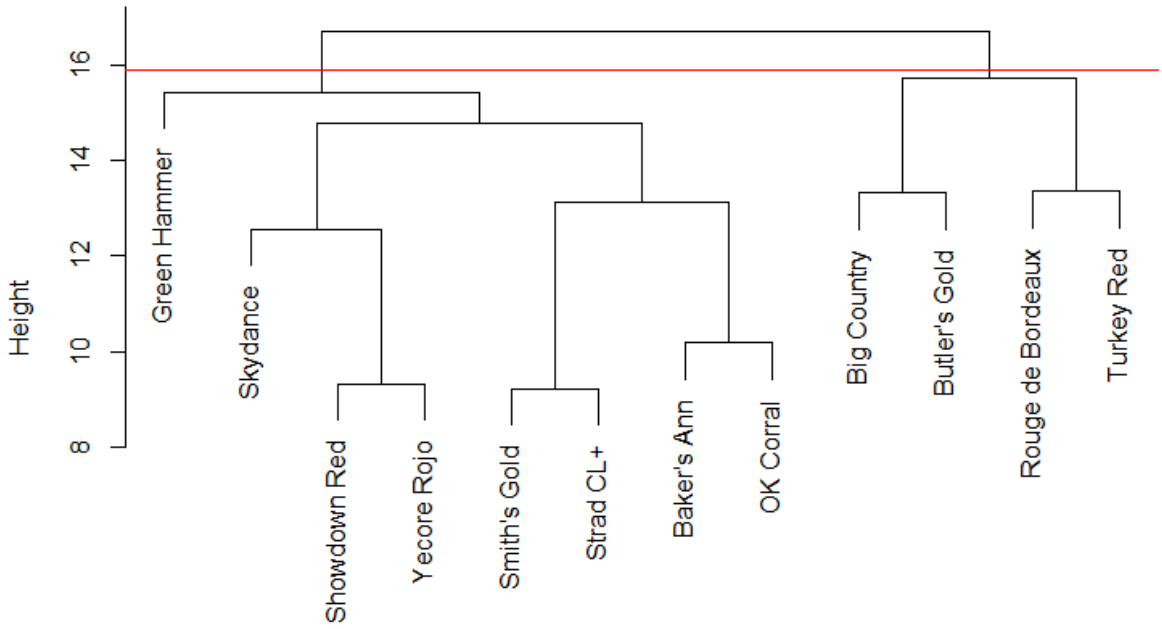

Figure 1.3. Whole Wheat Bread Sampling Dendrogram

Only defining two clusters across both whole wheat bread sessions shows that subjects who participated in the study were less able to perceive a difference among whole wheat breads as they were able to with white breads. This is consistent with the findings of Norwood and Albers-Nelson (2018). There is more consistency in the likeability scores and class assignments for whole wheat breads than white breads. For the whole wheat breads, varieties with the higher likeability scores are placed in the same class and those with lower scores in the same class.

Contrary to the white bread samples, there is no clear distinction between heirloom and OSU varieties. Yecore Rojo was the only heirloom variety grouped into cluster A while the remainder of varieties were grouped into cluster B. Yecore Rojo's distance from cluster B suggests that sensory properties of this variety are much different than the other heirloom varieties. In contrast, Big Country and Butler's Gold are the only two OSU varieties contained within cluster B. Worth noting is the fact that Green

Hammer and Skydance varieties are separated by large distances in the MDS plots for both the white and whole wheat case, suggesting these varieties lack compatibility and perhaps should not be combined in a flour. The ultimate goal is a scientifically rigorous and practically useful sensory methodology that can be incorporated into OSU's wheat breeding program.

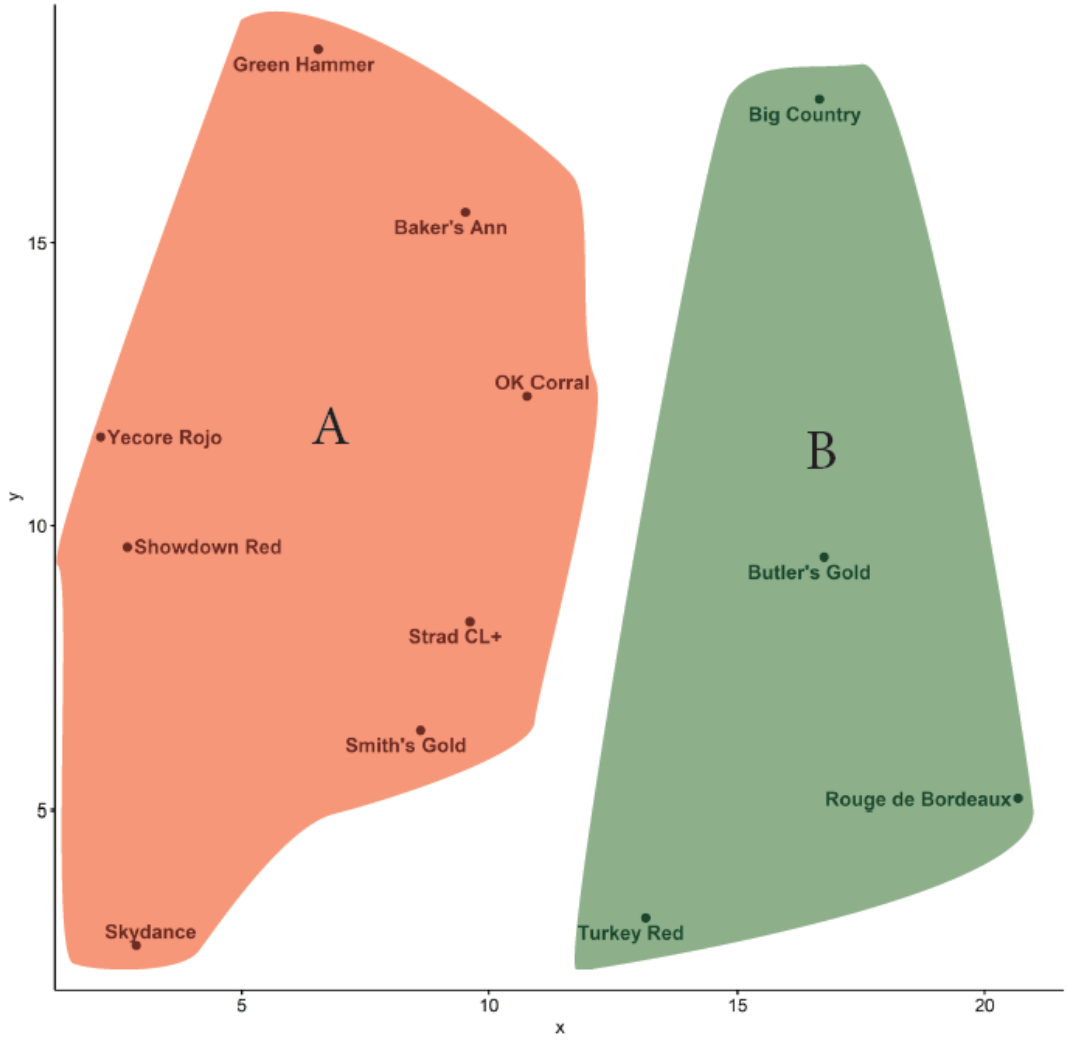

Figure 1.4. Ordinal MDS Plot of Whole Wheat Breads

Table 1.3. Likeability of Whole Wheat Bread Varieties

ID (Group B)	Variety (Class)	Average Likeability	Number of Times Variety was Place Highest	Number of Descriptors Provided
458 (573)	Green Hammer (A)	6.43	4	53
452 (837)	Yecore Rojo (A)	6.25	3	53
950 (254)	Baker's Ann (A)	6.14	6	63
798 (937)	OK Corral (A)	6.07	3	57
974 (140)	Showdown Red (A)	5.64	1	65
633 (235)	Strad CL+ (A)	5.64	1	61
245 (615)	Big Country (B)	5.36	3	46
522 (802)	Skydance (A)	5.29	1	64
147 (996)	Smith's Gold (A)	5.14	2	75
287 (747)	Butler's Gold (B)	5.07	2	50
762 (342)	Turkey Red (B)	4.29	1	61
362 (660)	Rouge de Bordeaux (B)	4.14	1	47

Notes: Multiple varieties could be rated the highest by the same subject since the totals are aggregated across both whole wheat bread sessions.

It is surprising that Rouge de Bordeaux has the lowest likeability score, given that it is a variety that has historically been touted for its superior flavor. This bodes well for the OSU wheat varieties, but it should also be acknowledged that boutique bakers using Rouge de Bordeaux are not necessarily using the same bread recipe in this study. It is likely they are using a more intensive and creative recipe that likely brings out the best in Rouge de Bordeaux, and perhaps the OSU varieties would not fare so well in these recipes. As such, these results suggest that OSU varieties are better tasting than Rouge de Bordeaux in all cases. Green Hammer, the most liked variety among whole wheat breads, was second-to-last for likeability for white breads. This suggests the Green Hammer germ and bran might possess special chemical properties that provide a satisfactory eating experience. The overall likeability scores for whole wheat bread are lower than

white breads, e.g., the top whole wheat variety had a score of 6.43 and the top white bread had a score of 6.79. This might reflect consumers' overall preference for white breads in such an eating experience and/or the superiority of white flours in this particular recipe.

To better understand the class memberships and likeability ratings, we refer to the qualitative bread descriptions derived from all focus group sessions and the keywords split by bread type contained within tables in Appendix C and D.

Qualitative Bread Descriptions

If a wheat breeding program is going to include sensory analysis, it would be helpful to develop a list of keywords that describe variety flavors. In pursuit of this, keywords are collected from the questionnaire. These keywords can then be used to help explain the likeability scores and class membership assignments described previously, as well as provide an evidence-based vocabulary for marketing the wheat varieties.

Table 1.4 below represent the adjectives subjects used to describe each heirloom variety over both white and whole wheat bread sessions. They are divided into attribute groups: texture/flavor, crust, aftertaste, color, and aroma. Since Table 1.4 is a combination of both white and whole wheat bread samples, there are some keywords such as "white-bread" and "wheaty" that only describe the white or whole wheat bread sample, respectively. There are also many instances where the same keyword is used in some capacity to describe each variety. In that case, we are more interested in keywords that are unique to a variety rather than repeated keywords used across every variety, such as "dry", "earthy", "bitter", "chewy", and "soft.". We also pay special attention to the top

10 keywords provided in Appendix E when comparing varieties, since we assume these keywords are the main descriptors of the breads.

Flavor is influenced by texture (Spence, 2017), and we did not ask subjects to evaluate texture separately from flavor. As such, keywords regarding texture and flavor are reported in the same attribute group. In analyzing the keyword responses, our focus is 1) relating keyword usage to likeability and class membership assignment and 2) understanding the true meaning of keywords that capture the uniqueness of each variety. Since our Napping exercise(s) show a clear distinction between the OSU and the heirloom varieties, keywords regarding the heirlooms are discussed first.

Heirloom Varieties

Unique keywords only pertaining to Rouge de Bordeaux (*e.g.*, herby, old, pungent) help explain why this variety was the least likeable over all bread samples. Focus group transcripts testify that "herby" means a fennel or rosemary taste, and that subjects generally associated this with a less likeable bread. The descriptor is divisive since some subjects appreciated an "herb" taste while others did not. "Old" and "pungent" are meant as negative descriptors with "old" meaning our subjects did not perceive the bread to be fresh, while "pungent" is supposed to capture the bitterness/aggressiveness of the variety. Subjects tended to prefer varieties that were less aggressive and more "light" in flavor. Recall that Rouge de Bordeaux was ranked highest for one individual; they described the variety as "strong", "bold", and "dense." Thus, while its strong taste was a detractor for most it was specifically appealing to one subject.

Turkey Red was described as a "fruity", and "spicy" variety. From the focus group conversations, it is evident these keywords reflect a different valence, as subjects

enjoyed varieties that had an element of sweetness/fruitiness and tended to dislike variety that were “spicy”. Turkey Red was ranked the highest for three individuals over both white and whole wheat bread sessions with the keywords “light”, “character”, and “sweet.” Referring to focus group transcriptions, we know “character” relates to the varieties’ ability to positively stand-out among the varieties. In addition, we see that “light” and “sweet” are used as positive descriptors for a variety and could lead one to believe these are the main factors subjects tended to seek out in a wheat variety.

Yecore Rojo contained many of the identical keywords as the previous two varieties, with an addition of “balanced” and “flavorful.” Both keywords here are perceived as positive and are likely the reason for Yecore Rojo’s higher likeability in whole wheat bread samples. Referring to the group discussions, our subjects remarked that “balance” describes the relative intensity of flavors across the crumb and crust while “flavorful” describes the absolute intensity of flavors within the bread crumb. Again, referring to Table 1.2 and 1.3, we can see that Yecore Rojo was regarded as the highest variety six times. Keywords used to describe Yecore Rojo when ranked the highest was “toasty”, “malty”, “soft”, and “earthy.

Table 1.4. Texture/Flavor Keywords for Heirloom Varieties across White and Whole Wheat Bread Sessions

Rouge de Bordeaux 181, 362 (660)	Turkey Red 427, 762 (342)	Yecore Rojo 857, 452 (837)
	Texture/Flavor	
Acrid	Bitter	Acidic
Bitter	Bland	Acrid
Bland	Chewy	Balanced
Bold	Crumbly	Bitter
Chewy	Darker	Chewy
Coarse	Dense	Coarse
Darker	Dry	Crumbly
Dense	Earthy	Darker
Dry	Elastic	Dense
Earthy	Fruity	Dry
Fluffy	Grainy	Earthy
Herb	Holes	Elastic
Holes	Light	Flakey
Malty	Malty	Flavorful
Nutty	Moist	Fluffy
Old	Nutty	Grainy
Plain	Plain	Light
Pungent	Rich	Malty
Rye	Rye	Moist
Smooth	Smooth	Nutty
Soft	Soft	Salty
Sour	Sour	Smooth
Spicy	Spicy	Soft
Sweet	Spongy	Sour
Toasty	Sweet	Spongy
Wheaty	Toasty	Sweet
	Wheaty	Wheaty
		Yeasty

Table 1.5 is a continuation of the heirloom variety keywords with considerations for the bread's crust, aftertaste, color, and aroma. All breads had similar color-related keyword responses and as such, are retained more for documenting rather than

comparison purposes. The goal in gathering descriptors for other parts of the bread besides texture/flavor is to get a more detailed and well-rounded description of the impact a variety has on all aspects of the baking process. For instance, crust attributes such as, “difference” for Rouge de Bordeaux, “dense” for Turkey Red, and “strong” for Yecore Rojo highlight the unique characteristics each variety imparts.

Referring to the transcribed group discussions, “difference” is relaying a perceived difference in the texture of the crust and crumb. Having a different texture in the crust was not well received among subjects and explains a part of Rouge de Bordeaux’s class membership and likeability results. “Dense” describing Turkey Red was used to highlight the heavier breads and is a reason the variety was not superior in either of the taste tests. Yecore Rojo was well received for whole wheat breads with a “strong,” and “sweet” crust. However, it was not well received in the white bread sessions with the terms “acrid”, and “dense” used to describe the crust. Again, we know from group discussions, the term “acrid” relates to a burnt taste of the bread, a taste not often sought in baked goods. (Recall the white flour for the three heirlooms actually contained small amounts of bran and germ.)

Aftertaste was a point of contention with the subjects. Some felt that an aftertaste was good while others did not enjoy it. Besides Rouge de Bordeaux having a “bad” aftertaste, many subjects considered the aftertaste and aroma to be “pungent” and lacked redeemable factors subjects looked for in a bread. In addition, Turkey Red was described to have a “sweet” and “good” aftertaste with a “floral” and “fresh” aroma but was not enough to change the average subject’s perception of the bread considering the negative crust attributes. Yecore Rojo had many descriptors for the aftertaste with “bad”, “bitter”,

and “earthy.” Subjects tended to describe earthy as a “soil like” taste with some expressing appreciation and some not. Subjects described the bitterness to be related to a burnt taste but with more caramelization. Among other descriptors used for the other heirloom varieties, it was described as “warm”, “sour” and “yeasty.” Warm generally reminded subjects of a fresh bread while “sour” and “yeasty” captured bitterness in the smell. As the breads were not described as a sourdough bread, most subjects reacted negatively to sour and yeasty flavors.

Table 1.5. Keywords for Heirloom Varieties across White and Whole Wheat Bread Sessions

Rouge de Bordeaux 181, 362 (660)	Turkey Red 427, 762 (342)	Yecore Rojo 857, 452 (837)
	Crust	
Chewy	Bitter	Acrid
Darker	Dense	Chewy
Difference	Dry	Darker
	Toasty	Dense
		Dry
		Strong
		Sweet
		Toasty
	Aftertaste	
Bad	Dry	Bad
Bitter	Good	Bitter
Pungent	Sweet	Dry
Sour		Earthy
		Sour
	Color	
Dark	Dark	Dark
	Light	Light
		Wheat
	Aroma	
Pungent	Bland	Acrid
Sweet	Floral	Good
Whole Wheat	Fresh	Great
	Good	Sour
	Great	Toasty
	Nutty	Warm
	Sweet	Whole Wheat
	Whole Wheat	Yeasty

OSU Varieties

This section focuses on the keyword responses for the nine OSU varieties. Keywords are again split into attribute groups with Tables 1.6 and 1.7 being a combination of white and whole wheat bread sessions. Table 6 contains the texture/flavor keywords and Table 1.7

with the remainder of the attribute categories: crust, aftertaste, color, and aroma. To accentuate keywords associated with more unusual likeability ratings, we concentrate on three varieties: Big Country, Green Hammer, and OK Corral. Big Country and Green Hammer each were the most liked variety for white and whole wheat bread, respectively. On the other hand, OK Corral was the only variety that maintained the same placement, coming in fourth across white and whole wheat bread samples.

Beginning with Table 1.6, we start with some of the unique keywords to understand why these varieties were positively (or negatively) received in each session. Big Country is described to be like “brioche”, a term that is synonymous with the bread having light and sweet characteristics. It’s also said to have a “mineral” taste that relates to the keyword “earthy” with them both describing a soil-like texture/flavor. Referring to Table 1.7, the crust, aftertaste, and aroma were described to be “malty”, “sweet”, and “floral”, respectively. “Malty” was described to taste like malt flavoring often added to milkshakes and most subjects agreed this was a good trait for crust flavor. However, Big Country dropped in likeability from first in white bread to seventh for whole wheat bread, with keywords such as, “acrid”, “bland”, and “sour” used to describe Big Country’s whole wheat sample. Referring to the previous description of these terms, one can assume they had a negative impact on Big Country and its likeability among subjects when tasting whole wheat breads.

The Green Hammer variety was eleventh for likeability among white breads but was first for whole wheat bread samples. Keywords such as “acidic”, “bitter”, “oily”, and “salty” for texture/flavor, and a “sour” aftertaste highlight the negative perception the variety had among white bread samples. Its redeeming factor as a white bread is its

"flavorful" crust and "floral" aroma. The keywords used for the whole wheat descriptors of Green Hammer were like most other varieties' descriptors. Therefore, we choose to mainly refer to group session discussions where subjects stated Green Hammer reminded them of an actual whole wheat bread they would buy in the store, explaining why the variety placed higher in whole wheat than white breads.

OK Corral, a Gallagher progeny that has historically been known for improved baking quality, had the same likeability ranking regardless of the form of bread. A main keyword that set it apart from the rest is "coffee." Subjects said the variety had an enjoyable coffee-like taste and was unique among the samples. Many keywords used to describe this variety are the same descriptors as other samples.

As is with the heirloom varieties, we are interested in understanding why OSU varieties were ranked the highest for individuals. There are OSU varieties ranked highest numerous times for the whole wheat bread sessions while never being ranked highest in the white bread sessions. Baker's Ann and Green Hammer were two varieties not ranked the highest over both white bread sessions while being ranked the highest variety six and four times for whole wheat bread, respectively. Some keywords used to describe Baker's Ann when it is the highest rank are "nutty", "toasty", "fruity", and "woodsy." While nutty and toasty are both common keywords used across the samples, fruity and woodsy are unique to Baker's Ann, showing that subjects prefer varieties with a sweeter element. Green Hammer, when ranked the highest, was described as "soft", "sweet", "tangy" and "nutty" variety. Again, these keywords are shared among multiple varieties and as such help researchers in understanding what descriptors to expect for future research.

Table 1.6. Texture/Flavor Keywords for OSU Varieties

Green Hammer 381, 458 (573)	Baker's Ann 713, 950 (254)	OK Corral 851, 798 (937)	Big Country 226, 245 (615)	Butler's Gold 509, 287 (747)	Strad CL+ 431, 633 (235)	Smith's Gold 369, 147 (996)	Showdown Red 696, 974 (140)	Skydance 562, 522 (802)
				Texture/Flavor				
"Holes"	Acrid	Acidic	"Holes"	Acidic	Acidic	"Holes"	Airy	Acidic
Acidic	Bitter	Airy	Acrid	Airy	Acrid	Acrid	Balance	Airy
Airy	Bland	Balanced	Airy	Balanced	Airy	Balanced	Bitter	Balanced
Balanced	Chewy	Bitter	Balanced	Bitter	Bitter	Bitter	Buttery	Bitter
Bitter	Dark	Chewy	Bland	Bland	Bland	Boujie	Chewy	Bland
Bland	Dense	Coarse	Brioche	Chewy	Burnt	Burnt	Cinnamon	Chewy
Chewy	Dry	Coffee	Buttery	Coarse	Ceramic	Chewy	Crumbly	Coarse
Coarse	Flavorful	Crumbly	Chewy	Crumbly	Chewy	Crumbly	Dense	Crumbly
Dense	Fruity	Dense	Dense	Darker	Coarse	Dense	Dry	Dark
Dry	Grainy	Dry	Dry	Dense	Dark	Dry	Elastic	Dense
Fluffy	Malty	Fluffy	Fluffy	Dry	Dense	Earthy	Flavorful	Dry
Hearty	Nutty	Grainy	Grainy	Elastic	Dry	Elastic	Fluffy	Flavorful
Herby	Old	Light	Light	Fluffy	Elastic	Flavorful	Grainy	Fluffy
Light	Plain	Malty	Malty	Grainy	Fluffy	Fluffy	Light	French
Moist	Salty	Nutty	Mineral	Light	French	French	Malty	Grainy
Nutty	Smokey	Salty	Plain	Malty	Fruity	Grainy	Nutty	Light
Oily	Soft	Sour	Smooth	Nutty	Light	Light	Plain	Moist
Plain	Sour	Sweet	Soft	Plain	Malty	Malty	Smokey	Not Malty
Roasted	Spongy	Toasty	Sour	Soft	Metallic	Nutty	Soft	Nutty
Salty	Sweet	Wheaty	Spongy	Sour	Nutty	Plain	Sour	Oily
Smokey	Tender		Sweet	Spongy	Plain	Smokey	Spongy	Plain
Smooth	Toasty		Toasty	Sweet	Soft	Soft	Sweet	Roasted
Soft	Tough		Wheaty	Toasty	Sour	Sour	Toasty	Smokey
Sour	Wheaty		Yeasty	Wheaty	Spongy	Spongy	Wheaty	Soft
Spongy	Woodsy			Yeasty	Sweet	Sweet	Yeasty	Sour
Sweet					Toasty White	Toasty		Spongy
Toasty					Bread	Wheaty		Sweet
Wheaty						Yeasty		Toasty
								Tough

	Wheaty
	Yeasty

Note: “Holes” refers to composition of cells within the bread crumb and is related to density. “Boujie” describes anything that is “upscale” or “fancy”.

Table 1.7. OSU Variety Keywords

Green Hammer 381, 458 (573)	Baker's Ann 713, 950 (254)	OK Corral 851, 798 (937)	Big Country 226, 245 (615)	Butler's Gold 509, 287 (747)	Strad CL+ 431, 633 (235)	Smith's Gold 369, 147 (996)	Showdown Red 696, 974 (140)	Skydance 562, 522 (802)
				Crust				
Browned Chewy Flavorful Malty Nutty Soft Acrid Dry	Chewy Darker Flavorful Acrid Bitter Dry Flakey Nutty Toasty	Soft Acrid Browned Dry Flakey Toasty	Browned Chewy Difference Malty Soft Toasty Wheaty Dry Flakey Flavorful Gritty	Chewy Light Nutty Tough Dry Flakey	Acrid Burnt Chewy Sweet Toasty Dry Nutty	Acrid Bitter Browned Burnt Chewy Nutty Toasty Dense Difference Flavorful Gritty Wheaty	Chewy Tough Nice Difference Flavorful Nutty Toasty	Chewy Flavorful Tough Bland Burnt Dry
				Aftertaste				
Sour	Nutty Sour	Bitter	Bitter Sweet	Bitter	Bad None	Smokey	Sour Sweet Fennel	Sweet Fennel
				Color				
Light Wheat	Dark Wheat	Dark Wheat	Buttery Yellow Light Wheat	Dark Light Wheat	Light White Wheat	Light Dark Wheat	Buttery White Yellow Light Wheat	Light Wheat
				Aroma				
Floral Good	Bitter Light	Toasty Sour	Aromatic Floral	Floral Good	Fresh Good	Good Nutty	Buttery Floral	Floral Fragrant

0	Standard Sweet Wheaty	Toasty Nutty Sweet Wheaty	Warm Wheaty	Light Standard Sweet Warm Wheaty	Wheaty Great Standard Sweet	Sweet White Bread Smokey Toasty Wheaty	Sweet Toasty Bad Smokey Wheaty Yeast	Nutty Toasty Standard Sweet Yeast	Whole Wheat Earthy

Focus Group Short-Responses Analysis

The last set of questions concerned the experiment overall. The first question related to how much the wheat variety influenced the flavor of the bread samples. An example of how the last questions are presented to our subjects is provided in Figure A.3 within Appendix A. The question is presented on a Likert-type scale from strongly disagree to strongly agree. To analyze responses, they are transformed into a scale of 1-7 and the average for the group is calculated. For example, if the response is a 1 then a subject strongly disagreed with the statement, and so on. The overall average for both focus groups including the whole wheat and white bread sessions together yielded a 5.5. That is, on average, a subject somewhat agrees (5) to agrees (6) that they were surprised how much the wheat variety influenced the flavor of the breads. Given the likely presence of acquiescence bias, whereby subjects prefer to agree rather than disagree with questions, this suggests only a modest element of surprise.

The next question asks if bread samples tasted mostly the same with an identical Likert-type scale applied. This is deliberately similar to the previous question to account for possible acquiescence bias. Overall, for whole wheat and white bread groups, the average was a 3.7, meaning, a subject somewhat disagreed (3) to neither agreed nor disagreed (4) with the question. Rounding 3.7 to 4, we can say it is likely the subjects had neutral feelings towards the question and were not sure if the bread samples tasted the same. Splitting averages by whole wheat and white bread, the results are 3.1 and 4.4, respectively, suggesting greater similarities between the whole wheat bread than the white bread. This result is consistent with the cluster analysis results.

The third question concerned whether it became more difficult to detect flavors of the bread and the experiment ensued due to palate exhaustion. There was a mostly even response with 15 subjects indicating they did, and 13 subjects stating they did not, suffer from palate fatigue at any point during the tastings. If a subject indicated they did have palate fatigue during the sessions, they were asked what sample in which it began. On average, subjects that indicated they did suffer from palate fatigue became fatigued after the seventh sample. (Note: there were only 14 subjects total between both focus groups, while there are 15 subjects who did suffer from palate fatigue, and this is due to each subject participating in two sessions. Therefore, a subject could be counted twice if their responses were the same for both sessions). The focus of this question is to tease out of the subjects where results could be skewed and require further analysis since they are likely not able to perceive flavors as often as more samples are tasted. We can then use this information to improve future focus groups when subjects are asked to taste a product.

Conclusion and Future Direction

This study initialized the first step in assessing perceived similarities and differences among OSU and heirloom wheat cultivars commonly used in commercial production. This was the first study to conduct a descriptive sensory in a specific wheat breeding program in an effort to explore how sensory analysis might be used in wheat breeding and marketing. Using 14 professionals in the food industry as subjects in sensory analysis and focus group sessions, they evaluated, in their own words, nine Oklahoma State University (OSU) and three heirloom wheat varieties.

The key characteristics of each variety provide valuable information on flavors each variety imparts to bread. These keywords can then be used to market the varieties and assess how distinct new varieties are to existing varieties in subsequent sensory analysis. Classification algorithms are also employed to determine which of the 12 varieties sampled impart the most similar flavors, which can be used by millers to ensure a consistent product when combining different wheat varieties.

Conclusions of the clustering and MDS plots suggest that (1) on average, subjects are less able to perceive variety characteristics among whole wheat samples compared to white bread samples (2) OSU varieties differ considerably and are liked better than traditional heirloom varieties marketed for their taste and (3) the heirloom Rouge de Bordeaux has the most distinct characteristics among all varieties regardless of bread-type. Relating likeability to clustering assignments, there is a pattern in the clustering of varieties that were well-received for white breads while whole wheat bread sampling was less distinct with only two significant clusters. Using keywords derived from subject's short responses, it can be said that subjects tend to prefer varieties that are "light" and "sweet." In fact, sweetness was a defining factor between clustering assignments for whole wheat samples. Furthermore, varieties that had an "acrid", "sour", or "dark" texture/flavor were not well received by subjects. Of course, these descriptions refer to settings where plain bread is consumed. In settings where bread is a component of a meal such flavors may complement the other components and become a positive attribute.

This study provided two types of information that will be used to design future sensory analyses for OSU wheat varieties. One type regards keywords that might be useful when using untrained food professionals as sensory analysts. These sensory studies

would be used to both highlight differences between OSU varieties as well as document how OSU varieties differ from other wheat types when used as bread. Overall, OSU varieties had similar flavor profiles, and were described as typical white breads in that they were generally sweet, light, and balanced (at least compared to the heirlooms). Those are keywords that could be used to generally describe breads made from OSU hard red winter wheat. An important note is that Big Country is a "white wheat" variety leading one to assume that it benefited from its lighter wheat grain in the white bread samples.

For keywords that help distinguish between OSU varieties, consider the differences between Green Hammer and Skydance for white bread, the two varieties most different from each other regardless of bread type. As shown in Table 2B, some keywords that were mentioned for one but not the other in the texture/flavor category (and are not captured by the terms sweet, light, and balanced) are "hearty", and "nutty". In the aftertaste category Green Hammer was described as sour while Skydance as sweet and fennel. In addition, Skydance had an earthy aroma crust that was described as burnt and chewy, and Green Hamer had a likeable floral aroma with a nutty and soft crust. Small and large millers alike are often interested in sourcing wheat varieties with nearly identical baking characteristics. Therefore, it is important to highlight the contrasting feelings towards these varieties since they are an example of varieties that would lack homogeneity in baking characteristics if milled into flour together.

Results suggest that the following keywords may be useful in similar studies to evaluate hard red winter wheat breads: sweet, light, balanced, hearty, nutty, sour, fennel (or perhaps herby), burnt, and chewy. One can imagine a simple rating system where

subjects evaluate the intensity of each attribute where a goal would be to improve the rating system used in this study and the responses given by our subject. Researchers can then easily understand their meaning and if the keyword has a negative or positive connotation. Results also suggest that the same words could have a positive or negative valence. “Earthy” is sometimes used as a positive attribute, but of course, an excessively earthy taste is not desirable. Thus, in addition to asking subjects to rate the intensity of an attribute it may be desirable to have them also indicate whether the intensity has a positive or negative valence.

Finally, asking subjects to taste plain whole wheat bread was useful for identifying some of their flavor properties but lacked the ability to capture how one may consume whole wheat bread. That is, most subjects would either consume whole wheat bread paired with a recipe or use a different recipe. Many of the participants shared their distaste for the whole wheat bread samples with “dry” and “bitter” being top keywords used to describe it. Researchers want to capture the flavor of the variety used in bread but do not want the recipe choice to distract from the variety’s flavor. As such, a change of recipe – or even maintaining the same recipe but pairing whole wheat bread samples with a food item are being considered to improve this portion of our study.

One shortcoming of this current study is that, while wheat samples were raised under similar production methods, they could have been grown in different Oklahoma regions. Future research will involve tasting the same variety grown in different regions to assess regional impacts on flavor. This future research will also borrow keywords from this study and ask subjects to evaluate the intensity of the keyword flavors to develop a more quantitative sensory description of the wheat varieties.

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APPENDICES

Appendix A. Questionnaire Provided to Subjects.

Sample 1

Taste the bread sample # _____ (after a sip of water and sniff of coffee). Please do not discuss what you taste until you have answered all the questions on this page and the moderator begins the discussion.

(1.a) In the space below please provide describe this bread.

(1.b) Are there any particular food items that would pair well with this bread? Or a particular way it should be consumed, given the bread's unique flavors?

(1.c) Using the scale below, how much do you like the taste of the bread?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like Nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely
☐	☐	☐	☐	☐	☐	☐	☐	☐

(1.d) Find the piece with the # _____ on it and place it somewhere on the grid. In future samples you will place them closer on the grid to breads they resemble and further from ones they don't, so we suggest you place this sample somewhere around the middle.

Figure A.1.1 Questionnaire Provided to Subjects for Each Bread Sample.

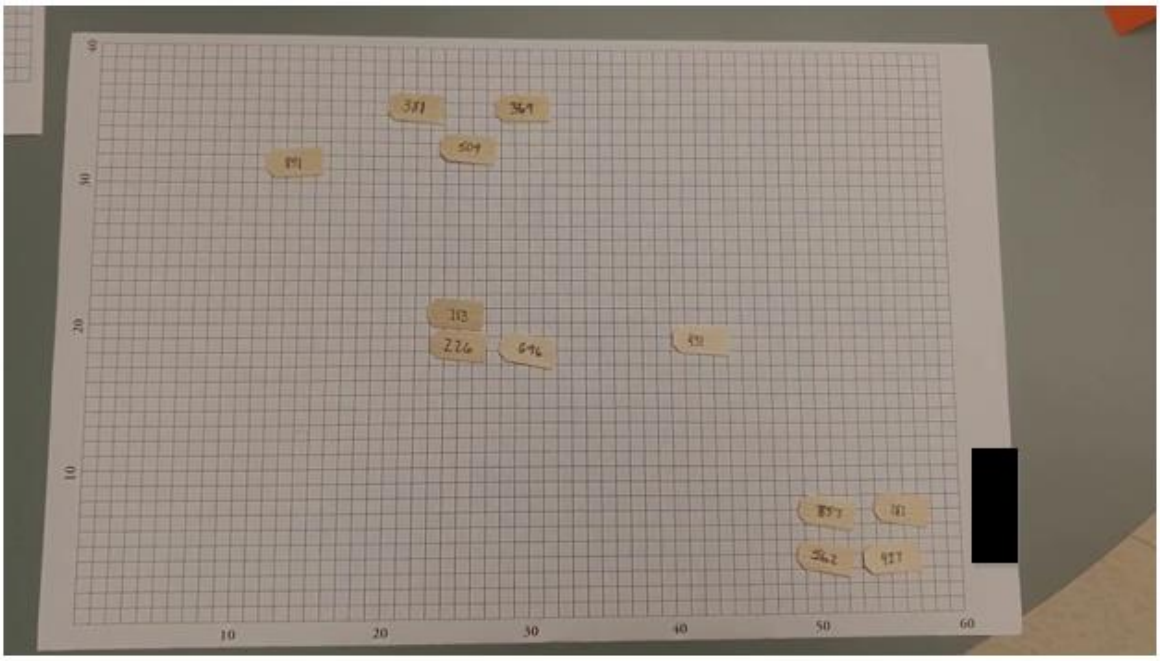
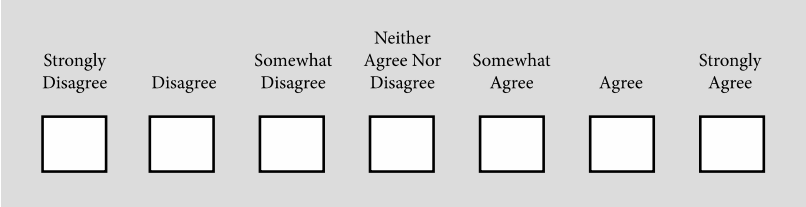
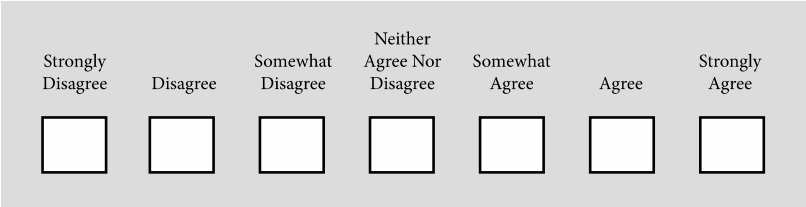


Figure A.1.2 Example of a Napping-Exercise Grid

(13) I am surprised how much influence the wheat variety has in the flavor of bread.



(14) The breads tasted mostly the same to me.



(15) Did your palate become weary in the process of tasting twelve samples, making it difficult for you to detect the distinct flavors of the breads?

☐ No

☐ Yes, my palate became weary after the _____ sample

(15) In general, were the breads distinguished more by their taste or by their aroma?

☐ Taste mattered more

☐ Aroma mattered more

☐ Taste and aroma mattered equally

☐ I don't know

Figure A.1.3 The last page provided to subjects in the questionnaire. These questions sought to get feedback from subjects and improve future focus groups.

Appendix B. Total Within Sum of Squares

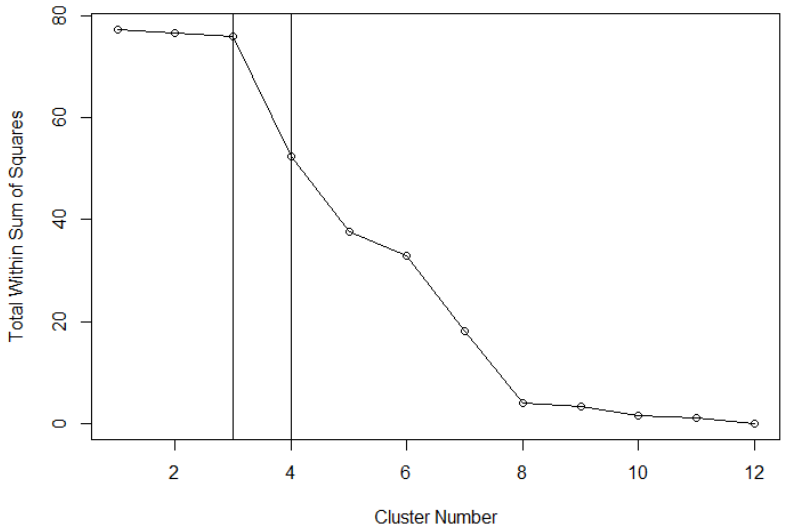


Figure B.1.1 Total Within-Cluster Sum of Squares - Average Link, White Bread

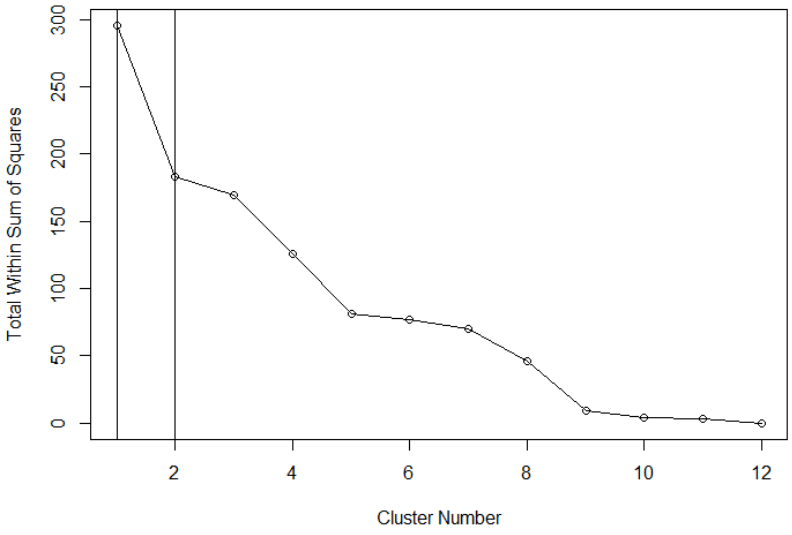


Figure B.1.2 Total Within-Cluster Sum of Squares - Average Link, Whole-Wheat Bread

Total within sum of squared errors (TWSS) for each grouping assignment is used as a metric to measure the variability of wheat varieties within each cluster. Specifically, TWSS measures the squared average distance of all the points within a cluster and is shown in Figure B.1 and Figure B.2 for white and whole wheat bread samples, respectively. Where each "clustering number" is the number of clusters determined using hierarchical clustering methods, i.e., "2" means wheat varieties are divided into 2 groups, while "12" means each variety is assigned to its own cluster. TWSS is calculated using the sum Euclidean distance of each observation in a cluster to its centroid. Using R statistical software, the centroid for each cluster is calculated and Euclidean distance is iterated for each observation within a cluster. Euclidean distance for each point is summed then divided by the number of observations. One drawback of using TWSS as a metric is the influence of observations on variation. For example, "1" cluster would have the highest variance while "12" clusters would have no variance. If chosen only for minimized variance, then 12 would be the optimal choice. Of course, this does not make sense in terms of clustering similar samples together. In this case, clusters that make sense based on the largest drop in variation and a subject's feelings towards varieties are retained. Referring to Figure B.1, we chose to retain four clustering assignments since it had a steep drop in variance and clusters Rouge de Bordeaux in its own group. This makes sense since the variety was the least liked and most distinct among all white bread samples. For whole wheat samples in Figure B.2, two cluster groups are retained. The rationale for retaining two groupings is based on the decrease for within cluster variation. In this respect, grouping assignments for whole wheat bread samples are less strict since perceptions of the varieties when baked into whole wheat bread are less distinct.

Appendix C. Additional White Bread Keyword Tables

Table C.1.1 Heirloom Variety Keywords from White Bread Sampling

Rouge de Bordeaux	Turkey Red	Yecore Rojo
181	427	857
	Texture/Flavor	
Acrid	Bitter	Acrid
Bitter	Chewy	Balanced
Bold	Darker	Bitter
Chewy	Dense	Chewy
Darker	Dry	Coarse
Dry	Grainy	Darker
Earthy	Light	Dense
Fluffy	Malty	Dry
Holes	Moist	Earthy
Malty	Nutty	Flakey
Plain	Plain	Fluffy
Pungent	Rye	Grainy
Rye	Soft	Light
Smooth	Sour	Malty
Sour	Spongy	Nutty
Spicy	Sweet	Soft
Sweet	Wheaty	Sour
Wheaty	Toasty	Spongy
Toasty		Sweet
		Wheaty
		Yeasty
	Crust	
Chewy	Bitter	Acrid
Darker	Dense	Chewy
		Darker
		Dense
		Sweet
		Toasty
	Aftertaste	
Pungent	Dry	Bitter
		Dry
	Color	
Dark	Light	Dark
	Aroma	
Pungent	Fresh	Acrid
Sweet	Nutty	Toasty
Whole Wheat	Whole Wheat	Warm
		Whole Wheat

Table C.1.2 Texture/Flavor Keywords for White Breads made from OSU Varieties

Green Hammer 381	Baker's Ann 713	OK Corral 851	Big Country 226	Butler's Gold 509	Strad CL+ 431	Smith's Gold 369	Showdown Red 696	Skydance 562
Texture/Flavor								
Acidic	Acrid	Airy	Airy	Airy	Acrid	Acrid	Airy	Acidic
Airy	Bitter	Balanced	Balanced	Balanced	Airy	Balanced	Balance	Airy
Balanced	Bland	Bitter	Bland	Bitter	Bland	Bitter	Bitter	Balanced
Bitter	Chewy	Chewy	Brioche	Bland	Burnt	Bouijie	Buttery	Chewy
Chewy	Dense	Fluffy	Buttery	Chewy	Ceramic	Burnt	Crumb	Crumb
Dense	Dry	Light	Chewy	Darker	Chewy	Chewy	Dense	Flavorful
Dry	Grainy	Malty	Dry	Dense	Fluffy	Flavorful	Dry	Fluffy
Fluffy	Malty	Nutty	Fluffy	Dry	French Bread	Fluffy	Flavorful	French Bread
Hearty	Nutty	Salty	Light	Fluffy	Light	French Bread	Fluffy	Light
Nutty	Plain	Sweet	Malty	Light	Malty	Grainy	Grainy	Moist
Oily	Salty	Toasty	Mineral	Malty	Metallic	Light	Light	Not malty
Plain	Soft		Plain	Nutty	Nutty	Malty	Malty	Oily
Roasted	Sour		Smooth	Plain	Plain	Nutty	Nutty	Plain
Salty	Spongy		Soft	Soft	Soft	Plain	Plain	Roasted
Smooth	Sweet		Sour	Sour	Spongy	Soft	Soft	Soft
Soft	Tender		Spongy	Spongy	Sweet	Spongy	Sour	Sour
Sour	Toasty		Sweet	Sweet	Toasty	Sweet	Spongy	Spongy
Spongy	Tough		Toasty	Toasty	Toasty	Toasty	Sweet	Sweet
Sweet	Wheaty		Wheaty	Wheaty	White Bread	Wheaty	Toasty	Toasty
Wheaty			Yeasty	Yeasty		Yeasty	Wheaty	Tough
							Yeasty	Wheaty

Table C.1.3 Keywords used to Describe White Breads made from OSU Varieties

Green Hammer 381	Baker's Ann 713	OK Corral 851	Big Country 226	Butler's Gold 509	Strad CL+ 431	Smith's Gold 369	Showdown Red 696	Skydance 562
				Crust				
Browned	Chewy	Soft	Browned	Chewy	Acrid	Acrid	Chewy	Chewy
Chewy	Darker		Chewy	Light	Burnt	Bitter	Tough	Difference
Difference	Flavorful		Difference	Nutty	Chewy	Browned		Flavorful
Flavorful			Malty	Tough	Sweet	Burnt		Tough
Malty			Soft		Toasty	Chewy		
Nutty			Toasty			Nutty		
Soft			Wheaty			Toasty		
				Aftertaste				
Sour	Nutty	Bitter		Bitter	Bad		Sour	Sweet
	Sour						Sweet	
				Color				
Light	Light		Buttery	Dark	Light	Light	Buttery	Light
			Yellow	Light	White		White	
							Yellow	
				Aroma				
Floral	Bitter	Toasty	Aromatic	Floral	Fresh	Good	Buttery	Floral
Good	Light		Floral	Good	Good	Nutty	Floral	Fragrant
	Toasty		Light	Wheaty	Sweet	Sweet	Nutty	Whole Wheat
					White Bread	Toasty	Toasty	

Appendix D. Additional Whole Wheat Bread Keyword Tables

Table D.1.1 Keywords Used to Describe Wheat Bread made from Heirloom Varieties

Rouge de Bordeaux 362 (660)	Turkey Red 762 (342)	Yecore Rojo 452 (837)
	Texture/Flavor	
Acrid	"Holes"	Acidic
Bitter	Bitter	Acrid
Bland	Bland	Bitter
Coarse	Crumbly	Chewy
Dark	Dense	Crumbly
Dense	Dry	Dense
Dry	Earthy	Dry
Herb	Elastic	Elastic
Nutty	Fruity	Flavorful
Old	Grainy	Light
Soft	Rich	Moist
Toasty	Smooth	Nutty
Wheaty	Sour	Salty
	Spicy	Smooth
	Toasty	Soft
		Spongy
		Sweet
		Wheaty
		Yeasty
	Crust	
Difference	Bitter	Dry
	Dry	Strong
	Toasty	Toasty
	Aftertaste	
Bad	Good	Bad
Bitter	Sweet	Earthy
Sour		Sour
	Color	
Dark	Dark	Light
		Wheat
	Aroma	
Sweet	Bland	Good
	Floral	Great
	Good	Sour
	Great	Toasty
	Sweet	Wheaty
		Yeast

Table D.1.2 Texture/Flavor Keywords for White Breads made from OSU Varieties

Green Hammer	Baker's Ann	OK Corral	Big Country	Butler's Gold	Strad CL+	Smith's Gold	Showdown Red	Skydance
458 (573)	950 (254)	798 (937)	245 (615)	287 (747)	633 (235)	147 (996)	974 (140)	522 (802)
Texture/Flavor								
"Holes"	Chewy	Acidic	"Holes"	Acidic	Acidic	"Holes"	Bitter	Acidic
Bitter	Dark	Bitter	Acrid	Bitter	Acrid	Bitter	Chewy	Bitter
Bland	Dense	Coarse	Bland	Bland	Bitter	Crumbly	Cinammon	Bland
Chewy	Dry	Coffee	Chewy	Chewy	Bland	Dense	Crumbly	Chewy
Coarse	Flavorful	Crumbly	Dense	Coarse	Bland	Dry	Dense	Coarse
Dense	Fruity	Dense	Dry	Crumbly	Coarse	Earthy	Dry	Crumbly
Herby	Nutty	Dry	Grainy	Dense	Dark	Elastic	Elastic	Dark
Light	Old	Grainy	Light	Dry	Dense	Grainy	Flavorful	Dense
Moist	Smokey	Light	Soft	Elastic	Dry	Light	Grainy	Dry
Nutty	Soft	Nutty	Sour	Grainy	Elastic	Nutty	Nutty	Flavorful
Plain	Sweet	Sour	Sweet	Nutty	Fruity	Smokey	Plain	Grainy
Smokey	Toasty	Sweet	Toasty	Soft	Light	Soft	Smokey	Nutty
Soft	Wheaty	Toasty	Wheaty	Toasty	Nutty	Sour	Soft	Plain
Sweet	Woodsy	Wheaty		Wheaty	Soft	Sweet	Sour	Smokey
Toasty					Sour	Toasty	Spongy	Soft
Wheaty					Sweet	Wheaty	Sweet	Spongy
					Toasty		Toasty	Sweet
							Wheaty	Toasty
							Yeasty	Wheaty
								Yeasty

Table D.1.3 Keywords for White Breads made from OSU Varieties

Green Hammer 458 (573)	Baker's Ann 950 (254)	OK Corral 798 (937)	Big Country 245 (615)	Butler's Gold 287 (747)	Strad CL+ 633 (235)	Smith's Gold 147 (996)	Showdown Red 974 (140)	Skydance 522 (802)
				Crust				
"No Difference" Acrid Chewy Dry	Acrid Bitter Chewy Dry Flakey Nutty Toasty	Acrid Browned Dry Flakey Toasty	Dry Flakey Flavorful Gritty Toasty	Dry Flakey Nutty	Dry Nutty Toasty	Bitter Burnt Dense Difference Flavorful Gritty Toasty Wheaty	Nice Difference Flavorful Nutty Toasty	"No Difference" Bland Burnt Chewy Dry
				Aftertaste				
Sour			Bitter Sweet		None	Smokey	Fennel	Fennel
				Color				
Light Wheat	Dark Wheat	Dark Wheat	Buttery Light Wheat	Wheat	Wheat	Dark Wheat	Light Wheat	Wheat
				Aroma				
Standard Sweet Wheaty	Nutty Sweet Wheaty	Sour Warm Wheaty	Standard Sweet Warm Wheaty	Good Great Standard Sweet Wheaty	Good Smokey Sweet Toasty Wheaty	Bad Smokey Sweet Toasty Wheaty Yeast	Standard Sweet Yeast	Earthy Floral Wheaty

Appendix E. Top Ten Keyword Tables

Table E.1.1 Top Ten Keywords used to Describe White Bread Samples

Description	Count
Light/Fluffy	115
Sweet	66
Chewy	62
Malty/Toasty	50
Wheaty	39
Dry	38
Nutty	27
Dense	23
Bitter	22
Balance	21

Table E.1.2 Top Ten Keywords used to Describe Wheat Bread Samples

Description	Count
Dry	79
Dense	52
Sweet	42
Soft	38
Wheaty	35
Bland	30
Sour	24
Toasty	22
Nutty	21
Moist	18

CHAPTER II

DOES GROWING REGION IMPACT WHEAT FLAVOR?

Introduction

Wheat is often perceived as the classic commodity in agriculture. Much of the production surrounding wheat has been streamlined for yield and protein content of the grain. More recently, breeders have been turning their focus to the production of high-quality grains, with an emphasis on hybrid vigor. However, little focus has pertained to the flavor a variety imparts to baked goods (Norwood and Albers-Nelson, 2018, Loy et al., 2023). Currently, producers in Oklahoma rely on varieties developed at Oklahoma State University (OSU) to ensure plant genetics are adapted to local growing conditions (WIT, 2018, WIT, 2022). While hybrid vigor as it pertains to disease and pest resistance are important genetic traits, niche markets surrounding flavor of a variety are becoming increasingly popular in Oklahoma.

Oklahoma State wheat breeders do not have a formal mechanism for documenting a variety's flavor. Previous analyses have investigated taste considerations for particular wheat cultivars and have shown untrained assessors can perceive differences in flavor (Norwood and Albers-Nelson, 2018, Loy et al. 2023). These studies did not account for flavor differences among the same wheat cultivar across different growing regions. Pursuing an understanding of regional impacts is important since many commercial

millers already purchase large sums of wheat across multiple regions, where varieties are milled together for similar protein percentages. Soil-type, weather conditions, and agricultural practices are just a few regional differences a wheat producer faces in a growing season. These different agricultural practices (e.g., tilling, irrigation, and dryland), temperatures, or soil-types (e.g., nitrogen amounts in Oklahoma soils) play a crucial role in flavor of wheat grain, which is a critical factor in determining the quality of wheat grain at harvest.

As explored in previous studies, there is an emerging interest for value-added marketing channels for certain wheat cultivars (Loy et al., 2023). Currently, these marketing channels are in the emerging stages and have a focus on niche millers and boutique bakers. Independent millers in Oklahoma have begun using OSU wheat varieties to develop a demand for variety-specific flour and market the product to boutique bakeries. The current scale of value-added wheat production is small; since most wheat producers grow a particular variety that has been bred for regional specific pest, disease, and drought resistance. These varieties are utilized by the wheat producer in order to maintain profitable yield per acre and limit production costs. The aim of developing marketing channels is to pull dollars back to the producer should they choose to grow certain wheat cultivars that have a higher demand in the marketplace (i.e., a premium to grow varieties). A variety which has high demand in the marketplace due to its flavor or baking characteristics may not be the same variety that is ideal to grow in that location. The goal is to discover if there is an avenue to incentivize producers to cultivate wheat cultivars that are promoted for their superior flavor. Due to the current

scale of value-added wheat production, the supply of specific wheat cultivars would need to adapt to a growing demand if marketing channels are to be further developed.

Since the current market structure for variety specific flour is small, scalability in certain wheat varieties will require sourcing the grain from further regions. Therefore, special attention paid to maintaining desired flavor characteristics will become increasingly important to millers. This research seeks to further document the flavor imparted by major OSU wheat varieties while accounting for the region they are grown in. Using five OSU wheat cultivars, each sourced from two growing regions, the objective is to analyze characteristics of varieties and the extent to which growing region impacts flavor. Twelve chefs tasted the bread and 1) completed a questionnaire 2) participated in focus group discussions and 3) completed a napping ultra-flash profile exercise. The questionnaire and discussions identify unique characteristics of OSU varieties and their growing region's impact on flavor. Napping ultra-flash profile data are analyzed using clustering algorithms to group varieties that have similar flavor properties.

Background on Regional Impacts and Bread Sensory

Growing regions can impact grain quality in a multitude of ways. For example, studies focusing on protein concentration in wheat grain are increasingly popular (Asseng et al., 2018, Bloom and Plant, 2021). Research has focused on the growing region as an important factor influencing protein concentration and overall grain quality. In the case of this research, similarities are drawn from studies on grain quality and protein concentration to highlight the importance of flavor considerations in different regions.

Regional impacts on wheat can be divided into categories such as climatic change (e.g., high temperature or abnormal rainfall), soil type, and agricultural practices of a specific area. Research such as Asseng et al. (2018), has investigated changes in wheat

grain quality in the presence of climate change. Their study found wheat grain quality was significantly diminished in regions of Australia with variable rainfall and higher temperatures than the country's average. Where protein yields were shown to be highly variable in regions with low-rainfall. The study highlighted potential benefits of increasing atmospheric carbon dioxide on nitrogen uptake with these benefits being negated from rising temperatures and changes in rainfall. Bloom and Plant (2021) provide a comprehensive study on the rise of temperatures impact on wheat grain quality while accounting for other factors like cultivar, location, and water availability. Results show that over the period of 1985 – 2019, wheat protein yield declined 13% (Bloom and Plant, 2021).

Soil type and agricultural practices of wheat cultivation simultaneously influence each other. That is, the soil type of a region often requires different agricultural practices such as fertilizer application requirements. For example, nitrogen in the soil is closely related to the protein concentration in wheat grain. Li et al. (2016) investigated nitrogen application rates at different growth stages of wheat under varying soil conditions and found nitrogen application timing and pre-plant nitrogen levels in the soil greatly influence protein concentration at harvest. At the same time, increasing atmospheric temperatures also influence nitrogen levels in the soil. Kimball et al. (2001) found growing regions with higher temperatures and elevated carbon dioxide concentrations will increase negative effects of low soil nitrogen; however, the effects were mitigated by the application of nitrogen.

Sensory analyses are often employed to investigate differences in taste and texture in bread, where a trained panel of assessors or industry professionals provide perceptions

of flavors. Bread sensory analyses have only been recently refined and utilized in a professional capacity (Elia, 2011; Callejo, 2011; Norwood and Albers-Nelson, 2018; and Loy et al. 2023). For example Elia (2011) compiled a methodology and procedure for the evaluation of bread samples by defining a set of descriptive terms relating to visual, odor, flavor, and texture with crust and crumb attributes of the bread considered separately. Similarly, Callejo (2011) serves as a starting point to standardize the profile of bread flavors using trained sensory assessors while also comprising a list of possible flavors of bread with the respective intensities and meaning of each flavor. For example, the aroma of a bread could be described as "nutty." In this instance, "nutty" could impart varying intensities depending on the assessor's perception and relates to the aroma characteristics of mixed nuts such as, walnuts or hazelnuts (Callejo, 2011).

The use of trained assessors can be costly and time consuming (Hersleth et al. 2005). Therefore, using existing literature as a basis for a sensory methodology, procedure, and keywords are important if one uses a panel of untrained assessors. Norwood and Albers-Nelson (2018) employed a panel of untrained assessors to see if the untrained panel of typical consumers can distinguish between wheat varieties baked into bread. Results indicate the consumers can distinguish between breads made from similar varieties and the extent to which they can distinguish depends on the wheat variety (Norwood and Albers-Nelson, 2018). Loy et al. (2023) extended bread sensory analysis by recruiting food industry professionals to develop flavor profiles of OSU and heirloom wheat varieties. This study served as an exploratory analysis in developing flavor profiles for OSU varieties and laid the foundation such that future studies can adopt a more rigorous quantitative instrument to highlight differences among wheat varieties. Loy et al.

(2023) also outlined how to 1) use untrained food professionals in a focus group setting, 2) employ open-ended questionnaires and Likert-type answers, and 3) how to conduct and analyze a Napping Ultra-Flash Exercise.

The purpose of this research is to determine to what extent growing region impacts the sensory properties of bread produced from OSU flour. The target audience is food industry professionals such as chefs, bakers, business owners, and millers. Results of this study are to be used in a food industry capacity. For this research, food industry professionals with minimal sensory training are employed. Following methodologies used in previous studies, we employ focus groups, Likert scales, and Ultra-Flash Napping exercises to evaluate regional differences in wheat grain flavor. A non-parametric sign test is then used to determine if there exist more similarities between breads of the same variety but grown in different regions that helps highlight if choice of variety or growing location has a bigger impact on the flavor imparted to baked goods.

Methods

Subjects

The sensory panel consisted of twelve subjects. Of the subjects, eleven are professionals in the food industry in some capacity (e.g., a head/sous chef, professional miller, or owner of a restaurant) while one has a reputation for being an at-home gourmet with an extensive background in food history. Six of the subjects have participated in similar bread sensory studies and are familiar with the design and purpose of the experiment. Each participant was local to Oklahoma, recruited personally, and compensated $590 to participate in two separate focus group sessions. The twelve participants were split into a seven-person (Group A) and five-person group (Group B). One participant did not participate in both sessions for Group B; therefore, they are only included in one session.

Group A attended the sessions on October 11 and 13 and Group B attended sessions October 18 and 20, both in 2022 and from 2 – 4 pm.

Materials

The motivation of this research is to identify differences in flavor profiles of bread made from five popular OSU varieties but grown in two different regions. Five OSU varieties were chosen based on the previous bread sensory analysis (Table 2.1). Varieties are retained for this study since they imparted distinct flavors to the bread and/or were highly regarded by the previous assessors. All varieties are categorized as hard red winter wheat, besides Big Country, which is a hard white winter wheat. Each variety included in this study is available to the public and is grown throughout Oklahoma.

The two growing regions considered were defined to be North and South of Interstate 40 in Oklahoma. Interstate 40 travels east-west across the center of Oklahoma and divides the state into two halves, north and south. These growing regions were chosen due to different climatic pressures across the state. Thus, each variety had a north and south counterpart in the study (e.g., Big County "North" and Big County "South"). The Oklahoma Wheat Commission and Oklahoma Foundation Seed Stocks procured all five varieties for each region during the 2022 wheat harvest.

Table 2.1. Ordered Wheat Varieties for Each Session

Group A		Group B	
10/11/2022	10/13/2022	10/18/2022	10/20/2022
White Bread	Whole Wheat Bread	Whole Wheat Bread	White Bread
Big Country (S)	Smith's Gold (N)	Big Country (S)	Showdown Red (S)
Green Hammer (S)	OK Corral (N)	Big Country (N)	Big Country (N)
Showdown Red (S)	Green Hammer (S)	Green Hammer (N)	Big Country (S)
Smith's Gold (N)	Showdown Red (S)	Green Hammer (S)	OK Corral (N)
OK Corral (S)	Showdown Red (N)	OK Corral (S)	Green Hammer (S)
Smith's Gold (S)	Smith's Gold (S)	OK Corral (N)	OK Corral (S)
Showdown Red (N)	Big Country (N)	Smith's Gold (S)	Smith's Gold (S)
Big Country (N)	Green Hammer (N)	Showdown Red (S)	Showdown Red (N)
OK Corral (N)	Big Country (S)	Showdown Red (N)	Smith's Gold (N)
Green Hammer (N)	OK Corral (S)	Smith's Gold (N)	Green Hammer (N)

Note: Varieties are presented in the order subjects tasted them in each session. “(S)” indicates south I-40 and “(N)” indicates north I-40

All five varieties and their regional counterparts are milled into whole wheat flour at Chisolm Trail Milling in Enid, Oklahoma, using a Mockmill 200 Professional, that utilizes fine granulation for whole wheat flour. Whole wheat flour is sifted, and the mill is thoroughly cleaned after each variety to control for cross-contamination of flavors. The whole wheat flour differs from commercial whole wheat flour in it being more refined (i.e., less of the germ is preserved) and milled in small batches. White flour was milled at the Food and Agricultural Products Center (FAPC) at Oklahoma State University, where it is defined as the USDA standard 100% white flour.

Each flour was then baked into palatable loaves following the AACC International Method 10-10.03 recipe. All breads were baked the morning before the experiment, vacuum sealed immediately after baking, and then cut into half-inch slices using the Mini-Supreme Bread Slicer 709. The whole loaves were maintained in the vacuum sealed.

Sensory Experiment

Both Group A and B conducted the sensory analysis in a standard ISO sensory room (e.g., white walls, no pictures, and neutral odors), located in FAPC at OSU. The design of the experiment was reviewed by OSU's Institutional Review Board with approval under application IRB-21-246. Group A's first session focused on white breads while the second session pertained to whole wheat breads. The order of sessions was opposite for Group B where their first session focused on whole wheat breads. In each session, 10 bread samples were tasted corresponding to five OSU varieties grown in two different regions. Each bread sample was designated with a random three-digit number. Subjects tasted samples in the same order while the order of varieties was randomized by each session to control for potential biases as shown in Table 1.

Each session began by explaining to subjects how they will participate in tasting the ten bread samples. Subjects are also informed that each bread sample differs only by the wheat variety used and that we desire their honest feedback in the questionnaire and discussions. Each subject was provided with a bottle of water, a cup filled with coffee grounds, a questionnaire, and a grid for the Napping exercise. Single bread samples are given to subjects after they are asked to clean their palette by sniffing coffee grounds and sipping water. Subjects are provided ample time to taste the bread sample, answer the questionnaire, and participate in the Napping exercise.

The questionnaire consisted of 22 pages where a subject is asked to answer 13 questions for each bread sample. Each of the first 9 questions are two contrasting keywords provided on either side of a 12.8-centimeter horizontal scale, hereafter referred to as attribute intensity questions. Subjects are asked to rate the extent to which the bread sample is either keyword provided. For example, question 1 asks for subjects to rate

between the keywords “light” and “dense.” If a subject perceives a variety is more light than dense, they will place a mark closer to “light” on the scale and vice-versa if they feel the sample is dense. The 10th question consisted of a word bank containing 24 keywords retained from a previous sensory study and asked subjects to choose up to 3 keywords describing attributes of the bread not mentioned in questions 1-9. Question 11 is open ended and asked to provide descriptors of the bread not asked about in the questionnaire. Subjects are not required to describe the bread in question 11 if descriptors provided in question 10 are enough to relay their opinions. Question 12 consisted of a Likert-type scale question focusing on the bread’s likeability with the scale ranging nine-items from dislike extremely to like extremely. The last questionnaire task for each sample asked subjects to participate in a Napping Ultra-Flash Profile exercise.

After a subject answered all questions for an individual sample and before the next bread was dispersed, group discussions are conducted where subjects freely described and discussed their perception of the bread. Group discussions are open dialogue amongst subjects and the moderator. Feedback provided during sessions is used as reasoning for the chosen descriptors. Each session is recorded, and discussions are reviewed by the researchers.

The final page of the questionnaire contained three questions asking subjects their opinion on the session and how they judged samples. The first question asked a subject if their palate became weary and, if so, provide what sample the fatigue began. This question captures the point judgements of samples could become biased and results skewed; this allows researchers to capture areas of improvement for future studies. The second question asked subjects if bread samples were distinguished more by their taste,

aroma, or texture. Answers to the second question are important for future studies in order to refine sensory evaluation with an aim to focus on attributes that have the greatest impact on bread differences. Finally, the last question asked subjects to refer to their Ultra-Flash Napping exercise and provide the main attributes they employed to assess the similarities and differences among bread samples. This question is used to provide a narrative on how a subject constructed their grid.

Napping Ultra-Flash Exercise

Subjects were instructed at the end of each sample questionnaire to perform a Napping Ultra-Flash exercise. This procedure was adopted based on (Torgerson, 1952) and was insightful in previous sensory studies. The aim of this procedure was to capture the absolute differences/similarities among varieties without having to provide extensive sensory analysis training to our subjects. Furthermore, the exercised is designed to be quick in terms of conducting and analyzing the experiment, hence the term "Ultra-Flash:"

Each subject was endowed with a 60 cm x 40 cm blank grid and 10 identification tags containing random-number identifiers for each bread sample. The grid was entirely blank, including no labels for the x and y-axes. Labels were not included for this procedure since our analyses only seek to tease out the similarities among varieties and do not place a hierarchy on larger x or y-axes values. That is, grid placement only pertains to distance between samples. After a subject tasted a bread sample and answered the litany of questions, they were instructed to place the corresponding identification tag somewhere on the grid such that samples with similar properties were placed closer together. A great difference in sensory properties relates to a large distance between samples on the grid. Subjects are asked to place the first sample of the day directly in the

middle of the grid and place every variety thereafter where they deemed appropriate; a subject is allowed to update grid placement of samples throughout the session.

Data Analysis

Immediately following the completion of each session, Napping grids are photographed for preservation and all questionnaires are scanned and saved electronically. Napping grid coordinates are marked with permanent marker and organized by each session in Microsoft Excel. Every session is video recorded and transcribed through the use of artificial intelligence in its entirety. Recall the attribute intensity questions (e.g., questions 1 – 9 for each sample), measurements are conducted for each question and then recorded electronically. Measurements are reported in the number of centimeters a subject's "mark" is from the left side. A small value indicates a subject perceived the flavor similar to that of the left keyword while a large value indicated a subject perceived properties akin to the right-side keyword. Keywords either chosen from the word bank or provided in the short response are tabulated in an Excel spreadsheet and are aggregated across each session and divided by white or whole wheat breads. The keywords are tabulated and analyzed to create a narrative surrounding subjects' grid placement. Lastly, the Likert-type question was translated into a 1 – 9 scale. A score of 1 related to "dislike extremely" while 9 was "like extremely." Each response was aggregated across varieties and divided into each bread-type.

Conceptual Framework and Methodology

All analyses are separated into white and whole wheat bread samples. Both qualitative (e.g., responses from questionnaires, keywords, and group discussion) and quantitative data are recorded for each subject for each session they participated. Keyword responses are tabulated in an Excel spreadsheet by each session (Groups A and B). Keywords are

given through a word bank or short answer. Word bank responses pertain to the perceived texture/flavor of the crumb while short answer responses are utilized to tease out keywords not provided in the word bank. For example, a subject wrote “Dense crust, light interior” the answer would be recorded as “dense” for crust and “light” for texture/flavor attributes. Keywords are divided into attribute categories such as, crust, texture/flavor, color, etc. if a descriptor refers to a specific part of the bread sample; unless a subject directly refers to a specific part of the bread then the keywords are treated as texture/flavor of the crumb. Keyword and short answer responses are used as the supporting narrative for the quantitative data (e.g., attribute intensities, Likert-type responses, and the Napping Ultra Flash Exercise).

Attribute intensity questions refers to the first nine questions for each bread sample in the questionnaires. These results are analyzed through R and Matlab statistical software where box-and-whisker plots are employed to visualize a subject’s answers. Box and whisker plots provide the minimum, maximum, and median (middle) values for each of the questions across all sessions and subjects. For example, the box plot for one question shows the empirical distribution of responses across all subjects and sessions for one bread type. Likert-type responses are averaged across all subjects and sessions to report an average likeability for each variety for each bread type.

Recall that all coordinate data from the Napping grids are recorded and tabulated in Microsoft Excel. Each subject has an X and Y coordinate for each sample in each bread type. Following methodology developed by Torgerson (1952) and utilized in a similar focus group setting by Loy et al. (2023), coordinate data are analyzed through distance matrices for each subject. These matrices are created using Euclidean distance

between each bread sample and then averaged across all subjects for each session to create a master (or aggregate) distance matrix for each bread type. The master distance matrices are used as input data to perform Ordinal Multidimensional Scaling (MDS) (Torgerson, 1952); MDS seeks to input a distance matrix, project the data in a two-dimensional space, and represent how a subject would have constructed their grid, on average. Ordinal MDS is employed since the distance between varieties has no hierarchy and is merely a measure of distance. The representative grid was generated using the isoMDS function in the MASS package in R.

The same master distance matrices are then used as data to perform hierarchical clustering algorithms. Clustering is employed to assist in analyzing the Napping data. A bottom-up clustering algorithm was adopted following Loy et al. (2023) and was used to assign varieties into classes based on previous knowledge and where subjects tended to place varieties on their grids.

To further understand similar groupings and the differences between varieties, we aim to understand 1) If there are more similarities between breads of the same varieties but grown in different regions than 2) breads of different varieties in the same region. Therefore, for each subject and each possible combination of non-identical varieties, we use Table 2.2 where the values A, B, C, and D are the attribute intensity scores given by each subject for any particular attribute (e.g., density, balanced).

Table 2.2. Combinations of Attribute Intensity Ratings

	Variety A	Variety B
South Region	A	B
North Region	C	D

Let S_V (same variety) be defined as a measure of similarity between the same variety but grown in different regions and S_R (same region) be a measure of similarity between different varieties but grown in the same region. Equations 2.1 and 2.2 below show how each measure is calculated based on Table 2.1 above:

$$S_V = (A - C)^2 + (B - D)^2 \quad (2.1)$$

$$S_R = (A - B)^2 + (C - D)^2 \quad (2.1)$$

where, differences within the equations (e.g., A-C) are squared to ensure non-negative values and smaller values of S_V and S_R indicate more similarity. That is, we are interested in situations where $S_R > S_V$. We then do a nonparametric test to calculate the percent times (across all individuals and possible variety combinations, providing 110 observations) where $S_R > S_V$. In other words, we are interested in cases where different varieties in the same region (SR) have more variability than same varieties grown in different regions (SV). We hypothesize this percentage to be greater than 50%, meaning that there are more differences in taste between different varieties in the same region than the same varieties in different regions.

We define the null hypothesis as:

$$H_0 = No\ differences\ between\ S_R\ and\ S_V$$

under H_0, the percentage (e.g., 50%) is distributed according to the Bernoulli distribution with a parameter, $p = 0.5$. Where, p, is the probability of "success" and defined as the instances where $S_R > S_V$. The problem can also be viewed as a Binomial distribution with 110 independent, Bernoulli trials. Consider the idea of a coin flip; a coin flip is fair

(e.g., equal chance of heads or tails) if, on average, $p = 0.5$. We are interested in testing if the differences among S_R and S_V are statistically different than 0.5 – or if the outcomes are more like that of a coin flip where there is an equal chance of each outcome occurring. For a binomial distribution with 110 trials and $H_0: p = 0.5$, the percentage of times $S_R > S_V$ would have to be less than 0.4 or greater than 0.6 to reject the null hypothesis of no differences between S_R and S_V. Failing to reject the null hypothesis would mean that differences among varieties could equally be attributed to differences in variety and region and that one is not more impactful than the other.

Results

The results are described by outlining clustering results to define key groupings of the same varieties but grown in different regions and using qualitative descriptors to better understand why those varieties are clustered together. Clustering results for white and whole wheat breads are discussed separately. Furthermore, attribute intensities and likeability scores are analyzed to try to provide further data that would impact classifications.

White Breads

White bread clustering results indicate the samples can be grouped into several classes. Figures 2.1 and 2.2 provide hierarchical clustering and an MDS plot (or representative grid), respectively, with three key classifications superimposed. The figure suggests that 1) Green Hammer (North) has distinct characteristics apart from other varieties, 2) Green Hammer (South) and Big Country (South) have similar attributes and 3) Smith's Gold (North) and Smith's Gold (South) are perceived to impart a similar flavor to the breads. We are mainly interested in the same variety across different regions rather than creating a narrative and sensory profile for every variety. Notice that some classifications between

clustering and MDS are slightly different; this is because the MDS plot utilized a different algorithm that should produce similar but not necessarily identical results. However, both figures suggest that Green Hammer is unique and both Smith's Gold samples are similar.

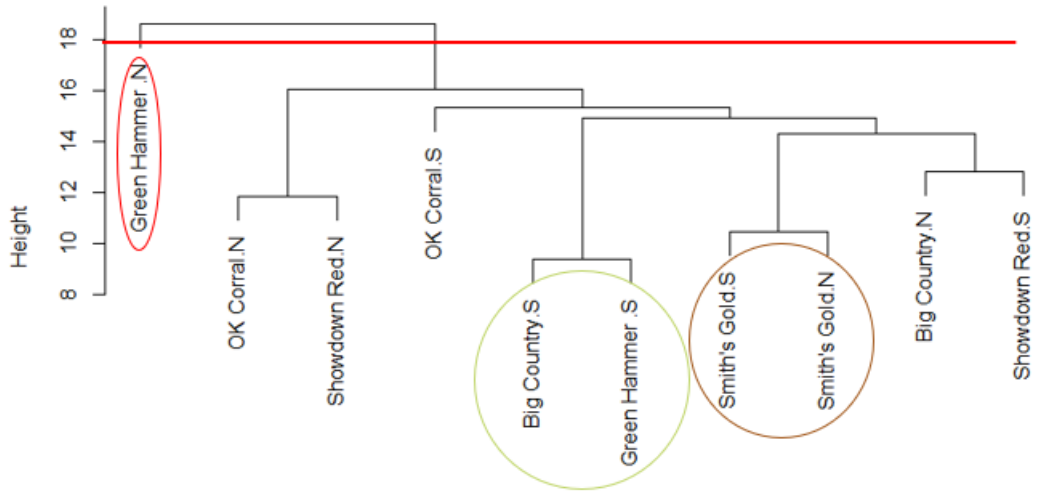


Figure 2.1. White Bread Sampling Dendrogram

The horizontal line represents the point where clustering is "stopped"; that is, nodes under the line are defined as a classification group. Line placement is generally arbitrary based on the knowledge of varieties or growing regions. If the line is moved up along the y-axis by just a minute amount, then all varieties are said to be in one classification and impart similar characteristics.

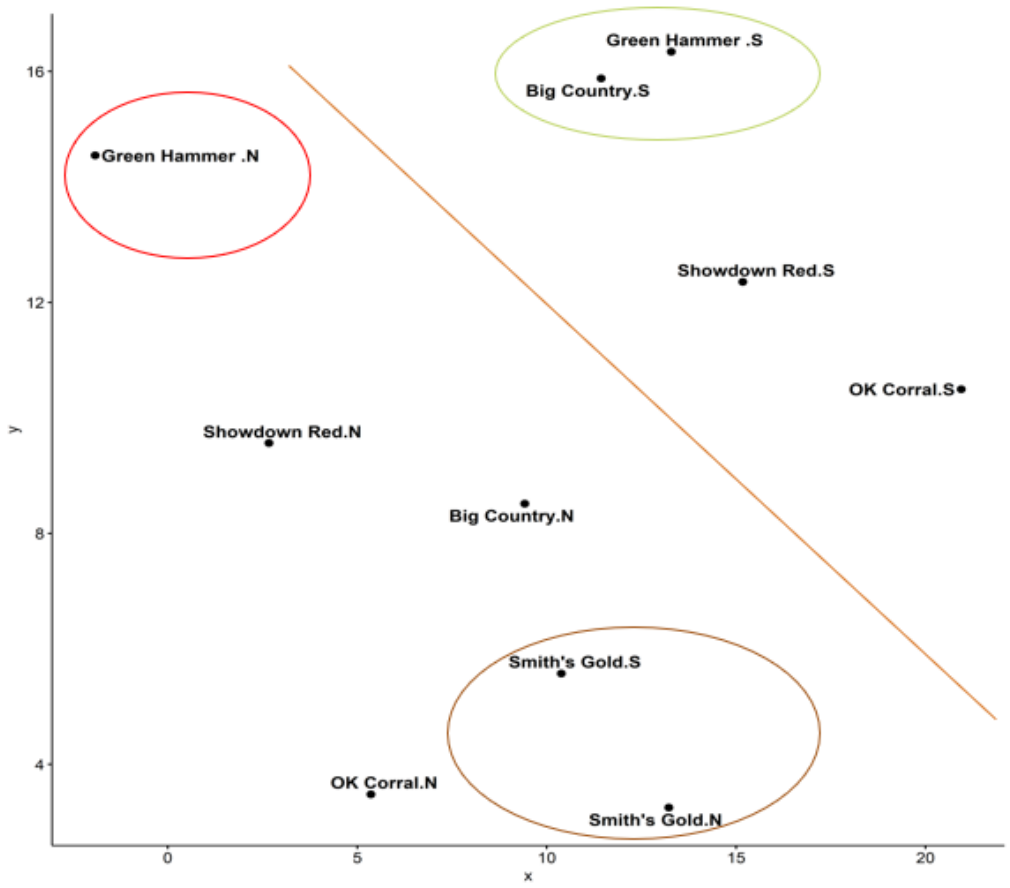


Figure 2.2. Ordinal MDS Plot of White Breads

Table 2.3. Likeability of White Breads

ID	Variety	Average Likeability
509	Green Hammer - South	6.73
713	Smith's Gold - North	6.36
851	Big Country - North	6.27
427	Smith's Gold - South	6.18
226	Showdown Red - North	5.73
369	Big Country - South	5.73
381	Green Hammer - North	5.73
431	OK Corral - South	5.64
181	OK Corral - North	5.36
857	Showdown Red - South	5.18

At first glance, it seems that the varieties in Figure 2.2 are distributed across the grid in a random pattern; three classifications can be highlighted with a diagonal line seemingly dividing varieties into two defining groups. Perusing Table 2.3, one can see there is no discernable connection between clustering and likeability. With these results, we ask if these differences in classifications and likeability are true - or are they attributed to data noise? Referring to the white bread keyword table provided in Appendix G, we can see that subjects tended to use identical keywords such as “light”, “dense”, “dry”, and “sweet” to describe each variety. Therefore, we are unable to confidently say (only based on keywords, clustering, and likeability) if these differences between varieties and growing region are significant – or if varieties impart too similar of a flavor for our untrained assessors to be able to tell a significant difference.

Whole Wheat Breads

It’s a common belief that flavor/texture differences are more pronounced in whole wheat breads. The retention of the bran, germ, and endosperm in whole wheat breads could impact the sensory profile more than white breads. Consistent with the findings of Loy et al. (2023), whole wheat bread clustering shows that subjects are often unable to discern major differences among the sensory profiles of these bread samples. As is with white bread samples, clustering results for whole wheat breads are given in Figures 2.3 and 2.4 below. There are two classifications of interest 1) Green Hammer (South) is unique among all varieties and regions (like its northern counterpart in the white bread analysis) and 2) Big Country (North) and Big Country (South) impart similar flavors and are most

like Smith's Gold (South) and OK Corral (South).

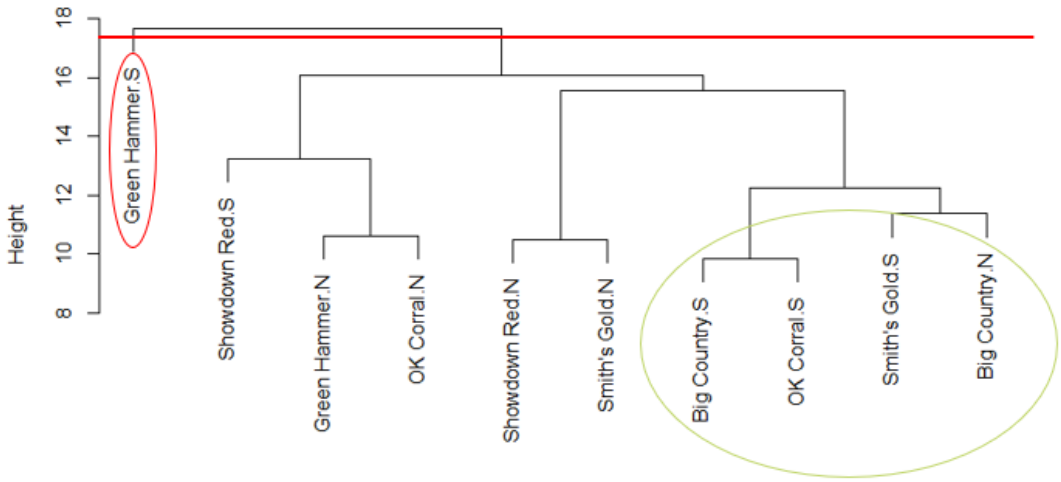


Figure 2.3. Whole Wheat Bread Sampling Dendrogram

The two main classifications of interest are superimposed over Figures 2.3 and 2.4. Again, if one were to move the horizontal line up the y axis in Figure 2.3, then all varieties are grouped in one classification and impart a similar flavor profile. This result is consistent with the white bread results given in the previous section. Since our objective in this research is to determine if growing region has a significant impact on flavor (as opposed to only developing sensory profiles), the random nature of grid assignments in Figure 2.4 and the few classifications in Figure 2.3 do not assist much in understanding why differences occur. Furthermore, if we analyze whole wheat bread keywords in Appendix G, we can see almost identical results as that of the white bread keywords except for "wheaty" that is said to remind a subject of a store-bought whole wheat bread.

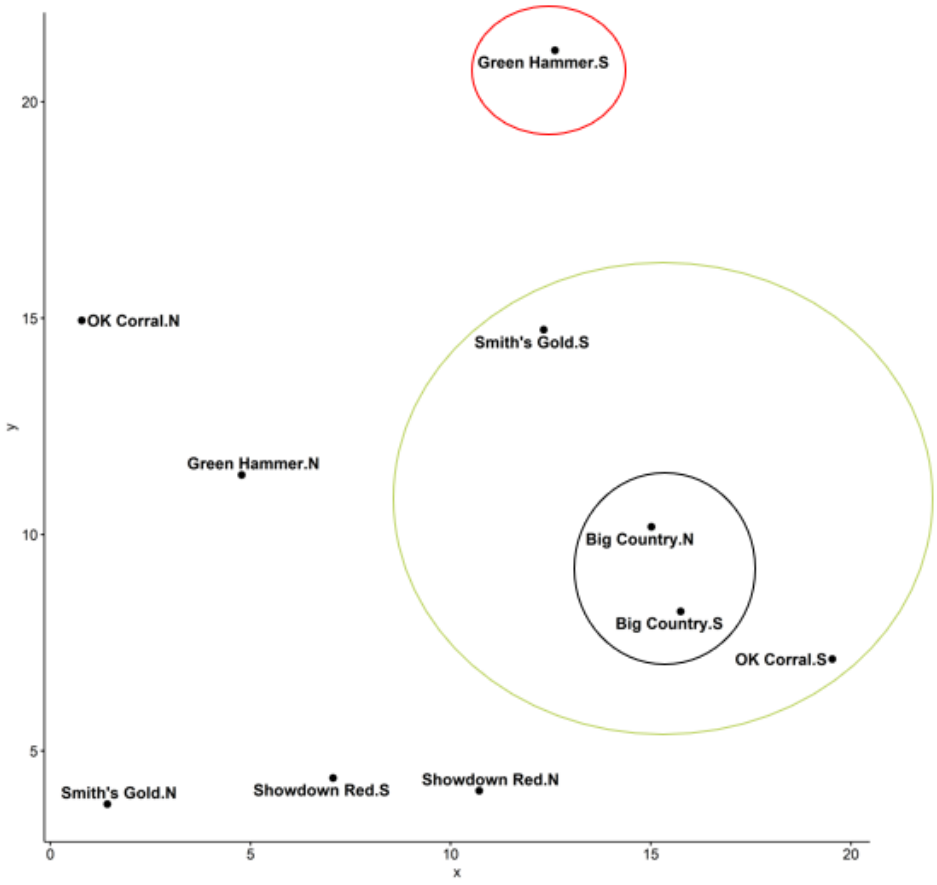


Figure 2.4. Ordinal MDS Plot of Whole Wheat Breads

Table 2.4. Likeability of Whole Wheat Breads

ID	Variety	Average Likeability
325	Green Hammer - South	6.45
632	Smith's Gold - South	6.45
975	Big Country - North	5.82
536	Big Country - South	5.27
785	Showdown Red - South	5.27
856	Smith's Gold - North	5.27
884	OK Corral - South	5.00
646	Green Hammer - North	4.91
936	OK Corral - North	4.91
555	Showdown Red - North	4.55

We focus on Table 2.4. in an attempt to draw similarities between clustering assignments in Figure 2.4 and likeability of a particular variety. Besides white bread samples being liked more overall, meaningful results are 1) Green Hammer (South) is the most liked variety for whole wheat breads and is also considered in its' own classification, 2) Big Country (North) and Big Country (South) are similarly ranked for likeability as well as being grouped together on the representative grid, and 3) Big Country (South), Showdown Red (South), and Smith's Gold (North) all have identical likeability scores. This result is the opposite of the white bread analysis as there are few similarities between likeability and classifications. However, It is still difficult to tell if these clustering assignments and likeability scores are significant and if growing region and/or variety differences have a greater impact on flavor.

Attribute Intensities

To further our understanding between region and variety, and to test if those differences and similarities are more attributed to region or variety, we utilize the attribute intensity questions in two ways: 1) box-and-whisker plots showing the distribution of answers per variety for each bread type and 2) a nonparametric hypothesis test for regional and variety impacts on flavor.

Tables 2.5, 2.6, 2.7, and 2.8, given below, contain the minimum, median, and maximum values for each attribute intensity question divided by bread type. Minimum and maximum values are provided in parenthesis below the median. These data are derived from box-and-whisker plots provided in Appendix H. Tables are presented in this section to provide a quick overview on how subjects perceived the intensities of flavor profiles. Recall that attribute questions are given on a 12.8-centimeter

scale; therefore, if the median value is greater than 6.4, then subjects believe the variety to impart the right-side keyword (vice-versa if the median is below 6.4).

Table 2.5. Median Attribute Intensity Scores for White Breads (South)

Questions	Big Country (S)	Green Hammer (S)	OK Corral (S)	Showdown Red (S)	Smith's Gold (S)
Light - Dense	4.60	3.20	3.60	7.40	4.40
	(2.5, 5.5)	(0.2, 8.7)	(1.0, 9.0)	(2.0, 10.2)	(2.0, 10.0)
Dry - Moist	4.50	6.50	5.70	4.60	6.20
	(3.0, 7.3)	(1.8, 9.5)	(2.4, 10.6)	(0.2, 6.7)	(2.0, 10.0)
Not Sweet - Sweet	4.50	3.60	5.50	3.30	6.50
	(1.0, 7.8)	(1.0, 6.7)	(0.4, 7.5)	(0.1, 8.5)	(1.0, 10.0)
Not Sour - Sour	1.70	2.70	3.70	2.10	4.00
	(0.1, 5.8)	(0.4, 7.8)	(0.8, 11.0)	(0.6, 3.7)	(0.6, 8.6)
Not Malty/Toasty - Malty/Toasty	4.50	4.40	5.30	2.30	4.70
	(0.1, 7.5)	(0.9, 10.2)	(1.1, 9.0)	(0.5, 7.8)	(2.2, 10.0)
Not Bitter - Bitter	1.60	2.40	2.30	2.00	3.60
	(0.3, 3.0)	(0.4, 6.5)	(1.0, 6.5)	(0.4, 8.1)	(0.5, 8.6)
Simple Flavor - Complex Flavor	2.30	4.80	5.80	3.70	4.40
	(0.3, 5.9)	(1.0, 9.1)	(0.3, 9.9)	(1.0, 7.7)	(2.1, 7.5)
Stale - Fresh	7.00	8.70	7.10	7.00	7.10
	(2.5, 9.9)	(6.0, 10.0)	(0.5, 11.0)	(3.5, 9.5)	(2.9, 11.0)
Unbalanced - Balanced	5.80	6.50	6.00	6.70	6.20
	(2.0, 9.4)	(3.8, 9.1)	(4.1, 7.6)	(4.9, 10.0)	(1.1, 10.4)

Table 2.6. Median Attribute Intensity Scores for White Breads (North)

Questions	Big Country (N)	Green Hammer (N)	OK Corral (N)	Showdown Red (N)	Smith's Gold (N)
Light - Dense	7.40	3.50	5.20	4.50	3.20
	(1.5, 10.7)	(1.5, 7.1)	(1.0, 10.2)	(2.0, 10.2)	(2.7, 10.5)
Dry - Moist	7.50	7.0	5.50	6.40	7.80
	(1.0, 11.0)	(3.3, 11.2)	(1.1, 10.6)	(3.6, 9.0)	(6.8, 9.2)
Not Sweet - Sweet	5.20	4.10	3.30	5.00	6.30
	(1.0, 8.8)	(1.5, 8.8)	(0.5, 8.0)	(0.2, 8.7)	(0.9, 8.5)
Not Sour - Sour	4.90	3.00	4.20	5.30	1.80
	(1.6, 9.0)	(0.5, 8.0)	(0.8, 8.4)	(0.5, 10.0)	(0.7, 8.9)
Not Malty/Toasty - Malty/Toasty	5.50	5.60	5.60	3.90	4.40
	(2.2, 10.0)	(0.5, 10.5)	(1.1, 9.7)	(2.0, 9.1)	(0.9, 10.8)
Not Bitter - Bitter	3.70	3.60	2.30	4.70	2.60
	(0.5, 10.5)	(1.0, 9.7)	(0.7, 6.3)	(0.9, 10.7)	(0.9, 9.9)
Simple Flavor - Complex Flavor	6.80	5.50	4.30	6.60	6.00
	(2.5, 8.9)	(4.5, 7.6)	(1.4, 8.3)	(0.3, 10.6)	(1.3, 9.5)
Stale - Fresh	8.00	8.30	6.00	7.50	8.50
	(4.2, 12.0)	(5.2, 11.3)	(2.9, 8.7)	(4.4, 10.7)	(4.0, 10.1)
Unbalanced - Balanced	6.20	7.10	5.50	7.00	8.00
	(4.3, 10.6)	(3.7, 11.2)	(3.5, 9.7)	(0.0, 8.2)	(5.1, 10.9)

Table 2.7. Median Attribute Intensity Scores for Whole Wheat Breads (South)

Questions	Big Country (S)	Green Hammer (S)	OK Corral (S)	Showdown Red (S)	Smith's Gold (S)
Light - Dense	5.20	5.60	5.50	5.50	4.30
	(2.0, 8.2)	(1.6, 10.5)	(3.0, 9.6)	(1.0, 8.5)	(1.1, 8.1)
Dry - Moist	4.60	6.80	4.10	4.90	7.00
	(3.2, 6.0)	(2.8, 8.7)	(0.5, 7.5)	(0.5, 6.7)	(4.3, 10.7)
Not Sweet - Sweet	4.30	3.60	1.60	3.30	7.80
	(0.0, 8.7)	(0.0, 8.7)	(0.3, 7.5)	(0.9, 7.5)	(0.5, 11.0)
Not Sour - Sour	3.00	3.40	2.10	4.10	3.20
	(1.1, 4.2)	(0.5, 9.2)	(0.4, 5.0)	(1.0, 9.1)	(0.6, 8.1)
Not Malty/Toasty - Malty/Toasty	4.60	6.80	5.70	5.00	5.50
	(1.2, 8.4)	(1.7, 9.5)	(0.6, 11.0)	(2.0, 8.9)	(1.5, 8.2)
Not Bitter - Bitter	3.00	2.70	5.30	3.50	1.80
	(0.1, 4.8)	(0.5, 5.3)	(1.0, 11.3)	(1.0, 11.2)	(0.8, 4.4)
Simple Flavor - Complex Flavor	4.20	5.60	4.90	5.50	5.70
	(3.6, 6.2)	(1.9, 9.9)	(2.1, 10.3)	(1.3, 7.0)	(1.5, 10.3)
Stale - Fresh	5.80	6.50	5.00	5.30	7.50
	(3.1, 9.1)	(3.3, 9.0)	(0.4, 9.1)	(2.7, 7.5)	(3.2, 11.3)
Unbalanced - Balanced	6.50	6.00	6.00	4.90	7.80
	(4.7, 9.4)	(3.5, 10.6)	(0.5, 9.2)	(0.0, 8.3)	(4.4, 9.3)

Table 2.8. Median Attribute Intensity Scores for Whole Wheat Breads (North)

Questions	Big Country (N)	Green Hammer (N)	OK Corral (N)	Showdown Red (N)	Smith's Gold (N)
Light - Dense	3.30	7.00	7.90	6.60	6.70
	(1.3, 9.1)	(2.5, 10.5)	(6.4, 8.9)	(1.5, 8.7)	(0.7, 10.4)
Dry - Moist	6.80	3.40	4.00	3.50	4.20
	(2.8, 10.5)	(0.5, 6.1)	(0.2, 8.3)	(0.2, 7.5)	(0.9, 11.7)
Not Sweet - Sweet	6.00	2.90	2.40	2.80	2.50
	(0.2, 8.7)	(1.5, 7.9)	(0.2, 7.1)	(0.2, 6.7)	(0.1, 6.0)
Not Sour - Sour	2.90	3.60	3.60	2.80	3.30
	(0.6, 7.5)	(1.5, 6.7)	(0.5, 8.6)	(1.6, 8.5)	(0.2, 6.0)
Not Malty/Toasty - Malty/Toasty	4.00	3.90	5.80	7.30	6.00
	(0.8, 8.1)	(1.8, 11.1)	(3.1, 8.7)	(2.8, 10.5)	(0.0, 8.6)
Not Bitter - Bitter	2.10	4.60	2.80	4.50	2.40
	(0.3, 5.5)	(0.5, 9.7)	(1.5, 8.9)	(1.3, 10.0)	(0.9, 7.3)
Simple Flavor - Complex Flavor	6.00	5.50	5.60	5.90	3.10
	(0.9, 8.5)	(1.8, 9.4)	(1.2, 10.1)	(2.0, 10.0)	(0.3, 7.9)
Stale - Fresh	7.90	5.80	4.70	5.10	5.20
	(4.9, 10.5)	(4.3, 6.2)	(1.2, 8.7)	(1.5, 6.6)	(0.3, 11.2)
Unbalanced - Balanced	7.50	6.00	5.60	5.30	6.80
	(4.9, 11.5)	(2.0, 10.5)	(0.0, 9.7)	(1.1, 7.4)	(0.0, 11.0)

The tables above are presented for two reasons: 1) highlighting the input data for testing if regional impacts are significant and 2) to present the type of attribute questions asked to our subjects. These questions are adopted following Loy et al. (2023), where the top keywords and their direct counterparts (e.g., dry and moist, simple and complex) used to describe the flavor profile of varieties are retained; these attribute intensity questions are employed to improve upon the previous study's quantitative measurements.

Recall that we are interested in knowing if there are more similarities between breads of the same variety that are grown in different regions than breads of a different variety grown in the same region. Table 2.9 contains the percentages where $S_R > S_V$, across all attributes. Estimated percentage values can be treated as a $\hat{p}$ test statistic and are compared against the null hypothesis value of $p = 0.5$. The null hypothesis is rejected if $\hat{p} < 0.4$ or if $\hat{p} > 0.6$. The rejection region is based on the cumulative binomial distribution under $H_0: p = 0.5$. The 95% confidence level, defined with a 2.5% rejection region on both tails, translates to values of 0.4 in the lower and 0.6 in the upper tail. Furthermore, p-values in Table 2.9 are calculated following the exact binomial test where significance is based on a cumulative binomial distribution with 110 independent trials with a probability of 50%; each $\hat{p}$ test statistic is then tested to discover if they are significantly from .50.

Table 2.9. Test Statistics for Sign Test

Attribute	White Bread	Whole Wheat Bread
Density	0.46	0.44
	(0.39)	(0.21)
Moistness	0.49	0.49
	(0.78)	(0.78)
Sweetness	0.47	0.57
	(0.50)	(0.15)
Sour	0.44	0.47
	(0.21)	(0.5)
Toasty/Malty	0.50	0.45
	(1.0)	(0.29)
Bitter	0.57	0.42
	(0.15)	(0.1)
Complex	0.38*	0.58
	(0.01)	(0.1)
Stale	0.45	0.47
	(0.29)	(0.5)
Balanced	0.48	0.41
	(0.63)	(0.07)

Note: Each value is given as the proportion of times $S_R > S_V$. Values in parentheses are exact binomial test p-values ($\alpha = 0.05$) .

In all instances except white bread flavor complexity, we fail to reject the null hypothesis and conclude that we cannot definitively report if region or variety have a greater impact on flavor profiles. For flavor complexity, we can reject the null hypothesis and since $\hat{p} < 0.4$, we conclude that more similarities of complex flavor exist between different varieties in the same region than the same variety grown in different regions. Even in the case where the null hypothesis is rejected, $\hat{p}$ values are not outliers from 0.5; Implying that 1) most wheat varieties taste nearly identical and sensory analysis on flavor profiles are unnecessary or 2) untrained assessors are unable to capture and compare attributes between varieties.

Final Questionnaire Responses

Recall each questionnaire contained 3 questions on the final page. These questions are answered in each session after the final bread sample is tasted. The first question asked subjects if they experienced palate fatigue and if so, what sample it began to occur. Sixteen subjects responded "no" and seven subjects "yes." Five subjects experienced palate fatigue in one session but not in the other. The changes in the answer varied between each session so it cannot be said white or whole wheat bread samples had more fatigue over the other. On average, the 7^{th} sample is where subjects experienced the most palate fatigue. In terms of skewing results, a future study would likely benefit from containing 7 samples or less.

Next, subjects were asked if bread samples are distinguished more by their taste, texture, or aroma. 11 subjects indicated only taste of the bread was the most distinguishing feature. 5 subjects said texture distinguished the breads apart from each other. And 7 subjects indicated that the most distinguishing attribute of each bread sample was a combination of taste/texture and/or aroma. Future research would benefit from this question in terms of developing the focus group. That is, the researcher has a well-rounding understanding of what attributes an average subject may judge a sample.

Lastly, the final question asked subjects to provide the main attributes they used to assess each bread sample. Referring to Table 2.10 below, subjects used a wide range of keywords and attributes to judge the bread. For example, some subjects focused on texture of the bread, the crust, the color, and even the aroma. Attributes are understood as a certain part of the bread while the keywords provided are used to describe that attribute. For example, the attribute, texture, can be described with the keywords "sweet", "sour", "neutral", or even "stale."

Table 2.10. Final Question Responses

Attributes	Keywords to describe attributes
Aroma	Basic
Color	Bland
Crust	Complexity
Density	Dark
Structure	Elasticity
Texture	Fresh
	Grittiness
	Light
	Lingering Taste
	Moisture
	Neutral
	Nutty
	Simple
	Smokey
	Sourness
	Staleness
	Subtle
	Sweetness
	Tenderness
	Toasty
	Wheaty

Note: Not every keyword was used to describe each attribute. Provided is each unique keyword subjects used.

Conclusion and Future Direction

This study took the next step in assessing the similarities and differences among OSU wheat varieties used in Oklahoma. This was the second study assessing the sensory properties of wheat varieties; research efforts set to improve quantitative instruments of the first study and explore if growing region has a significant impact on the flavor wheat varieties impart to breads. Using 12 professionals in the food industry as subjects, they tasted and evaluated five OSU varieties that were grown North of I-40 and South of I-40 (ten samples in each session).

We are more interested in investigating if there are differences between the same variety but grown in a different region rather than developing flavor profiles for each sampled variety. Flavor profile data (e.g., keywords and likeability) are tabulated and retained as a contribution to the body of knowledge on sensory properties of OSU varieties. This profile data helps improve the marketing of each variety. Classification algorithms are used to highlight groups containing the same variety but grown in different regions; an important question for millers if marketing channels are to have scalability while maintaining a consistent flavor.

Clustering and MDS plots are less informative when compared to the previous study. However, the clustering and MDS did provide key information that 1) on average, there are likely only minor differences among the wheat cultivars employed in this study such that subjects are unable to perceive meaningful differences (or similarities) (2) Green Hammer imparts the most unique eating experience, regardless of bread type and growing region; this is consistent with conventional beliefs as the Green Hammer variety had the most acres planted in Oklahoma compared to other varieties in this study. Both white and whole wheat bread sampling was less distinct where only a minor change in classification assignments would have all varieties in one grouping. We do not see any major similarities among likeability and clustering assignments, besides the instances with Green Hammer (South) and Big Country (North and South) in the whole wheat samples.

This study provided information that will be used when considering flavor profiles of wheat varieties in the future. Statistical tests show that one cannot determine the true flavor impacts of growing regions. This conclusion can be attributed to 1) employing an

untrained panel of assessors that may have difficulty creating a definitive sensory profile 2) growing region and variety likely equally matter in determining flavor or quality of the grain and 3) OSU varieties used in this study impart too similar of flavor profiles. Sensory analysis might then be unnecessary in the context of determining regional differences; if varieties do impart too similar of a flavor, then sensory analysis likely cannot be utilized in a useful manner besides creating keywords to better describe wheat cultivars.

Future direction will involve sourcing the same wheat varieties over multiple growing years (while accounting for growing region) to assess yearly impacts on flavor. This research will improve previous studies by improving the sensory analysis by employing trained food professionals as are our subjects. Similar quantitative instruments will be utilized in developing a more concise sensory profile of the wheat varieties.

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APPENDICES

Appendix F. Example Questionnaire

Sample 1

Taste the bread sample **# xxxx** (after a sip of water and sniff of coffee) and then answer the 12 questions on the next two pages

1. Rate the extent to which the bread is **light or dense** (by making a vertical mark on the scale below).

2. Rate the extent to which the bread is **dry or moist**.

3. Rate the extent to which the bread has a **sweet** flavor.

4. Rate the extent to which the bread has a **sour** flavor.

5. Rate the extent to which the bread has an **malty/toasty** flavor.

6. Rate the extent to which the bread has an **bitter** flavor.

7. Rate the extent to which the bread has a **simple or complex** flavor profile.

8. Rate the extent to which the bread has more of a **fresh or stale** flavor and texture.

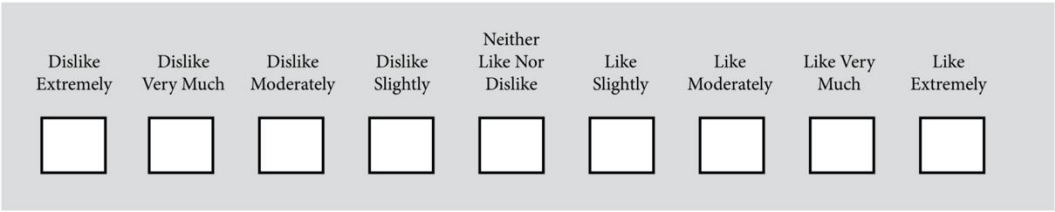
9. Rate the extent to which the bread has **balanced or unbalanced** flavor profile. (A balanced flavor profile has the right amount of each flavor while an unbalanced profile is dominated by one or two flavors that detract from the overall flavor.)

10. Did the bread have any **other attributes** not mentioned above? If so, please circle up to three words (but not more than 3) below that best describe these other attributes.

Dry	Fennel	Floral	Woodsy
Chewy	Cinnamon	Burnt	Earthy
Wheaty	Spongy	Spicy	Dense
Nutty	Dark	Herby	Elastic

11. Did you detect any particular flavor or texture **descriptors not asked about** in the questionnaire? If so, please describe them below.

12. Using the scale below, how much do you like the taste of the bread?



13. Find the piece with the # _____ on it and place it somewhere on the grid. In future samples you will place them closer on the grid to breads they resemble and further from ones they don't, so we suggest you place this sample somewhere around the middle.

Figure F.2.1. Questionnaire Example

Appendix G: Additional White and Whole Wheat Bread Keyword Tables

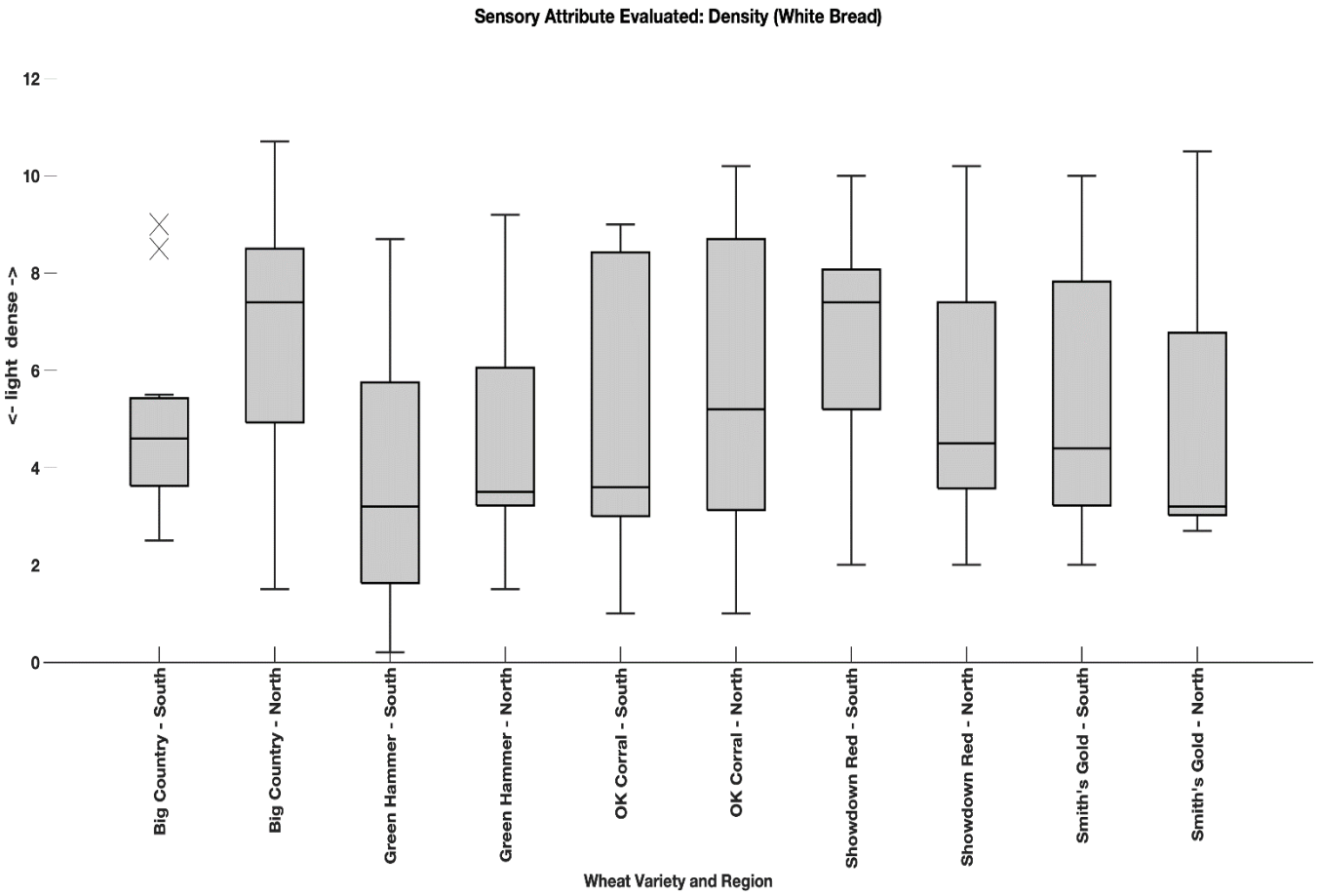
Table G.2.1. White Bread Keywords

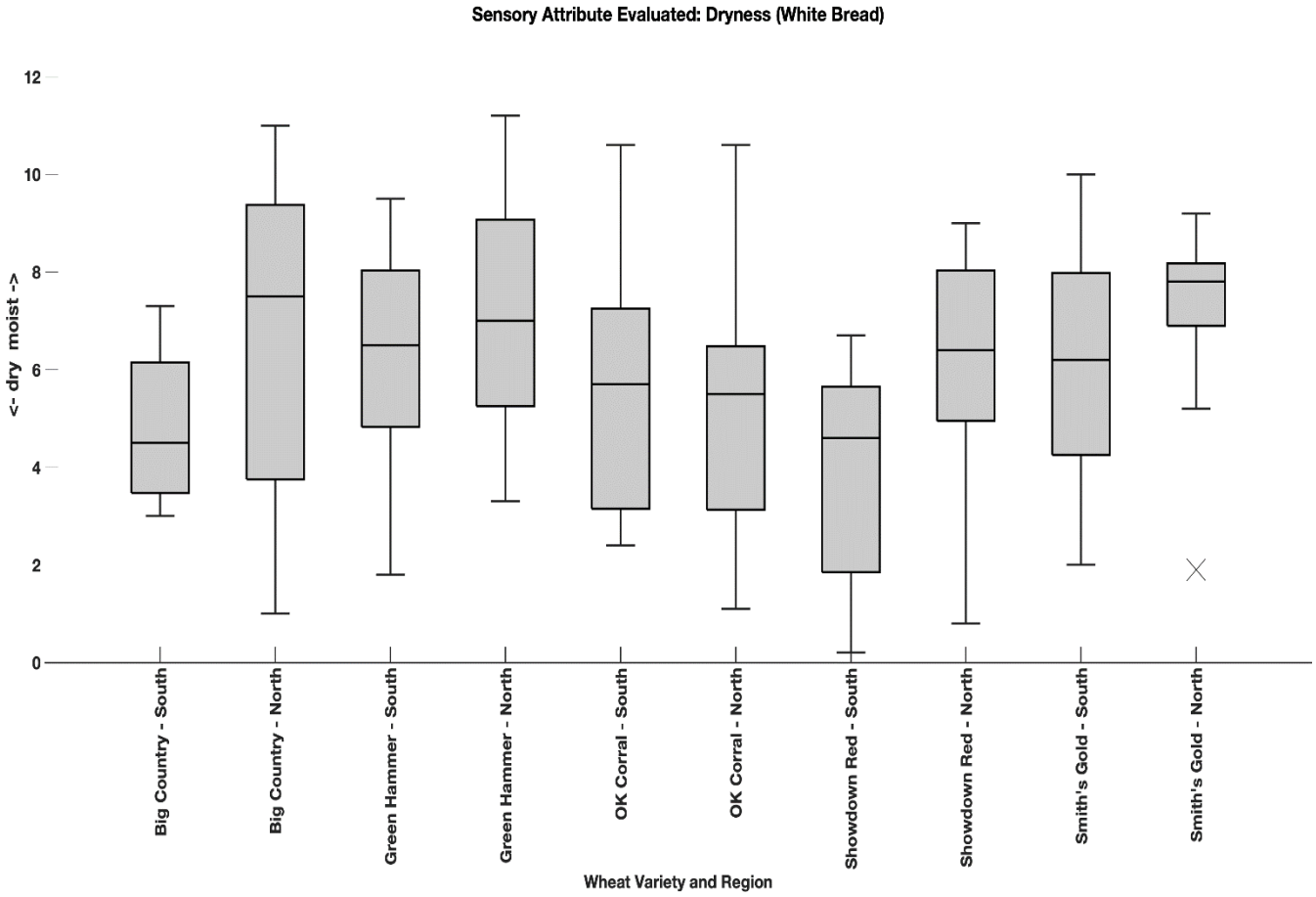
Big Country (S)	Big Country (N)	Green Hammer (S)	Green Hammer (N)	OK Corral (S)	OK Corral (N)	Showdown Red (S)	Showdown Red (N)	Smith's Gold (S)	Smith's Gold (N)
					Texture/Flavor				
Light	Gummy	Sweet	Open	Bland	Open	Dry	Open	Sweet	Open
Standard	Yeasty	Light	Strong	Acrid	Elastic	Elastic	Lovely	Open	Complex
Moist	Sourdough	Spongey	Earth	Boring	Complex	Open	Sweet	Average	Gritty
Fresh	Dense	Open	Rye	Toasted	Standard	Sweet	Nutty	Old	Soft
Bitter	Boring	Chewy	Nutty	Old	Yeasty	Earthy	Subtle	Chewy	Elastic
	Moss	Creamy	Bitter	Alcohol	Boring	Plain	Burnt	Soft	
	Roasted	Philly Steak Roll	Soft	Grainy	Soggy	Flakey	Caramelized	Dense	
				Dirty Grill	Sour	French Toast	Bitter	Balanced	
				Simple	Fermentation		Airy	Grassy	
							Soapy/Chemical	Standard	
							Standard		
					Crust				
Dense	Chewy	Dense	Light	Chewy	Tough	Acrid	Chewy	Chewy	Dense
	Burnt	Chewy	Dense		Mushroom	Chewy	Complex	Acrid	Chewy
		Sweet	Tough		Chewy	Elastic		Good	Tender
		Elastic	Molasses		Toasty	Dense			
						Stale			
						Tough			
					Color				
	Dark								
					Aroma				
									Fresh

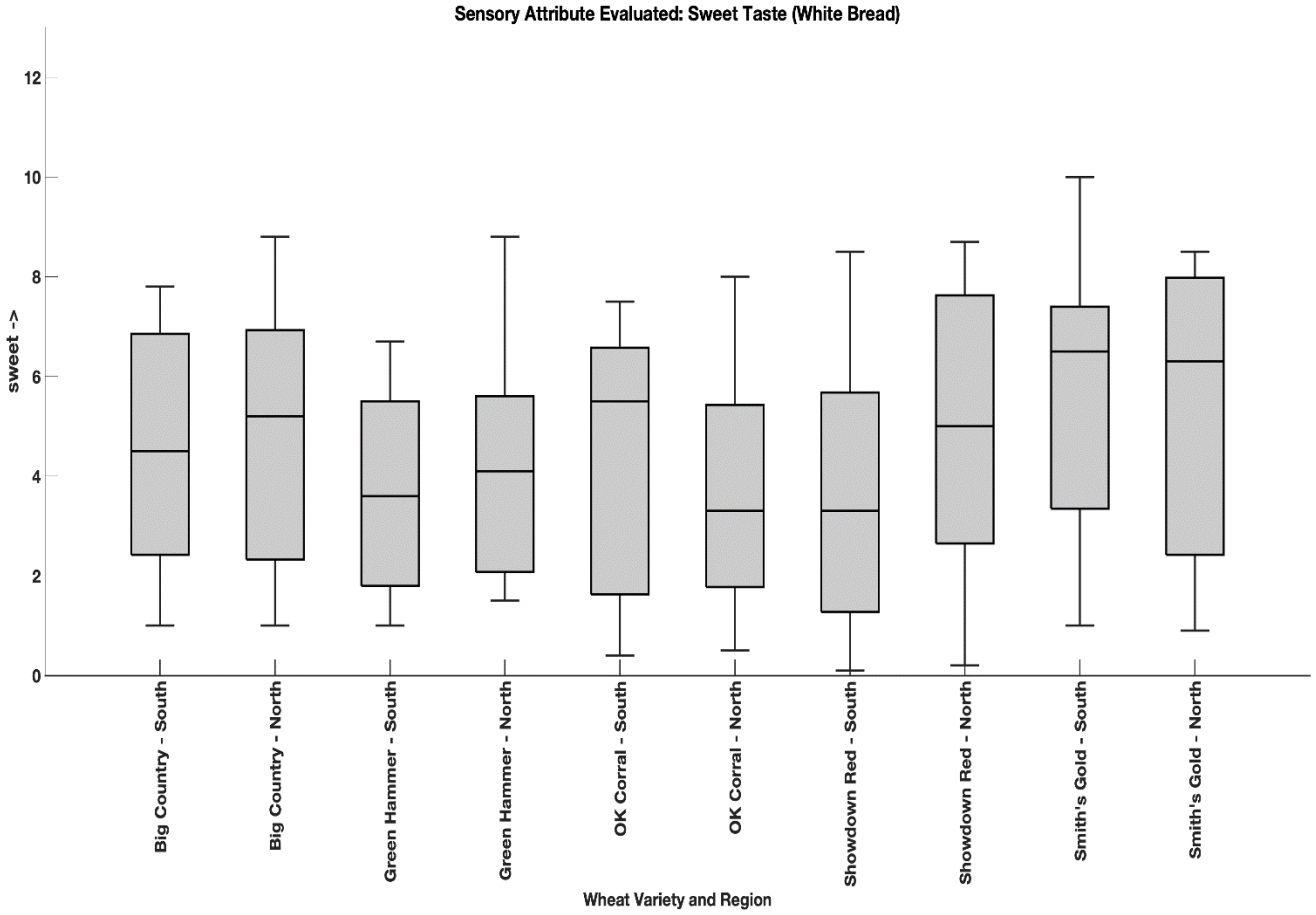
Table 7. Whole Wheat Bread Keywords

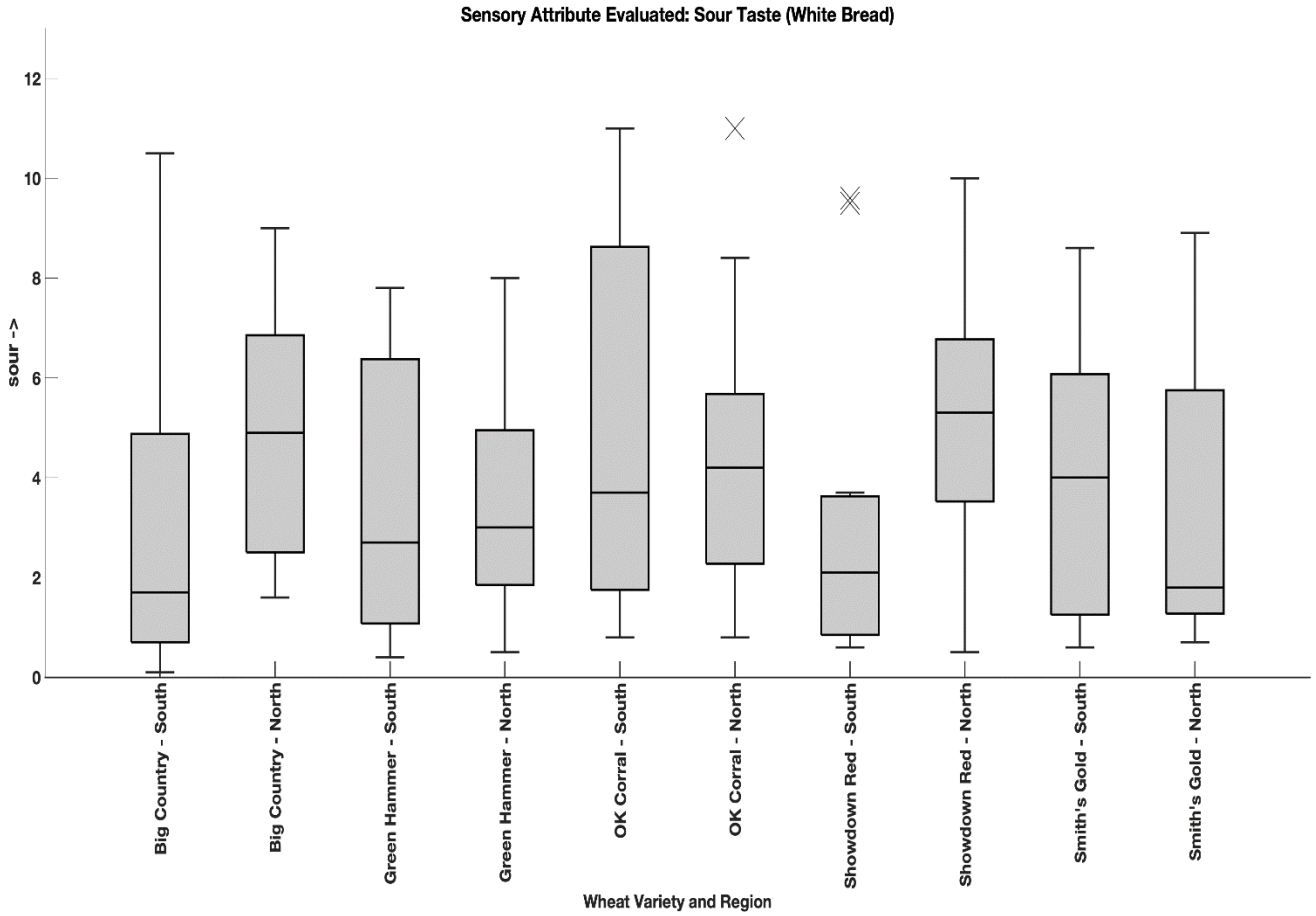
Big Country (S)	Big Country (N)	Green Hammer (S)	Green Hammer (N)	OK Corral (S)	OK Corral (N)	Showdown Red (S)	Showdown Red (N)	Smith's Gold (S)	Smith's Gold (N)
				Texture/Flavor					
Spongy	Cream	Buttery	Margarine	Dusty	Pollen	Elastic	Old Crayon Box	Brown Butter	Chewy
Moist	Fresh	Balanced	Toasted	Flavorful	Stale	Gritty	Soft	Buttery	Elastic
Toasty	Buttery	Toasted	Dry	Complex	Dry	Woody	Toasted	Toasty	Bland
Nutty	Bland	Open	Dense	Sweet	Gritty	Balanced	Chewy	Earthy	Standard
Sweet	Earthy	Complex	Sour	Sour	Elastic	Moist	Sour	Spongy	Dry
Light	Rye	Acrid	Sweet	Dry	Gummy	Dry	Burnt	Gritty	Tough
White Bread	Sweetness	Sour	Gummy	Light	Buttery	Gummy	Dry	Acidic	
Great	Open	Bitter	Boring		Nutty	Bitter	Barley	Pleasing	
	Gritty	Smokey	Wheat			Burnt	Stale	Sweet	
	Acidic		Earthy			Bland		Nutty	
	Gummy					Wheaty		Fresh	
	Dry					Plain		Light	
	Light					Comforting			
	Savory								
				Crust					
Chewy	Less Chewy	Burnt/Acrid		Thick	Chewy	Chewy	Burnt/Acrid		Soft
Sweet		Chewy		Wheaty		Acrid			Elastic
									Chewy
				Color					
	Yellow								

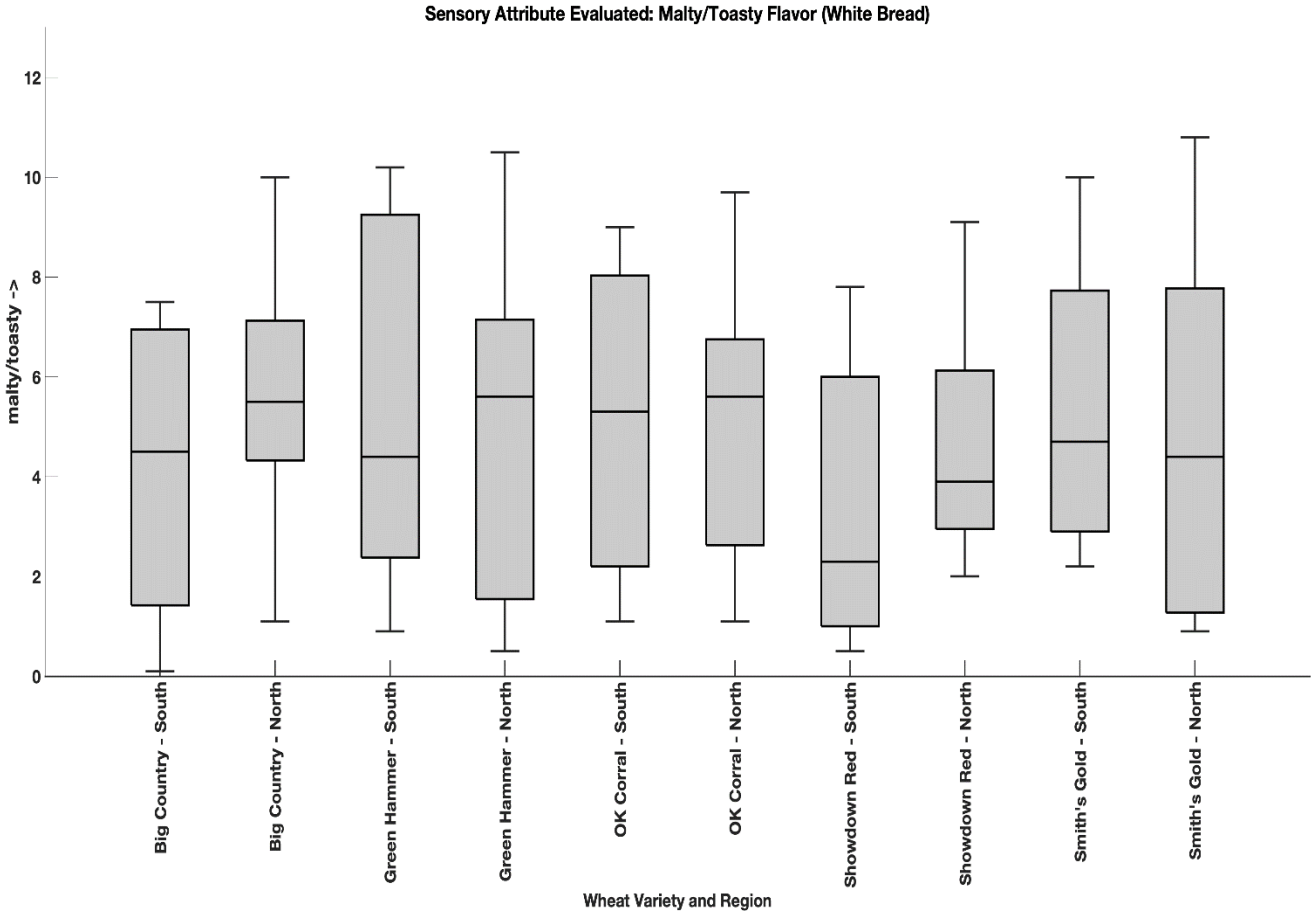
Appendix H. Attribute Intensity Plots for White and Whole Wheat Bread Samples

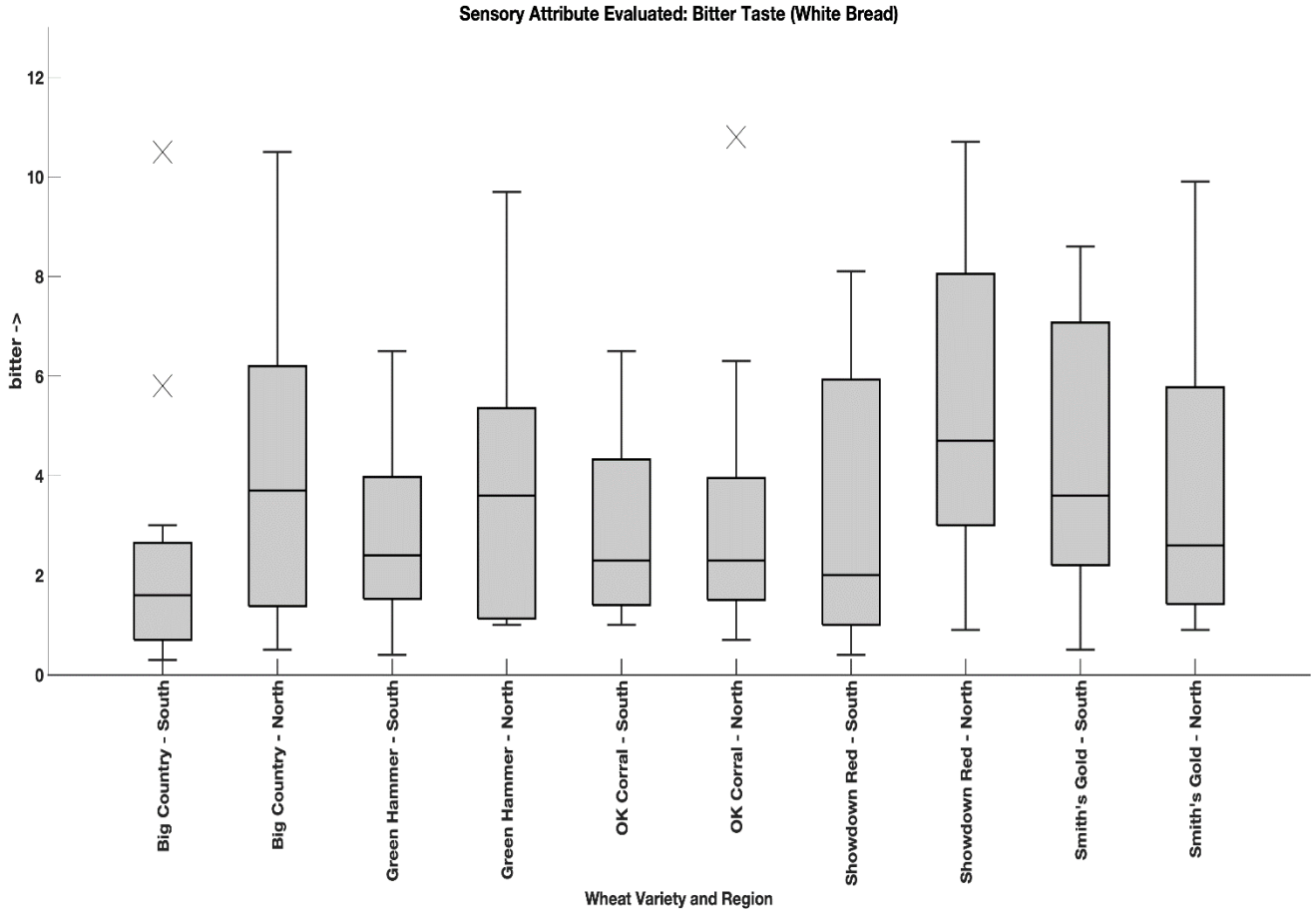


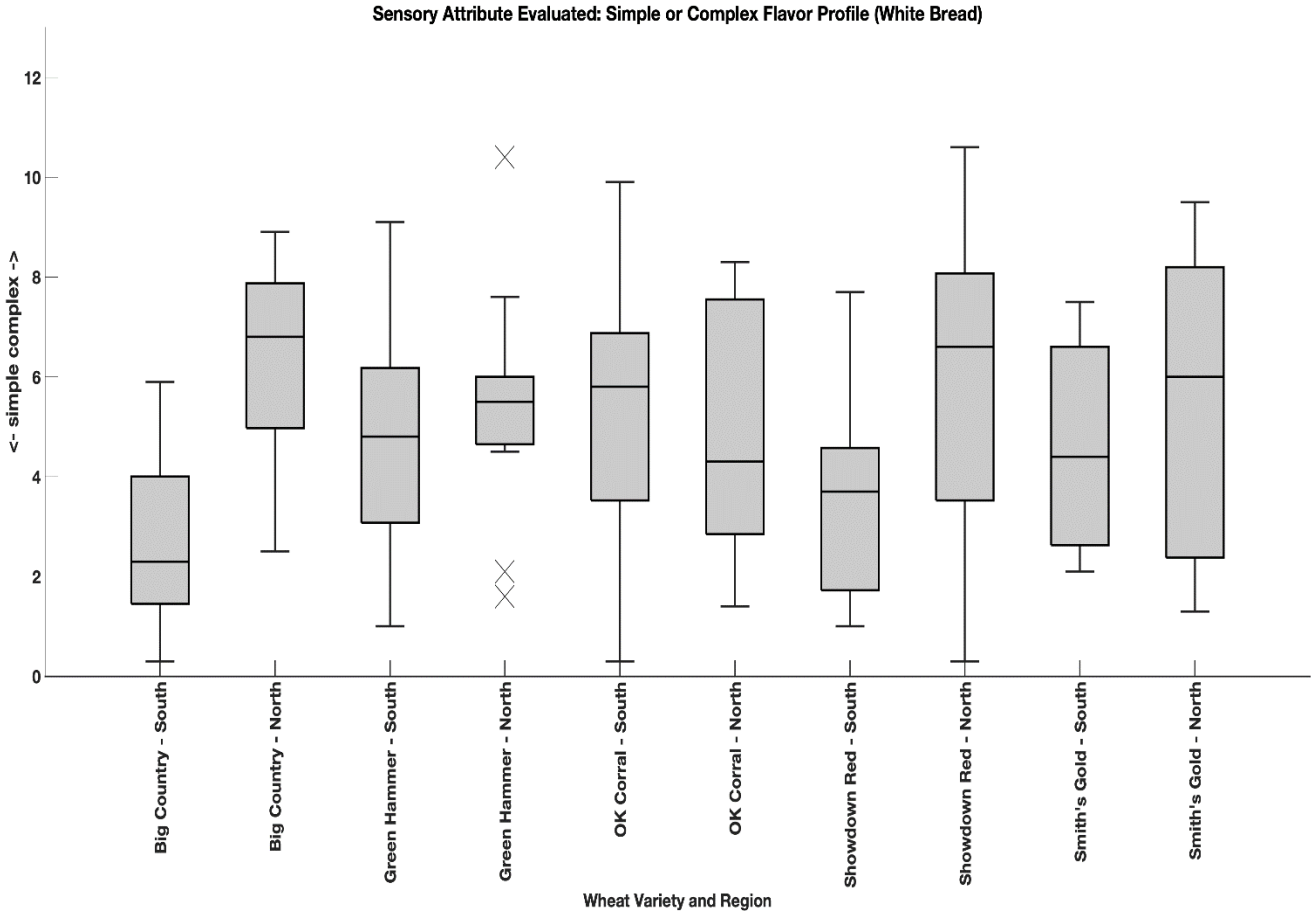

Sensory Attribute Evaluated: Dryness (White Bread)
<- dry moist ->
12
10
8
6
4
2
0
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region

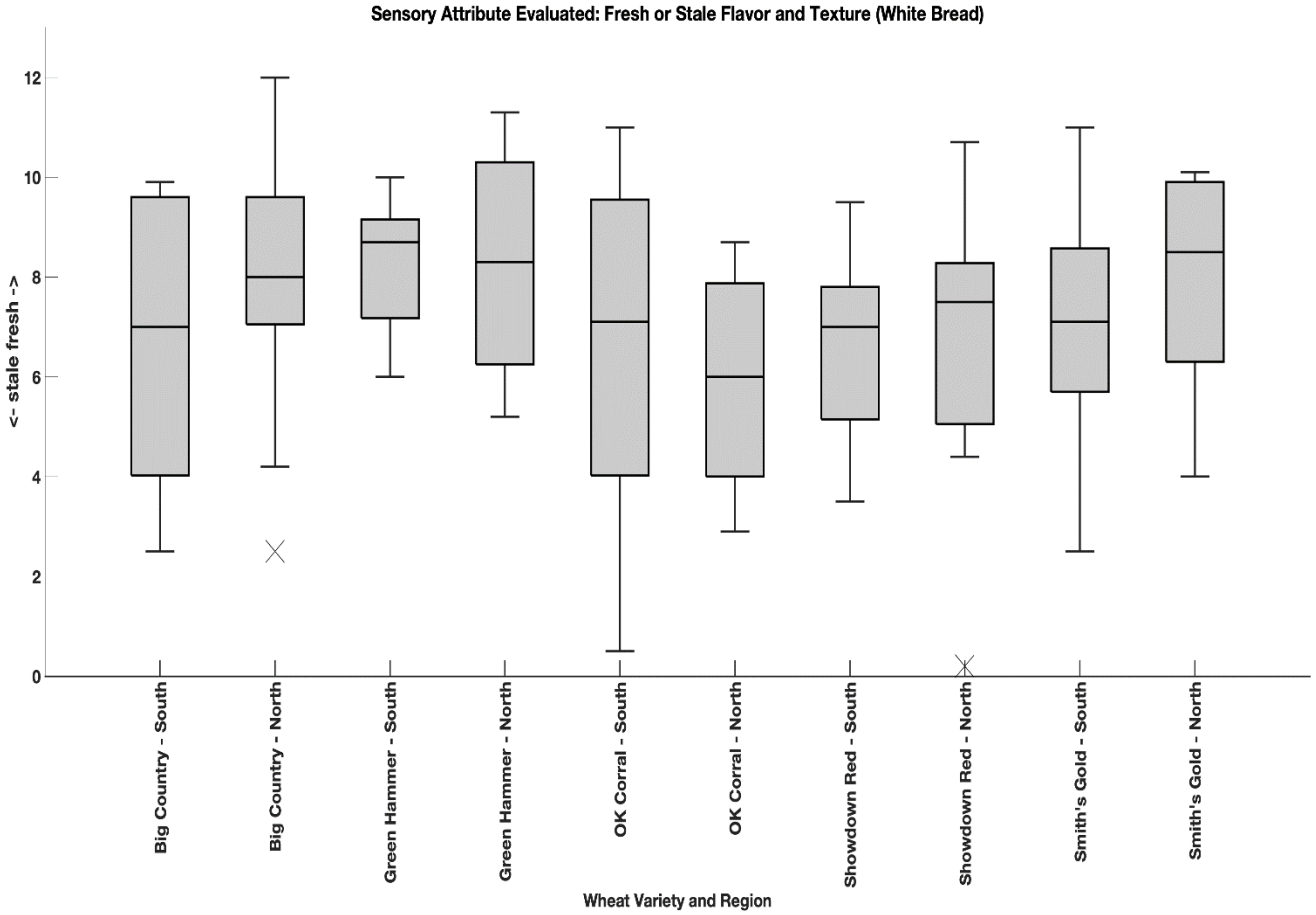

Sensory Attribute Evaluated: Sweet Taste (White Bread)
sweet ->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region

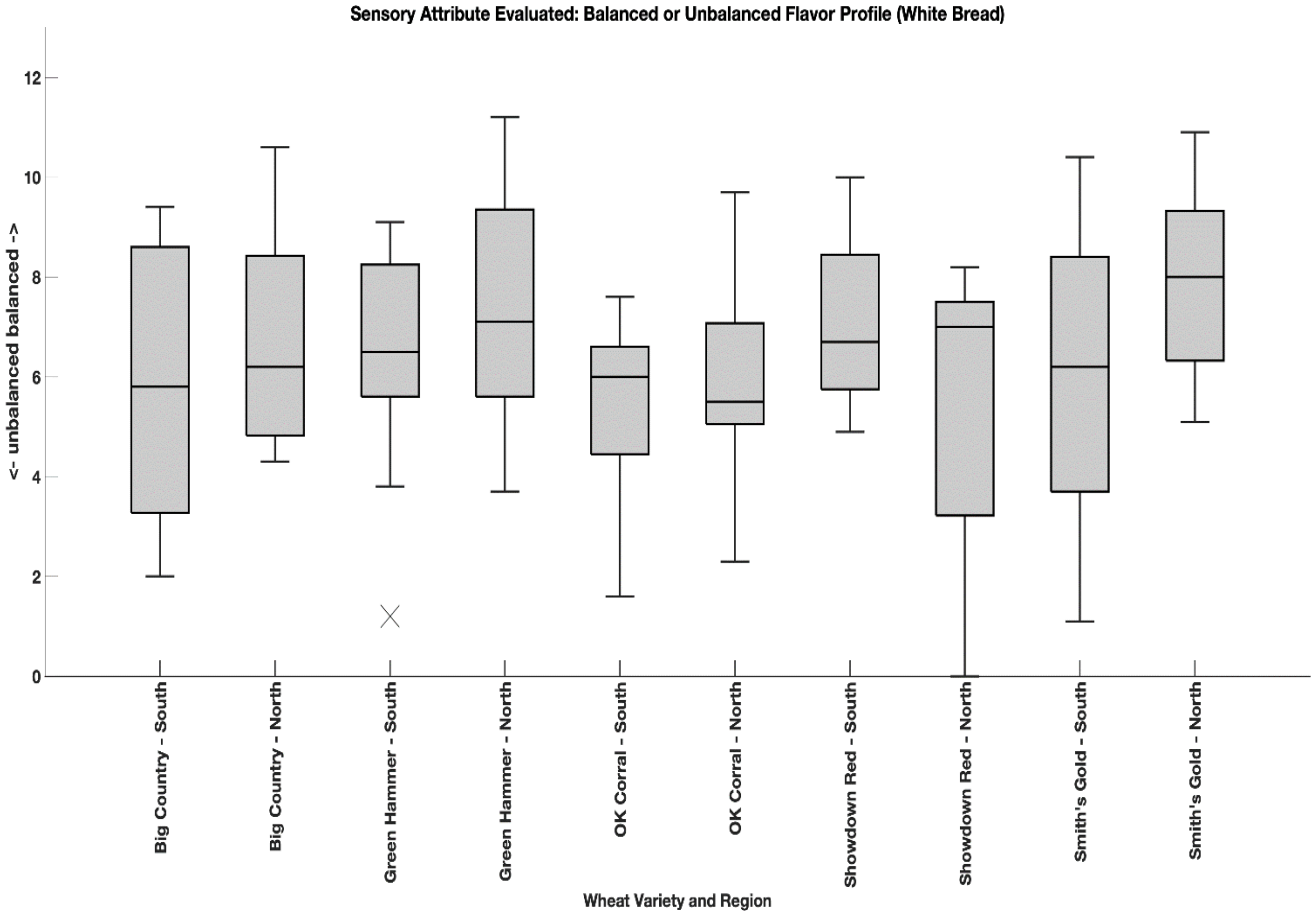

Sensory Attribute Evaluated: Sour Taste (White Bread)
sour ->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region

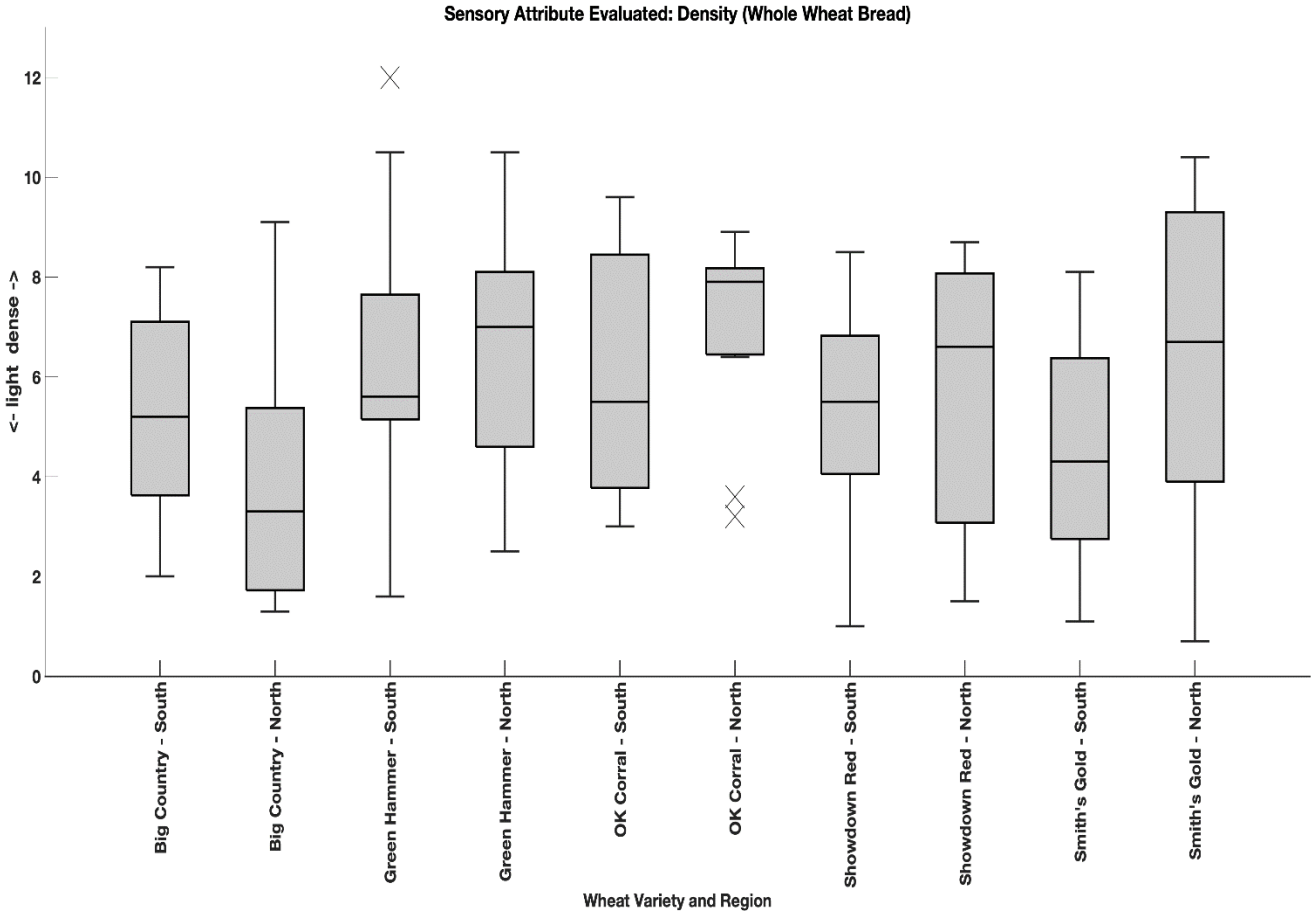

Sensory Attribute Evaluated: Malty/Toasty Flavor (White Bread)
malty/toasty ->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region

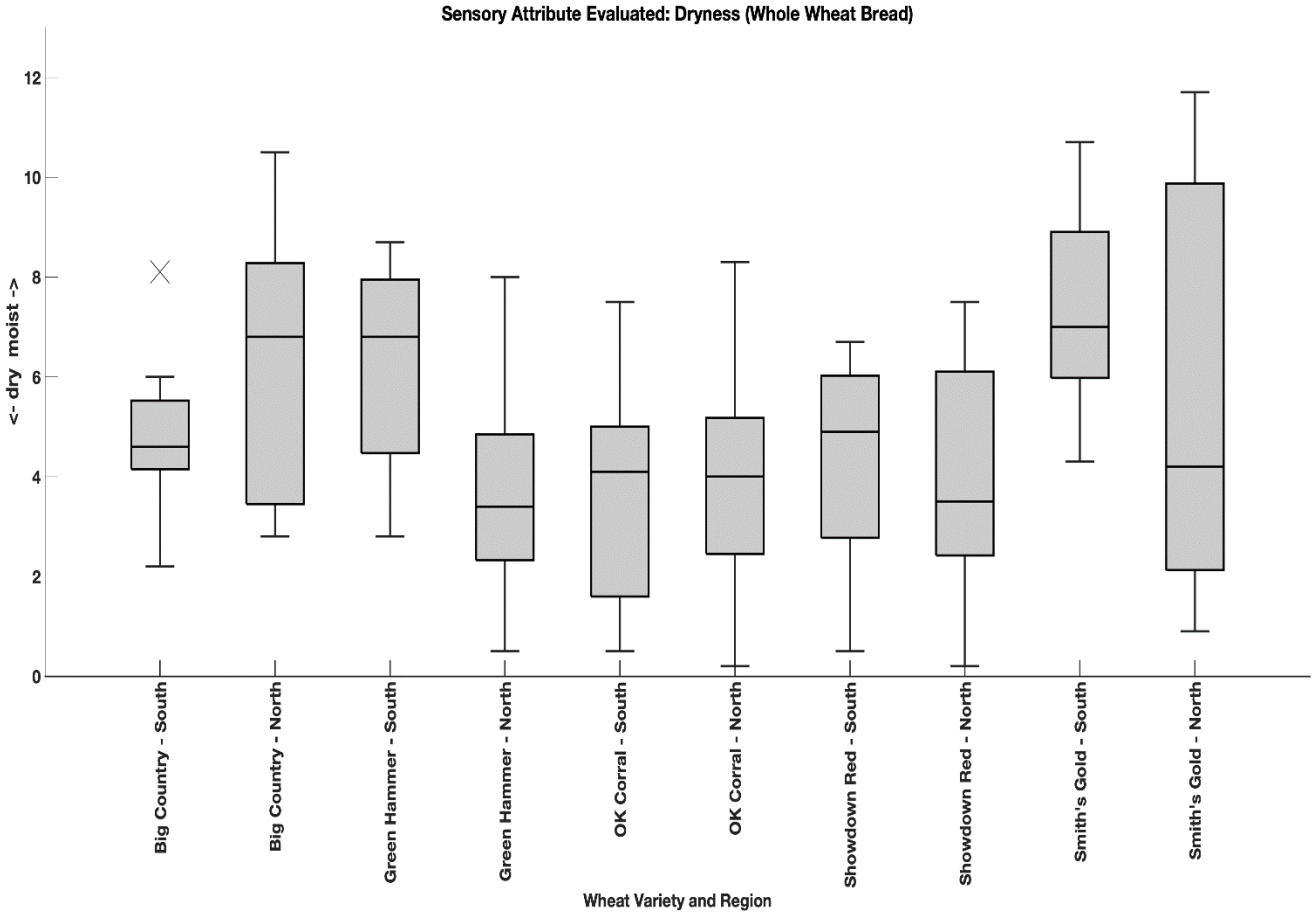

Sensory Attribute Evaluated: Bitter Taste (White Bread)
bitter ->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region

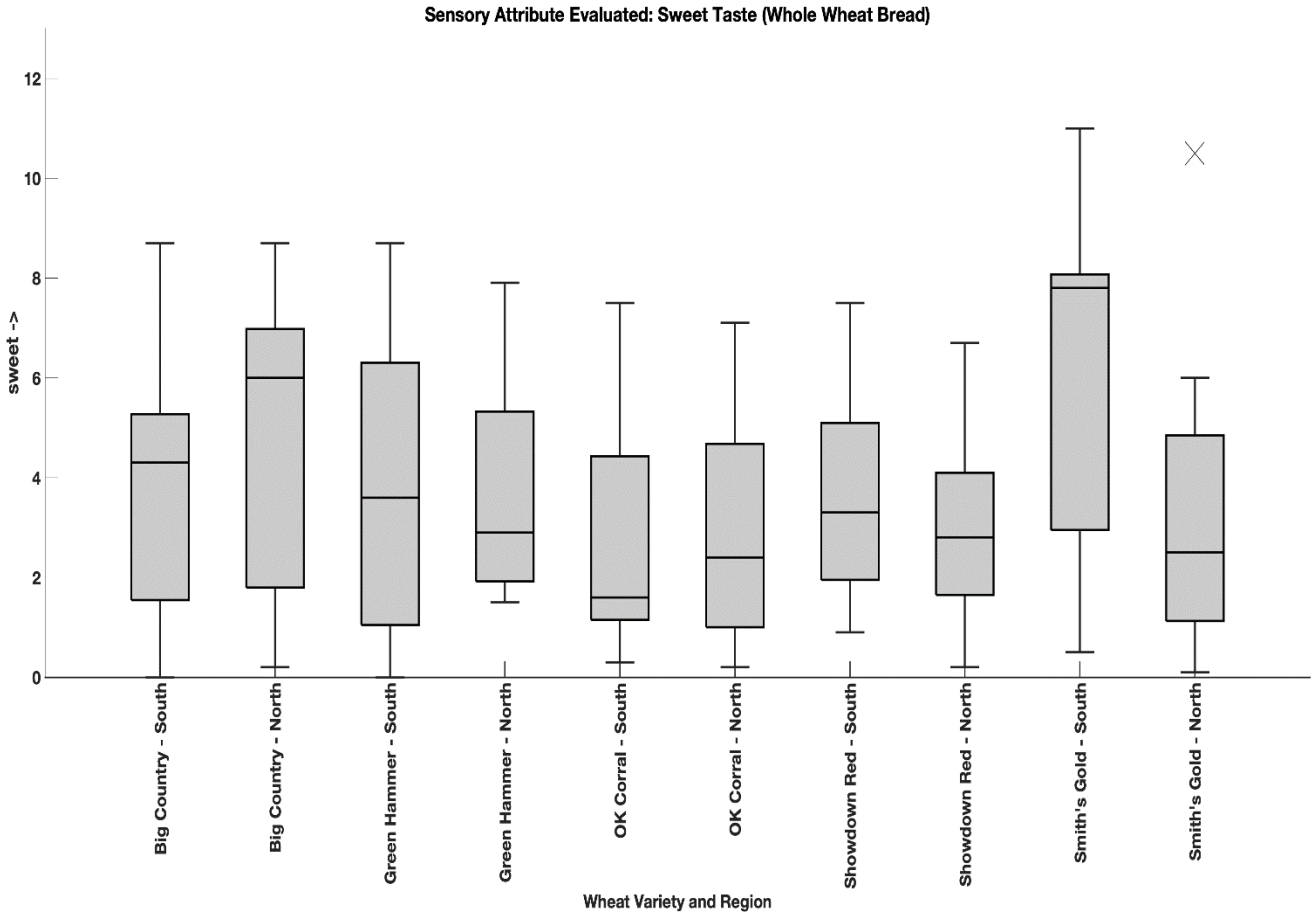

Sensory Attribute Evaluated: Simple or Complex Flavor Profile (White Bread)
<-- simple complex -->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region

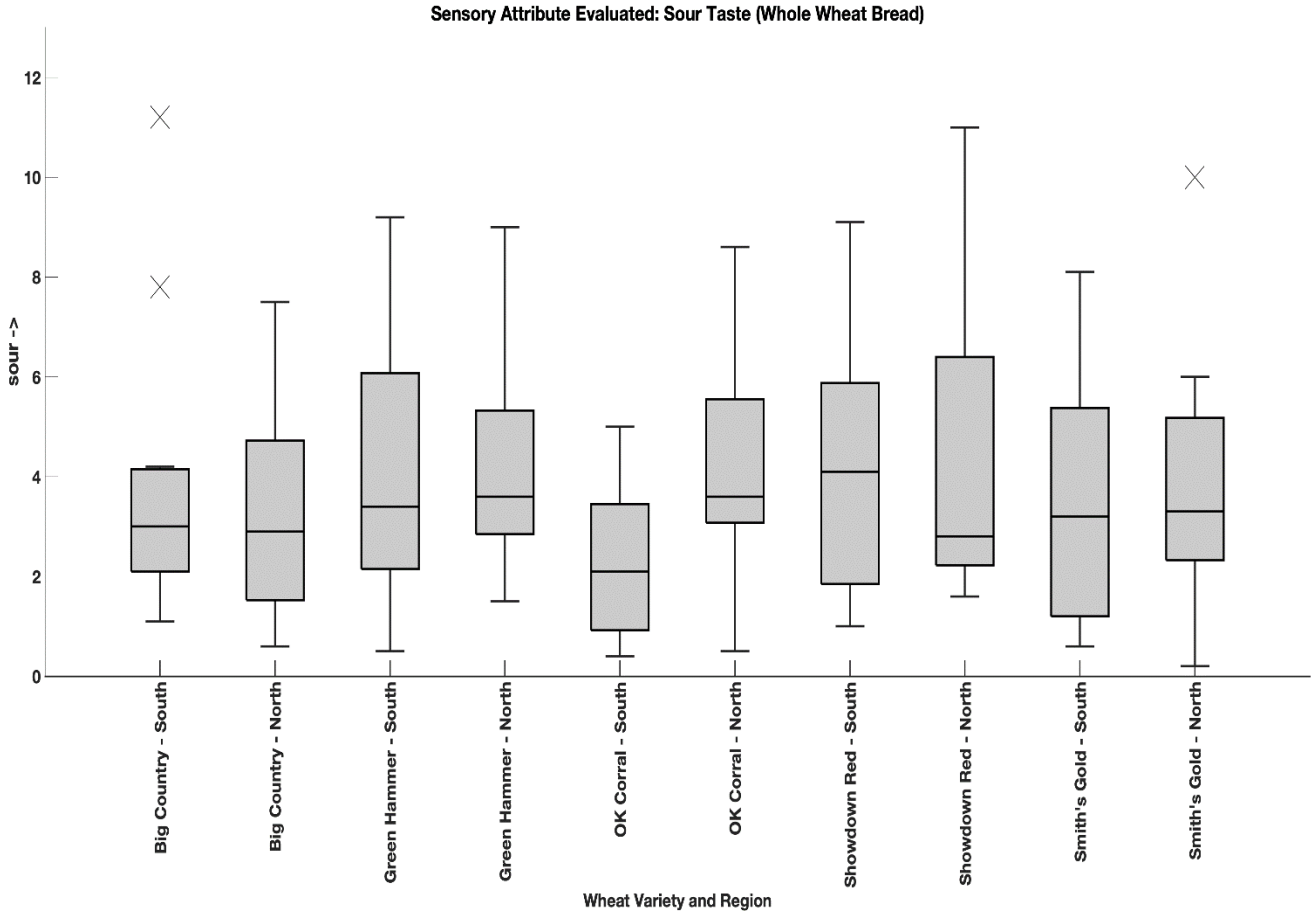

Sensory Attribute Evaluated: Fresh or Stale Flavor and Texture (White Bread)
<- stale fresh ->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region

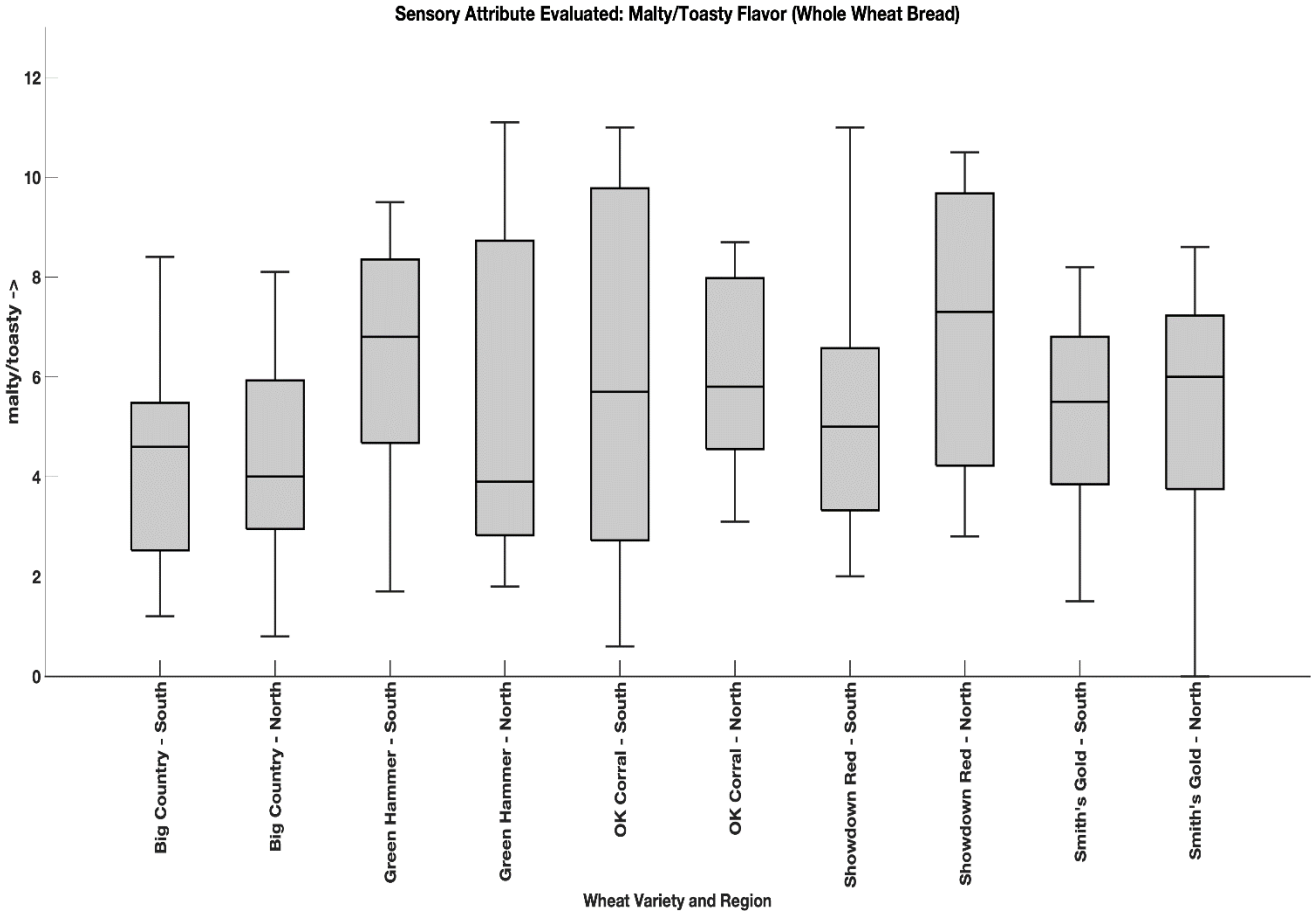

Sensory Attribute Evaluated: Balanced or Unbalanced Flavor Profile (White Bread)
<-- unbalanced balanced -->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region

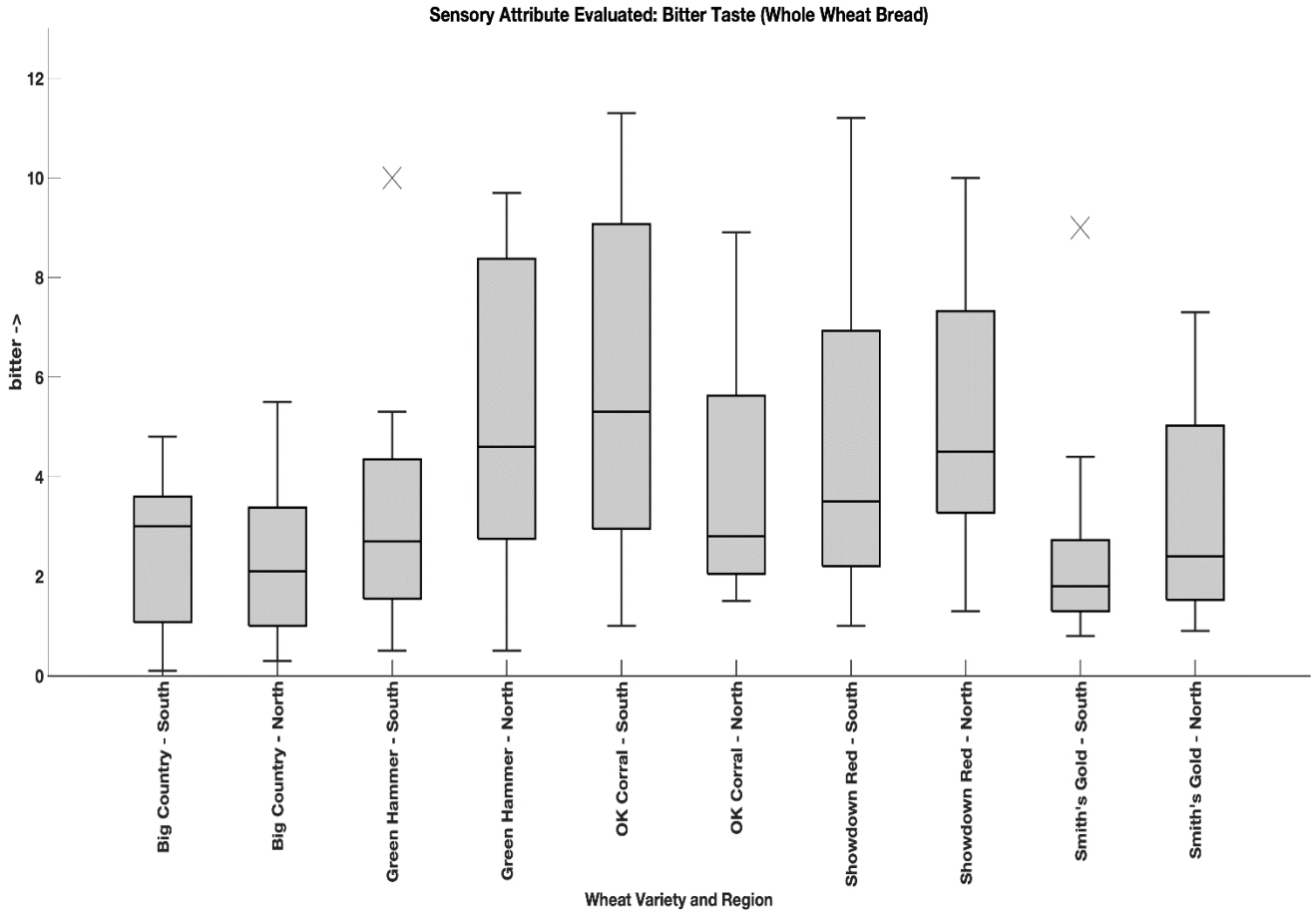

Sensory Attribute Evaluated: Density (Whole Wheat Bread)
<- light dense ->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region

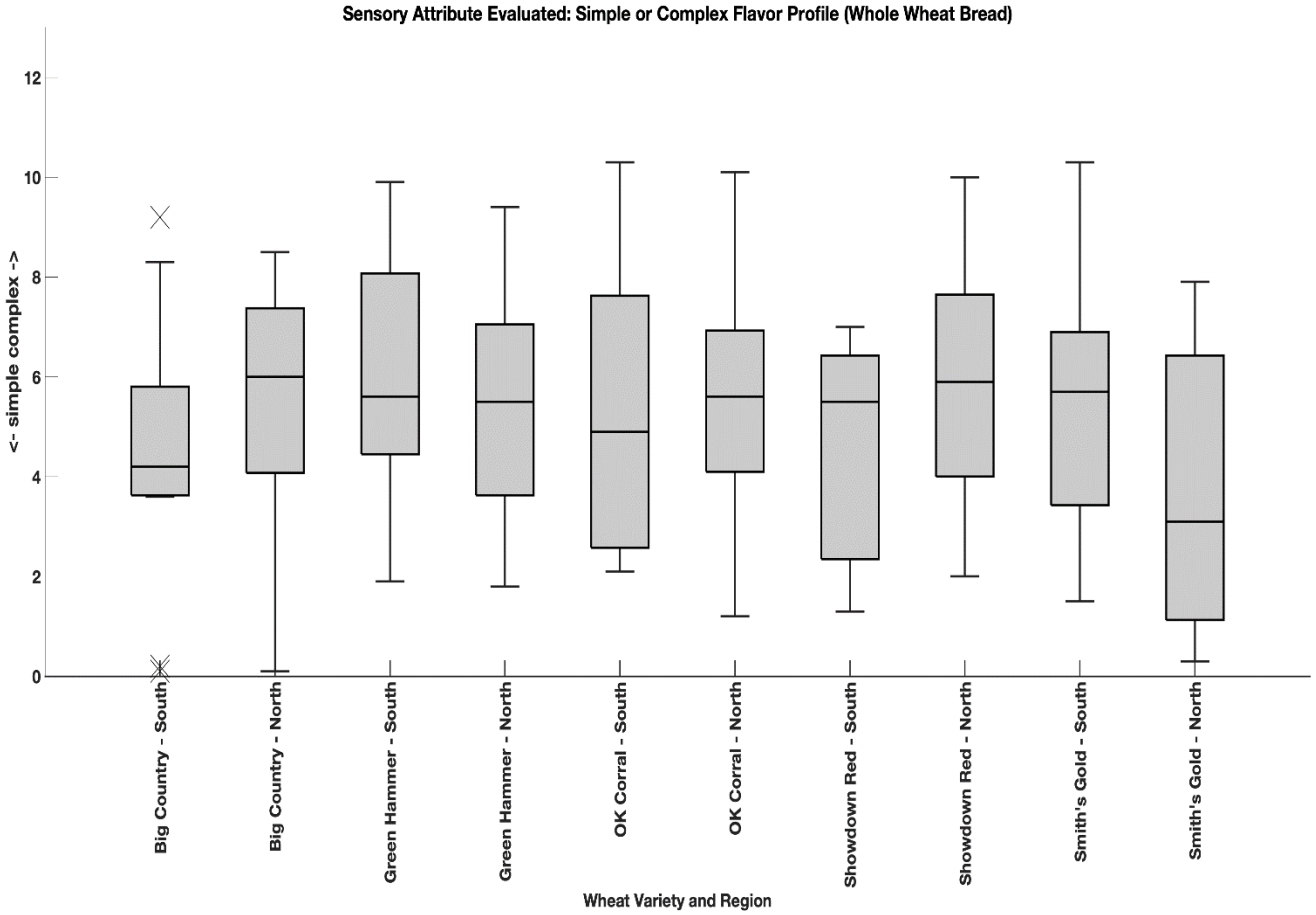

Sensory Attribute Evaluated: Dryness (Whole Wheat Bread)
<-- dry moist ->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region

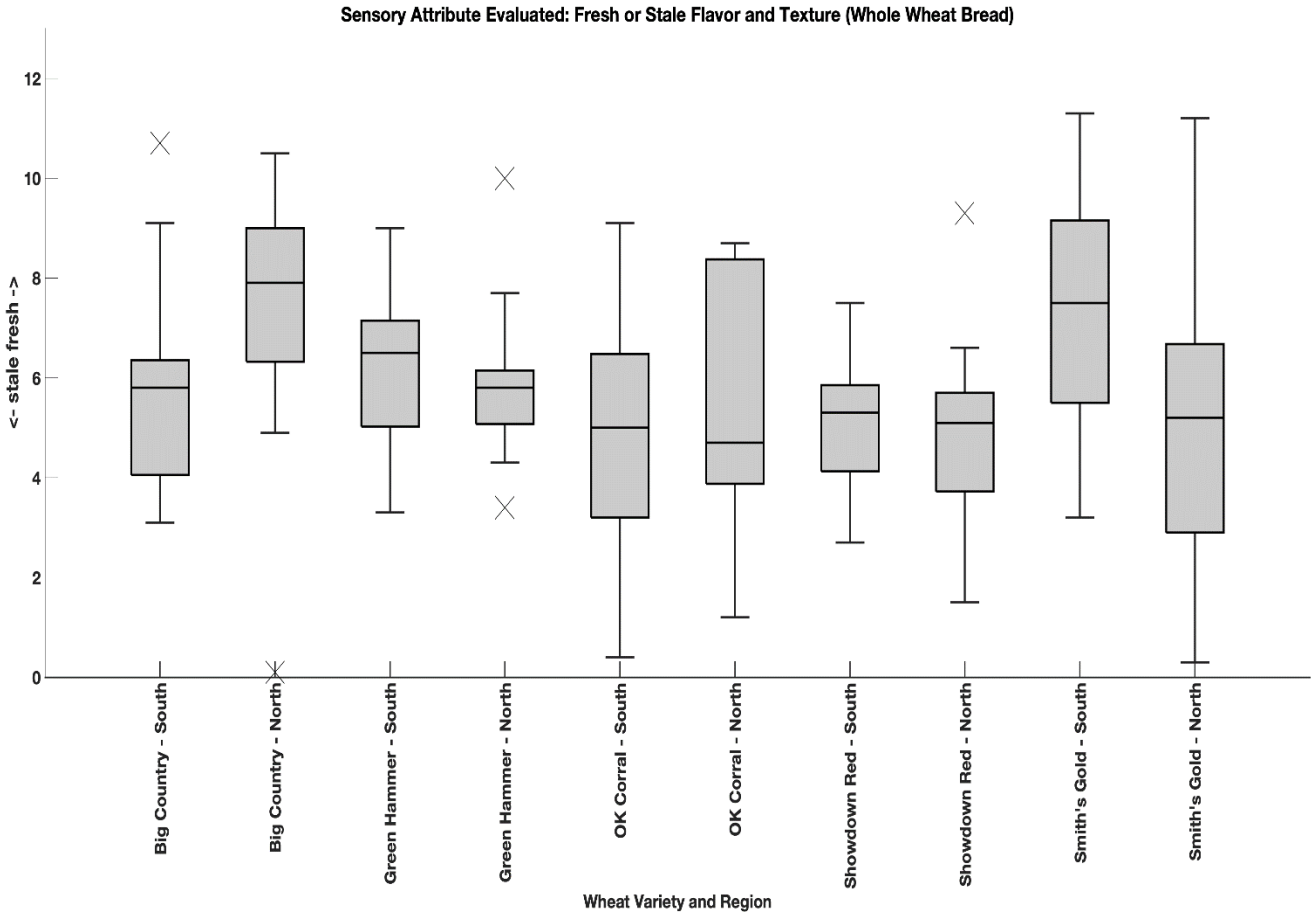

Sensory Attribute Evaluated: Sweet Taste (Whole Wheat Bread)
sweet ->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region

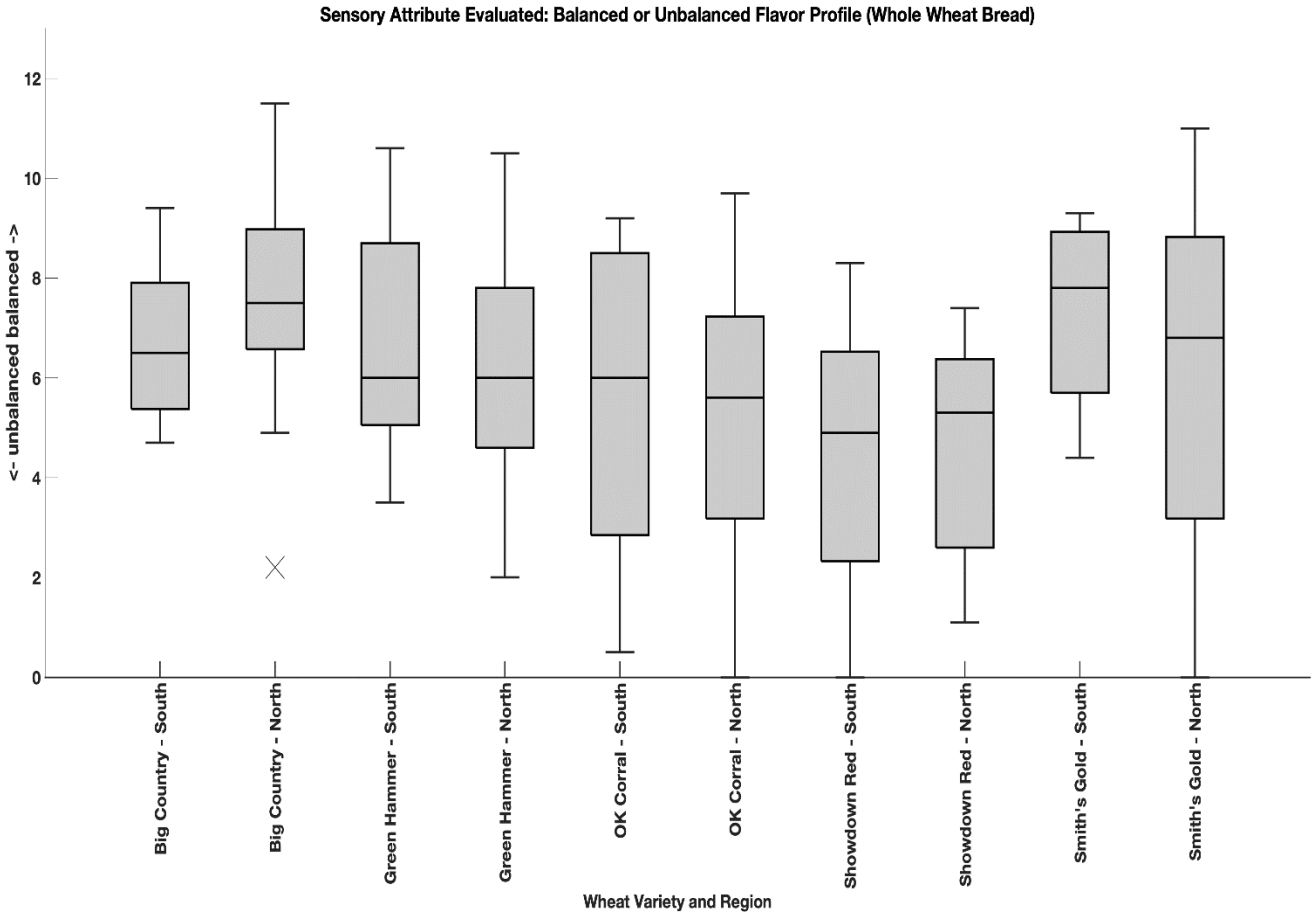

Sensory Attribute Evaluated: Sour Taste (Whole Wheat Bread)
sour ->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region


Sensory Attribute Evaluated: Malty/Toasty Flavor (Whole Wheat Bread)
malty/toasty ->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region


Sensory Attribute Evaluated: Bitter Taste (Whole Wheat Bread)
bitter -->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region


Sensory Attribute Evaluated: Simple or Complex Flavor Profile (Whole Wheat Bread)
<-- simple complex ->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region


Sensory Attribute Evaluated: Fresh or Stale Flavor and Texture (Whole Wheat Bread)
<- stale fresh ->
12
10
8
6
4
2
0
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region


Sensory Attribute Evaluated: Balanced or Unbalanced Flavor Profile (Whole Wheat Bread)
<-- unbalanced balanced ->
0
2
4
6
8
10
12
Big Country - South
Big Country - North
Green Hammer - South
Green Hammer - North
OK Corral - South
OK Corral - North
Showdown Red - South
Showdown Red - North
Smith's Gold - South
Smith's Gold - North
Wheat Variety and Region

VITA

Ryan Matthew Loy

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Graduate research and teaching assistant, Oklahoma State University Department of Agricultural Economics, Stillwater, Oklahoma, August 2018 – May 2023

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