AN ABSTRACT OF THE THESIS OF

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Hops contribute many desirable aromas to beer. Traditionally hop aromas have been described by the point of addition in the brewing process (dry-hop, finish-hop, or kettle-hop). The compounds present in the oil provide a wide range of aroma qualities. Since the composition of the oil is different for each hop variety it is reasonable to assume that the aroma qualities of each variety would be different. Moreover, since a different composition of compounds would be added to the beer at each addition point, it would be expected that different hop varieties would produce beers with different aroma qualities. Trained panel free-choice profiling was used to evaluate the aroma qualities of selected raw hops and of dry-hopped lagers and finish-hopped lagers produced with the same hops.

The first study compared the aroma qualities of eight commercial and seven experimental varieties of raw hops. The raw hops had intense aromas and were separated into five different groups based on their aroma qualities. Three experimental varieties were

found to have similar aroma qualities to varieties with German parentage. There was a strong correlation between the concentration of the hop oil compounds and the aroma qualities that separated the varieties.

The second and third studies compared the aroma qualities of American Lagers dry-hopped (second) and finish-hopped (third) with twelve of the fifteen hop varieties from the first study. In both studies the lagers were separated into three groups based on their aroma qualities. There was no relationship that could be applied to all varieties between the aroma qualities of the dry-hopped lagers and the finish-hopped lagers.

Comparing the aroma qualities of the hop varieties from all three studies, the aroma qualities of many of the raw hops were similar when used for dry-hopping, but changed when used for finish-hopping. Hallertauer Tradition and Spalter Select had fruity and floral qualities in all studies. Experimental variety 21683 had similar aroma qualities to Hallertauer Gold in all three studies.

Aroma Qualities of Raw Hops and Hops in Beer

by Trained Panel Free-Choice Profiling

by

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Gregory J. Stucky, Author

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

Aroma Qualities of Raw Hops and Hops in Beer by Trained Panel Free-Choice Profiling.

1. THESIS INTRODUCTION

Hop character can be defined as the flavor imparted to beer by the addition of hops by either dry-hopping, finish-hopping, or kettle-hopping. The later in the brewing process the hops are added, the more hop aroma is added to the beer (Moir 1987). Much chemistry has shown that different portions of the hops are present in the beer after each type of addition (Peacock et al. 1980, Peacock & Deinzer 1981a). Dry-hopped beer contains compounds more representative of the original hop oil than a corresponding finish-hopped beer (Haley & Peppard 1983). Hop character in beer is also determined by the variety of hop used (Peppard et al. 1989, Peacock et al. 1980, 1981). The chemistry of varietal and procedural differences have been well documented and research continues to enhance our knowledge of hop chemistry, however few researchers have looked at the actual flavor contributed by the addition of hops (Peppard et al. 1989), or the flavor contribution of hops from different types of hopping regimes (Haley & Peppard 1983).

Free-choice profiling was introduced about 1981 by Williams and his coworkers (Williams et al. 1981). It was introduced because different people have different sensory experiences and make different word associations, so that terminology used to describe flavors is inconsistent between people; and "forcing" people to associate specific sensory experiences with specific words, which may be unfamiliar, may cause confusion when trying to describe a sample. Since it's introduction it has been used with untrained consumers (Guy et al. 1989, McEwan et al. 1989, Williams & Arnold 1985), expert panels (Dumont 1994, Williams & Langron 1984), and trained panels (Jaime et al. 1993, Marshall & Kirby 1988, Rubico & McDaniel 1992). Research has shown that training a free-choice panel, allows for a high degree of separation (Heymann 1994, Rubico & McDaniel 1992). Training a free-choice panel offers many other benefits: Each panelist is able to use words they are comfortable with; Panelists are trained to use their words consistently; Panelists become familiar with the product; And the definitions of the words used by each panelist are known allowing for easy interpretation of the results.

This research was conducted to investigate the differences and similarities in the aroma qualities of different hop varieties as raw hops and as added for dry-hopping and finish-hopping beer. A secondary aim of this research was to determine if trained panel free-choice profiling was an adequate method for determining sample differences where the distinction between samples was slight. The specific objectives of each study were as follows:

Raw Hop Aroma Qualities

1. Identify a consensus configuration for the aromas of selected raw commercial and experimental hops.
2. Use the consensus configurations to identify experimental varieties that have aroma qualities similar to commercial varieties.
3. Determine if trained panel free-choice profiling is sufficient method for determining differences in the aroma of raw hops.

Dry-Hopping and Finish-Hopping Aroma Qualities

1. Identify consensus configurations for the aromas of American lagers dry-hopped and finish-hopped with selected commercial and experimental hop varieties.
2. Investigate changes in the aroma qualities of the hops, produced by dry-hopping and finish-hopping, and determine if the aroma qualities of the raw hop could be used to give insight into the aroma of the dry-hopped or finish-hopped beer.
3. Identify lagers made with experimental hop varieties which have aroma qualities similar to lagers made with commercial hop varieties.
4. Determine if trained panel free-choice profiling was a sufficient method for separating beers of a single style based on their aroma qualities.

2. LITERATURE REVIEW

2.1 Hop Aroma

Researchers in the brewing industry have been studying hop aromas for many years. Chemists have intensively researched hop aromas and determined the primary source of the aromas is the oil portion of the hop (De Mets & Verzele 1968, Sharpe & Laws 1981, Siebert et al. 1989, Tressl et al. 1978). Composition of hop oil has been studied extensively (Buttery & Ling 1967, Fukuoka & Kowaka 1985, Howard & Slater 1958, Likens & Nickerson 1967, Moir 1987, Sanchez 1992b, Sharpe & Laws 1981, Siebert 1994) and many of the compounds responsible for different aroma qualities have been identified (De Mets & Verzele 1968, Murakami et al. 1987, Peacock et al. 1980, Peacock & Deinzer 1981a, Peacock et al. 1981, Sanchez et al. 1992a, Sharpe 1988, Siebert et al. 1989, Tressl et al. 1978). A compilation of the major compounds and their aroma qualities are listed in Table 2-1. Hop aromas are dependent on the variety (Buttery & Ling 1967, Irwin 1989, Likens & Nickerson 1967, Peppard et al. 1989, & Sharpe & Laws 1981), growing region (Likens & Nickerson 1967), and maturity (Howard & Slater 1958, Likens & Nickerson 1967) as well as storage and handling(Foster & Nickerson 1985, Sharpe & Laws 1981). Much of the knowledge of hop chemistry has been compiled in books by Neve 1991 and Verzele & De Keukeleire 1991.

Most of the research on hop aromas has come from a chemical viewpoint. However, some researchers have bridged the gap to the sensory characteristics of hops and how the chemistry relates to sensory qualities. Morten Meilgaard is a pioneer in sensory properties of beer and hops. He identified and characterized the interaction effect of many hop and beer volatiles (Meilgaard 1975 a & b). His research lead to development of a beer "Flavor Wheel" so that researchers would have a common vocabulary (Meilgaard et al. 1982). Recently, researchers have begun using Gas Chromatographic Olfactometry (GCO) to determine the compounds responsible for different aroma qualities of hops (Sanchez et al. 1992 a &b, Siebert & Acree 1993). GCO allows the researcher to obtain chemical and sensory profiles of hops and to determine which chemical are responsible for the major aroma characteristics of hops. GCO is certain to be a valuable technique in the future.

Many questions about the sensory and chemical properties of hops still remain unanswered. What are the differences in aromas of hop varieties? Can chemistry of hops be used to predict hop aromas? How can raw hop aromas be used to predict aroma imparted to beer? How does oxidation affect the aroma qualities of hops? What are the aroma qualities of hops as they ripen on the vine? Can the aroma of hops be used to predict maturity level? These are but a few of the questions that need to be answered to increase knowledge of how the chemistry is correlated with the aroma qualities of hops.

TABLE 2-1: Some chemical components of hops and their aroma qualities

Compound	Aroma Qualities
α-terpineol (A)	Woody, Resinous
2-nonenone (B)	Oily, Solvent
2-Undecanol (B)	Floral
2-Undecanone (A)	Floral, Oily, Solvent
Caryophyllene Epoxide (C)	Menthol
Citral B (D)	Minty, Anise
Geraniol (A,E)	Geranium, Floral
Geraniol isobutyrate (E)	Floral
Geranyl Acetate (A)	Fruity
Humelenol II (C)	Sagebrush
Humulene Epoxide I (C,D)	Hay, Grass, Floral, Spicy
Humulene Epoxide II (C,D)	Moldy, Floral, Spicy
Humulol (C)	Hay, Grass
Isoamyl isobutyrate (B)	Fruity, Pineapple
Isoamyl isovalerate (B)	Fruity, Pineapple
Isobutyl isobutyrate (B)	Fruity, Pineapple
Linalool (A,B,D,E)	Floral
Methyl dec-4-enoate (B)	Fruity, Waxy
Myrcene (A,B)	Spicy, Resinous, Fruity, Floral
Terpinolene (A)	Woody, Resinous

(A) Sharpe 1988
(B) Whitear & Sharpe 1985
(C) Fukuoka & Kowaka 1985
(D) Sanchez et al. 1992
(E) Peacock et al. 1981

2.2 Free-Choice Profiling

Free-choice profiling is a descriptive sensory method used for determining sample similarities, differences and characteristics. Unlike other common language descriptive methods, i.e. Texture Profiling (Szczesniak, 1963), Quantitative Descriptive Analysis™ (Stone et al, 1974) and Spectrum™ (Meilgaard et al., 1991), free-choice profiling allows the panelists to describe the samples with their own words (Williams et al. 1981). Reviewing research using this method, it appears there is not a single approach to using this technique. Originally it was designed to be used with untrained consumer panels as a way to cut costs and speed up the collection of data (Gower 1975, Williams & Arnold 1984, Williams & Langron 1984). Since it's introduction it has been used with untrained consumers (Guy et al. 1989, McEwan et al. 1989, Williams & Arnold 1985), expert panels (Dumont 1994, Williams & Langron 1984), and trained panels (Jaime et al. 1993, Marshall & Kirby 1988, Rubico & McDaniel 1992). The technique is not standardized. It seems that each of these three types of panels have only one thing in common - the panelists are allowed to select their own words to describe the sample. But asking consumers, experts, or trained panelists to complete this task gives different results.

2.2.1 *Consumer Panels*

Naive consumers are able to produce an individual profile of each product, using his or her own terms for describing them, without the need to explain the meaning of such terms (Williams & Langron 1984). Thus, samples can be grouped for similarities according to individual descriptive profiles without the need of a trained panel. However, depending on the familiarity with product, consumers will use words for which they may or may not have definitions and which they may or may not be able to replicate. There is also a great chance that two consumers will use the same word differently (Marshall & Kirby 1988), which makes analysis difficult. Since definitions for descriptors are not known, only generalizations can be made as to how the consumers described the samples.

However, in conjunction with focus panel information, consumer free-choice profiling can be a very valuable tool for generating product concepts and gathering information about consumer opinion of a sample, over and above simple liking of the sample.

2.2.2 *Expert Panels*

An untrained group of experts (i.e. professional wine judges) will usually have the same vocabulary between people, and usually this vocabulary is very extensive. Experts use more descriptive words than naive consumers and are able to define the words they use (Williams & Langron 1984, Heymann 1994), which allows the analyst to determine a list of aroma qualities for each sample. Since an expert panel is sensitive to many factors of the product to which the general public is insensitive, they can be very useful for monitoring product quality. Since experts are very comfortable with their common vocabulary and can define the words they use, the need for panel training is minimal. The disadvantages of an expert panel are: the data may not relate to what average consumers think of the product; the panelists use many descriptors with poor replication which results in a high degree of statistical noise (Williams & Langron 1984); and for some products experts may be hard to find.

Another type of expert is the sensory expert. This is a person that has had formal training in sensory evaluation and has participated on many different descriptive panels. These people were called "sensory savvy" by Heymann (1994). Because of their background and training they will have a large word base with which they are comfortable, and will be able to give a definition for most if not all the words they use. The advantage of using sensory experts over naive consumers is they are more likely to choose terms they understand and can use consistently (Heymann 1994). The disadvantage is no two people have the same background so not all the panelists use the same definitions for the same words.

2.2.3 *Trained Panels*

Training a free-choice profiling panel involves allowing each panelist to develop a set of descriptors for a product class, then defining each of the descriptors with standards. Training protocols are comparable to training many one person common language descriptive panels, but allowing each panelist to develop and define their own words. This training method allows for many panelists using the same word, but each defining it differently. Similar to a descriptive panel, monitoring the panel for repeatability and consistency measures is important for determining how well the panel is trained. The advantages of a trained free-choice profiling panel are: the panelists are familiar with the product; they are consistent and repeatable with the words they use; and the definition for each descriptor used is known so the analyst is more informed about how each product is described. The only disadvantage of a trained panel is they must be trained. This is more time consuming than non-trained panels, but ultimately produces more information, and better sample separation.

2.2.4 *Advantages of Free-Choice Profiling*

Naive consumers can be used to determine sample differences and similarities. This means that panelists do not need to have experience with characteristics of product or definitions of vocabulary (Piggott et al. 1992). Panelists are not forced to use words and definitions they may not understand. Free-choice profiling overcomes many obstacles that common language descriptive techniques can not overcome. Namely the problems with individual differences: both with how samples are perceived and with the measurement scale used to quantify their perception (Powers, 1984), that panelists use the same descriptor differently (Williams & Arnold 1985), or that the panelists interpretation of the major differences between samples may differ (Tunaley et al. 1988). Free-choice profiling also allows smooth connection between a focus panel session and obtaining quantitative data from the same people.

2.2.5 *Disadvantages of Free-Choice Profiling*

When free-choice profiling is compared to other descriptive techniques, there are certainly some disadvantages to a free-choice profiling study. The statistical output of Generalized Procrustes Analysis (GPA) is not well known, or as well understood by sensory scientists as the output from ANOVA. Since GPA doesn't produce a separation at a given probability the person analyzing the data may confer their own opinions when showing the results and drawing conclusions. When running a consumer panel, the panelists are sometimes unable to describe what they perceive when the samples are presented in the isolation of sensory booths (McEwan et al. 1989). When using a trained panel the training time is not any shorter than other descriptive panel methods.

2.2.6 *Trained Descriptive or Free-Choice Panel*

A very important question to answer is, "When should I use a trained common language descriptive panel and when should I use a trained free-choice profiling panel?" Since there is not going to be a difference in the amount of time spent training the panel, the decision to use a free-choice profiling panel must be based on the project objectives.

Free-choice profiling with a trained panel produces a consensus configuration revealing the relationships between the samples based on the descriptors given to each sample by each panelist. The common language descriptive methods, i.e. Texture Profiling (Szczesniak, 1963), Quantitative Descriptive Analysis™ (Stone et al, 1974) and Spectrum™ (Meilgaard et al., 1991) produce a word profile of each product and sample groupings for each descriptor based on LSD or other statistical separation methods.

2.2.7 *Objectives of a Study Which Would Allow Use of Free-Choice Profiling*

Since the decision to use free-choice profiling must be based on the objectives of the project, the following is a list of project objectives which would allow for free-choice profiling to be used:

1. Describe the differences or similarities between samples.
2. Describe the samples.

3. Group similar samples together.
4. Determine the demographics of consumers who like/dislike the sample.
5. Determine the relationships between analytical measures and product description or product attributes.
6. Make a smooth transition between a focus panel session and a quantitative data collection session with the same people.

2.2.8 *Summary*

Free-choice profiling can be used with three different types of panels to give varying degrees of information. A panel of naive consumers will give basic information about product separation. It is the least expensive free-choice method. No training is involved, and product profiles are vague. An expert panel usually costs more to run than a consumer panel, but the clarity of separation is better and product profiles can be obtained if the panelists are asked to define the words they use. A trained free-choice panel is the most expensive to run since a large amount of training is required. The clarity of sample separation is better than a consumer panel, and product profiles are easily obtained since all descriptors used have clear definitions.

One thing is certain: In order to understand the results clearly, the definitions for each descriptor used, whether consumer, expert, or trained, must be known. If these definitions are not known, the only information that can be obtained is general sample groupings. And even then the grouping of samples is left to the interpretation of the analyst.

2.3 Procrustes Analysis

> "Procrustes," a Greek term meaning "to beat out," described a Greek innkeeper in Attica who seized travelers and tied them to the iron framework of his beds where he stretched the legs of short men and cut the legs of tall men so that they would all fit in his beds. The name "Procrustes" conceptually describes, to some extent, what is done with data in a Procrustes analysis.
>
> -Oreskovich et al. (1991)

2.3.1 *History*

Initially, Procrustes analysis was used to match one configuration or matrix to a target configuration. This method was called the "Pair-wise" approach and was first used by Moiser (1939) and Green (1952) to compare methods of statistical analysis. The name "Procrustes," used to describe the transformation of one matrix to match another, was given to the procedure by Hurley and Cattell in 1962 because, "[the] program lends itself to the brutal feat of making almost any data fit almost any hypothesis" like Procrustes made travelers fit his beds. Since then there have been many changes to the method. Cliff (1966) restricted the transformation of the matrices to only orthogonal transformations. Schönemann (1966) also used orthogonal transformations for matching configurations, and later (1968) referred to the orthogonal transformations as the "two-sided" orthogonal Procrustes problem. In 1971 Kristof and Wingersky introduced "generalized" Procrustes analysis in which many matrices could be fit to a common centroid matrix. Their method did not include any transformation of the matrices. Building on previous work Gower (1975) introduced a translation and scaling step to the generalized method as well as a method for summarizing the Procrustes results in an analysis of variance format. TenBerge (1977) and TenBerge and Kroll (1984) made further changes to the generalized method which allowed for the transformation of matrices with different numbers of columns. In 1988 Peay introduced the consensus configuration to the generalized method. In 1991 King and Arents developed a Monte Carlo approach for determining if the consensus configuration obtained by GPA actually gives a picture of the true consensus between panelists, as opposed to being merely an artifact of the analysis. This statistical test determines if the panelists are in agreement and are able to separate the samples, or if the apparent separation seen in the consensus plot was "created" by the analysis. Most statistical analysis software packages now use Gower's and Peay's methods and give many options for changing the analysis for specific types of problems. Oreskovich et al. (1991) supply a fairly complete overview of the Procrustes procedure, some history, and many applications for the field of Sensory Evaluation.

2.3.2 *The Generalized Approach*

The method which is important when working with sensory data is the generalized method. The generalized method compares all configurations to a target configuration, from which a consensus configuration is derived. For a complete example with a data set, refer to Oreskovich et al. (1991). The raw data (initial panelist configurations) are initially transformed and scaled to match a target configuration. This results in Transformed Panelists Configurations which are matched to a Transformed Target. This produces new Transformed Panelists Configurations and a new Transformed Target. The new configurations are rotated and scaled over and over (Procrustes algorithm loop) until the change in the Procrustes statistic is either minimal, or has met some predetermined tolerance. After the final transformation of the panelists configurations is made, a consensus configuration can be determined by rotating the transformed panelist configuration to the principal axes where the first axis shows the highest percentage of variation among the objects or samples.

2.3.3 *The Steps Of Generalized Procrustes Analysis*

The goal of the analysis is to blend the individual configurations into a common space. Three geometric transformations can be used to transform the raw data to the consensus set: Initialization (Translation), Rotation and Scaling.

2.3.3.1 Initialization/Standardization

2.3.3.1.1 Translation

Translation can be defined as centering the individual spaces (configurations) to a common origin. The points are transformed to deviations from their mean scores, which eliminates level differences between variables. This step can account for the variation due to different levels of the scale being used by different panelists. It can remove the effect of individual panelists who consistently under- or overscore a particular attribute.

2.3.3.1.2 Normalization

Normalization adjusts a matrix so that its elements are of comparable magnitude to other normalized matrices. This step is particularly important when comparing matrices obtained from two different sources. This allows for the comparison of two different sensory panels or a sensory panel and analytical measures.

2.3.3.2 Rotation

Rotation can be defined as the rotation of each panelists configuration to match or optimally fit the target configuration. This accounts for variation in individual panelists' interpretation of the same term.

2.3.3.3 Scaling

Scaling is the stretching or shrinking of a cloud of data points (equi-distant in all directions). Scaling accounts for the dispersion of the data points within each panelists configuration. Which is the range of the scale that a panelist used to describe the differences between samples on a particular attribute. The data will be stretched if the panelist used only a small amount of the scale and shrunk if a large portion of the scale was used.

2.3.4 *The Procrustes Algorithm (Iteration)*

The Procrustes algorithm is simply rotating and scaling the configurations to match or optimally fit the target configuration. Each time the configurations are rotated and scaled a new target configuration is made and the individual configurations re-fit. This is an iterative procedure that continues until the change in the Procrustes statistic is negligible or a preset tolerance is met.

2.3.5 *Procrustes Statistic*

The Procrustes statistic is the distance between a pair of configurations. It can be calculated for panelists by summing the squared distances between the corresponding points of two configurations. A low Procrustes statistic indicates similarity or agreement between panelists and a high value indicates differences or disagreement. The statistic can also be determined for samples by summing the squared distances for all panelists from the consensus positioning to an individual panelist's final position for each sample. A small value indicates high agreement between panelists on the final positioning of the sample.

2.3.6 *Sensetools Software*

The Sensetools software (Procrustes-PC 1989) begins with Standardization which involves transformation of raw data (Translation) and scaling of the variance (Normalization). The second step is Rotation. The third is Scaling. The second and third steps are part of the algorithm which runs through an iteration loop until further iteration yields little change in the Procrustes statistic. At the end of the iteration loop the solution is rotated to the principal axis of a consensus space where the first axis explains the greatest percentage of the variation between objects (samples). As with most software programs many of the variables at each stage of the analysis may be set/changed or added/eliminated.

2.3.7 *Applications of Procrustes Analysis for Sensory*

The range of applications of Procrustes analysis for sensory analysis is quite vast. There are five categories into which most applications fit.

2.3.7.1 Describing samples and sample differences

Describing the differences between samples is certainly the most common application of Procrustes analysis. Sample separation is based on the attributes by which the panelists most clearly differentiate the samples. Procrustes analysis has been used to differentiate between the appearance, flavor, and aroma of commercial ports (Williams and Langron, 1984), coffee aroma (Williams and Arnold, 1985), flavor and odor profiles of fish spoilage (Quarmby and Ratkowsky, 1988), perceptual characteristics of sweeteners (Tunaley, 1988), appearance, flavor and texture of chocolate (McEwan et al., 1989), cheese texture (Marshall and Kirby, 1988), consumer profiling of whisky (Guy et al., 1989), canned lager beers (Gains and Thompson, 1990), texture of meat patties (Beilken et al., 1991), flavor, texture and aroma of gels (Jaime et al., 1993), flavor of selected acids (Rubico and McDaniel, 1992), texture of sweet orange gels (Costell et al., 1995), texture and appearance of cheddar cheese (Jack et al., 1993), and aroma of vanilla and vanillin (Heymann, 1994).

2.3.7.2 Comparison of analytical data with sensory data

Comparisons between instrumental and sensory measurements provide a means of testing the reliability of instruments to provide sensory information about samples. Depending of the type of analytical data collected, the matrices of the different analytical measurement can be compared to the sensory measurements in one of two ways: the consensus configurations from the analytical and sensory can be compared, or the matrix of the analytical data can be analyzed with the sensory data to obtain a single consensus configuration. Analytical data can also be analyzed by a separate method and compared to the principal axes of the sensory consensus plot.

2.3.7.3 Assessment of panelist performance

Procrustes analysis is useful in determining panelist performance as well as discrepancies between panelists. This is helpful when selecting , training, and monitoring panelist and panel performance over time. Williams et al. (1981) described in detail how generalized Procrustes analysis can be used to investigate the effects of panelists using different words to describe the same stimulus, and the variation in scale usage for individual attributes and over all attributes. King and Arents (1991) developed a Monte Carlo approach for determining if the consensus configuration obtained by GPA actually gives a picture of the true consensus between panelists, as opposed to being merely an artifact of the analysis. Rubico and McDaniel (1992) compared the amount of agreement between panelists for individual acid samples. Williams and Langron (1984) compared expert and non-expert panelists in their evaluation of port. Jaime et al. (1993) used GPA to determine the reliability of panelists and the agreement among gelatin samples. Marshall and Kirby (1988) used GPA to determine the ability of a trained panel to replicate texture measurements of cheese samples. Costell et al. (1995) compared the residual variance of the panelists with the assessor plot of the first two dimensions to determine panelists which were describing samples different from the rest of the panel. They also plotted individual consensus space diagrams to determine reproducibility and ability to separate the samples. Heymann (1994) compared "sensory-savvy" and "sensory-naive" individuals for their ability to separate vanilla and vanillin samples.

2.3.7.4 Comparison of methodologies

Different sensory methodologies can be compared with Procrustes analysis by comparing consensus configurations. This comparison can be made between any descriptive techniques. Williams and Arnold (1984) compared conventional profiling, similarity scaling and free-choice profiling using coffee samples. Jaime et al. (1993) compared texture measurements and flavor and aroma measurements. McEwan et al. (1989) compared the traditional free-choice profiling method with a structured method based on Kelly's repertory grid method (Kelly 1955). Heymann (1994) compared free-choice profiling and multidimensional scaling methods.

Comparison of samples from different studies can be made. Since the translation step accounts for different scale usage, data from different panels which used different scaling methods could be compared. Using Generalized Procrustes analysis multiple descriptive panels could be compared since the method allows for multiple matrices with different number of attributes.

2.3.7.5 Acceptance and preference testing

GPA can be used to group samples based on their acceptance or preference. Benedict et al. (1988) showed that samples could be divided based on their similarities with a technique called "natural grouping." This method allows consumers to group samples based on their similarities which could include preferences or other acceptance ratings. Williams et al. (1988) related sensory information and acceptance data by using

Procrustes analysis. The consensus configuration dimensions from descriptive analysis could be superimposed on a graph of acceptability. In addition subgroups of panelists who perceive samples similarly and have similar acceptance could be determined.

3. RAW HOP AROMA QUALITIES BY TRAINED PANEL FREE-CHOICE PROFILING

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3.1 Abstract

The technique of trained panel free-choice profiling was applied to characterize the aromas of eight commercial and seven experimental varieties of raw hops. Analysis of the panelists' scores by Generalized Procrustes Analysis (GPA) provided information on the relationships between samples. The GPA resulted in three significant principal axes (PA) which separated the commercial samples into five significantly different groups. Hallertauer Tradition, Spalter Select, and Hallertauer Gold were characterized as fruity, spicy, grassy, musty aroma. Mt. Hood, Nugget and Fuggles were characterized as hay, earthy, fishy, green, mango aroma. Tettnanger had a musty, smoky, pine, apricot aroma, and Perle had an apricot, green, fishy aroma. Experimental varieties 21689, 21683 and 21688 were characterized as hay, fruity, floral aroma and were similar to the German varieties (Hallertauer Gold, Hallertauer Tradition and Spalter Select). 21684 and 21686 were characterized as fruity, floral, spicy, herbal aroma which was not similar to any of the commercial varieties. 21685 and 21687 had a hay, smoky, apricot aroma which was similar to Tettnanger. There was a strong correlation, based on data from GC analysis of the hop oils and aroma descriptors, between the concentration of β-pinene and the intensity of sage aroma, between myrcene and fruity and pine, between linalool and floral, and between limonene and fruity, citrus aromas.

3.2 Introduction

Much work has been done to identify the chemical composition of the aroma fraction of hops, both in the raw form and in beer (DeMets & Verzele 1968, Murakami et al. 1989, Peacock et al. 1981, Peacock et al 1980, Siebert et al. 1989). There has been only a small amount of sensory research on the characterization of aromas of different varieties (Peacock et al. 1981, Peacock et al 1980, Sanchez et al. 1992a). The lack of sensory information has resulted in confusion as to the perceived aromas of hop varieties (Hop Research Council 1996, Pyle & Tinseth 1995). This study focuses on raw hops since they are used for research of new and improved varieties, and control and knowledge of raw ingredients is necessary for a consistent finished product.

Free-choice profiling is a sensory method used for determining sample similarities, differences and characteristics. Originally it was designed to be used with untrained consumer panels as a way to cut costs and speed up the collection of data (Gower 1975, Williams & Arnold 1984, Williams & Langron 1984). Since it's introduction it has been used with untrained consumers (Guy et al 1989, McEwan et al. 1989, Williams & Arnold 1985), expert panels (Dumont 1994, Williams & Langron 1984), and trained panels (Jaime et al. 1993, Marshall & Kirby 1988, Rubico & McDaniel 1992). Free-choice profiling allows the panelists to describe the samples in their own words. The result of this method is a consensus configuration revealing the relationships between the samples based on the descriptors given to each sample by each panelist.

This research aims to identify a consensus configuration for the aroma of some raw commercial hops and use this configuration to identify experimental varieties that have similar aroma qualities. This allows for a better selection process in determining which experimental varieties will continue to be researched, and begins a list of some aroma qualities of commercially available hops.

3.3 Experimental

3.3.1 *Samples*

From the 1995 crop, fifteen raw hop samples, eight commercially available and seven experimental varieties, were evaluated by a trained sensory panel. Mt. Hood, Nugget, Fuggles, Tettnanger, and Perle samples were obtained as cuts from full bales from the Oregon Hop Commission (OHC). Spalter Select, Hallertauer Tradition, Hallertauer Gold, and experimental varieties 21683, 21684, 21685, 21686, 21687, 21688, and 21689 were obtained as cuts from mini-bales from experimental plots in a commercial growers yard in Oregon. Samples from the OHC were stored at 1°C for a maximum of one week before receipt. The remaining samples were stored at -20°C after baling, before receipt. After receipt samples were stored separately, each sample in two vacuum sealed Ziploc® freezer bags, in a -34°C freezer one month before testing.

3.3.2 *Panelists*

The panel consisted of five female and three male graduate students and staff from Oregon State University. Ages ranged from 22-45. Only one male and one female did not have prior experience as trained descriptive analysis panel members.

3.3.3 *Training and Standards*

The panel met for one-half hour five days a week, for a total of 18 panel sessions. The panel spent five days learning to identify fifty standards that had been chosen from previous hop aroma work (Sanchez et al 1992a & b). After the panel had a solid word base, they were given hop samples and asked to describe the aromas with any words. Standards were made to represent each of the terms used by the panelists (Table 3-1). To rate the intensity of each descriptor, the panel was trained to use a 16-point intensity scale (0 = none, 7 = moderate, and 15 = extreme). To anchor the intensity scale the panelists were provided with four intensity standards: 30 ml Saffola fresh safflower oil "3", 30 ml Hi-C orange juice "7", 30 ml Welches grape juice "11" and one stick Big Red cinnamon gum "15" (each in a 240ml teardrop wine glass). Panelists had their own ballots with the descriptors listed that they previously used to describe the hop aromas. Panelists were able to add or delete terms from their ballot during any session. Panelist consistency was determined before actual testing to insure that all panelists were reproducing their ratings on replicate samples.

3.3.4 *Presentation of Samples*

For assessment, the hops were removed from the freezer and three grams, approximately 10 to 14 cones, were placed in a Kerr 120 ml wide mouth screw cap glass bottle with a Teflon coated plastic lid. Each bottle was wrapped in aluminum foil and coded with a three digit random number. Samples rested for two hours before testing to allow them to reach room temperature. Samples were made new each day. For actual assessment samples were presented in a randomized incomplete-complete block design, using Cochran and Cox (1994) Table 11.24, with Rep. VI replicated for the eighth panelist, as a basis for the pre-randomization order (Cochran & Cox 1994). Three samples were presented at each session, and two sessions were completed each day, with a minimum ten minute break between sessions. Two separate replications were made.

3.3.5 *Assessment Procedure*

A panelist opened each bottle and took three short sniffs. The lid was replaced while the panelist rated the sample. If additional sniffs were required the samples were allowed to sit momentarily to recover the volatiles.

Table 3-1: Standards used for training and describing of raw hop aroma

Attribute	Reference (Company)
Anise	Extract (French's®, Rochester, NY)
Apple (red)	Cubed fresh Jonathan red apple
Apple (green)	Cubed Granny Smith apple
Apricots	Cubed apricots (Dole, San Jose, CA)
Banana	Cubed fresh banana
Basil	Basil spice (Spice Islands®, San Francisco, CA)
Burned Match (sulfurous)	Tips of two burned matches (Diamond®, Minneapolis, MN)
Butter	Butter flavoring (Schilling®, Hunt Valley, MD)
Caraway	Caraway seeds (Schilling®, Hunt Valley, MD)
Carnation	Essence on aroma stick (Uncomon Scents®, Eugene, OR)
Cedar	Cedar oil on an aroma stick (Uncomon Scents®, Eugene, OR)
Cheesy	0.01% Valeric acid (K & K Lab)
Cinnamon	Ground cinnamon (Spice Islands®, San Francisco, CA)
Clove	Ground clove (Spice Islands®, San Francisco, CA)
Cooked Potato	Cubed boiled white potato
Canned Green Beans	Canned green beans (Del Monte, San Francisco, CA)
Dill Weed	Dill Weed (Spice Islands®, San Francisco, CA)
Ethanol	95% ethanol (Clear Spring®, Frankfort, KY)
Fishy	Tetra Fin fish food flakes (Tetra Sales, Blacksburg, VA)
Fresh Peas	Sliced fresh peas
Garlic	Garlic powder (Flavorite™, Chaska, MN)
Geraniol	98% geraniol on an aroma stick (Aldrich®, Milwaukie, WI)
Grapefruit	Cubed fresh red grapefruit
Grassy	0.01% cis-3-hexenal (Bedoukian Research, Inc., Danbury, CT)
Hay	One long sprig cut into one inch pieces
Linalool	97% linalool on an aroma stick (Aldrich®, Milwaukie, WI)
Lemon	Cubed fresh lemon
Magnolia	Essence on aroma stick (Uncomon Scents®, Eugene, OR)
Marjoram	Marjoram spice (Spice Islands®, San Francisco, CA)
Minty	Mint leaves (Spice Islands®, San Francisco, CA)
Mushrooms	Cubed dried Picksweet mushrooms
Musty	Terpene-4-ol on aroma stick (Aldrich®, Milwaukie, WI)
Nutmeg	Ground nutmeg (Spice Islands®, San Francisco, CA)
Orange	Cubed fresh orange
Orange Peel	Sliced orange peel
Oregano	Ground oregano (Spice Islands®, San Francisco, CA)
Peach	Canned peaches (Dole, San Jose, CA)
Piney	Dried pine needles
Prunes	Cubed prunes (DelMonte®, Fullerton, CA)
Rancid	Rancid Canola oil (Wesson, Fullerton, CA)
Rose Petal	Essence on aroma stick (Uncomon Scents®, Eugene, OR)
Rosemary	Rosemary (Spice Islands®, San Francisco, CA)
Sage	Sage (Spice Islands®, San Francisco, CA)
Smoky	Extra long WB cut™ tobacco (US Tobacco Co., Nashville TN)
Sweet/Honey	Sweet Clover honey (Sue Bee®, Sioux City, IW)
Tarragon	Tarragon (Spice Islands®, San Francisco, CA)
Thyme	Thyme (Spice Islands®, San Francisco, CA)
Tobacco	Tobacco from one Winston cigarette (Winston®, Winston-Salem, NC)
Vinyl	STP vinyl protectant (STP®, Danbury, CT)
Violet	Essence on aroma stick (Uncomon Scents®, Eugene, OR)
Wet Hay	One cut hay sprig with 8ml of distilled water

3.3.6 *Hop Oil Extraction*

A weighed sample, 200-250g, of whole hops was placed in a 12-L flask containing 5 L of 0.01M sodium phosphate, pH 6.0, buffer and distilled for 6hr, using a modified Wright and Connery oil trap (ASBC 1992). The amount of hop oil collected was measured volumetrically and the oil transferred to glass ampoules and sealed. The ampoules were held at -20°C until analyzed by gas-liquid chromatography.

3.3.7 *Gas Chromatographic Analysis*

A Hewlett-Packard 5890A gas chromatograph equipped with a Chrompack WCOT Fused Silica 60m x 0.25mm column coated with CP Wax 52CB DF=0.25um, automatic sample injector, and flame ionization detector was used. Helium was the carrier gas. Temperature conditions were: inlet 220°C, detector 245°C, and oven 80-240°C at 4°C/min. 1µl of 10% solution of hop oil in pentane was injected, split ratio 1:100. Identification of the individual peaks of interest were verified by comparison with past GC/mass spectrophotometry runs and retention times of reference compounds.

3.3.8 *Statistical Analysis*

Sensory data were analyzed by Generalized Procrustes Analysis using Procrustes-PC version 2.0 (Dijksterhuis & van Buuren 1989) and by Statistical Analysis System for Personal Computer (SAS 1987). Analysis of variance on the principal axes scores was used to ascertain differences among samples and, where appropriate, least significant difference using $p \leq 0.05$. The data were analyzed with all fifteen samples, then separately with only the commercial varieties, and with only the experimental varieties. Correlation of each principal axis with the concentration of each compound identified by gas chromatography of the hop oils was made with Microsoft Excel 5.0. Scatter plots were used to verify correlations and to determine any non-linear relationships between axes and compounds. Simple linear regression was used to determine significant relationships between axes and compounds where appropriate.

3.4 Results and Discussion

3.4.1 *Generalized Procrustes Consensus Configurations*

The final result of a Generalized Procrustes Analysis (GPA) is a consensus configuration of the samples for the different principal axis combinations, as presented in Figures 3-1 - 3-4. These figures illustrate the intersample differences. The first principal axis separates the samples by the intensity of the aromas which give the highest percentage of separation. The second principal axis separates the samples by the intensity of the aromas which give the next highest percentage. The samples are grouped together to show significantly different sample groupings. The descriptors, determined by GPA, which have loadings ≥ 0.30 or correlation ≥ 0.40 are summarized over panelists for each principal axis and are listed at the end of the axes. The farther along the axis a sample lies, the more intense the characteristics of that axis direction.

3.4.2 *Product Separation*

To supplement the graphical information from GPA, an analysis of variance (ANOVA) of the scores on each of the first three principal axes was completed. A summary of the ANOVA separation for all samples, commercial samples only and experimental samples only is shown in Table 3-2. This summary was determined by comparing the ANOVA separation of each of the principal axes, giving the most weight to the first principal axis. The ANOVA on each of the principal axes gives only a guideline for the separation of the samples, since after GPA the samples are no longer considered independent. This separation was ultimately based on inspection of the ANOVA results and descriptor loadings from each panelist. This subjective interpretation allows for a degree of uncertainty in the statistical significance of the separation of the samples. So the stated p-value may not be accurate for this set of results.

3.4.3 *Aroma Qualities and Consensus Configurations*

Figure 3-1 shows the grouping and separation of two repetitions of all samples for principal axis one and two. This figure shows there were five significantly different groups. Group 1: Perle; Group 2: Tettnanger, 21685 and 21687; Group 3: Mt. Hood, Nugget, and Fuggles; Group 4: Hallertauer Gold, Hallertauer Tradition, Spalter Select, 21683, 21688, and 21689; and Group 5: 21684, 21686 and Hallertauer Tradition. Notice Hallertauer Tradition was not significantly different from any of the varieties in groups four or five. Each group could be defined by the descriptors along the axis where the group is located. It is interesting to note that Group 4 was basically centered around zero on both axis. These samples were the same samples which had low agreement between panelists (Figure 3-5). They did not have any specific aroma descriptors that allowed them to be separated from the other varieties. In Group 2 Tettnanger and 21685 could be separated from each other, but neither was different from 21687.

Table 3-2: Hop variety separation and aroma qualities for all significant axes

Variety	Separation*	Aroma Qualities	
All Samples			
21684	a	Fruity, Floral, Spicy, Herbal	
21686	a b	Fruity, Floral, Spicy, Herbal	
Hallertauer Tradition	b c	Fruity, Floral, Spicy, Grassy, Musty	
Hallertauer Gold	c d	Fruity, Floral, Spicy, Grassy, Musty	
Spalter Select	c d	Fruity, Floral, Spicy, Green, Hay, Earthy	
21689	d	Hay, Fruity, Floral	
21688	d	Hay, Fruity, Floral	
21683	d	Hay, Fruity, Floral	
Mt. Hood	e	Hay, Earthy, Fishy, Green, Fruity, Spicy	
Nugget	e	Hay, Earthy, Fishy, Green, Mango	
Fuggles	e	Hay, Earthy, Fishy, Green, Mango	
21685	f	Hay, Wet Hay, Smoky, Cedar, Pine, Basil	
21687	f g	Hay, Wet Hay, Smoky, Cedar	
Tettnanger	g h	Musty, Smoky, Tobacco, Pine, Cedar, Apricot, Prune	
Perle	h	Apricot, Prune, Sweet, Green, Fishy	
Commercial only		**Experimental only**	
Tettnanger	a	21687	a
Perle	b	21685	a b
Fuggles	b c	21683	b c
Nugget	c	21689	b c
Mt. Hood	c	21688	c
Hallertauer Gold	d	21686	d
Hallertauer Tradition	d	21684	d
Spalter Select	e		

*Separation over all significant axes (different letters indicate a significant difference at p ≤0.05)

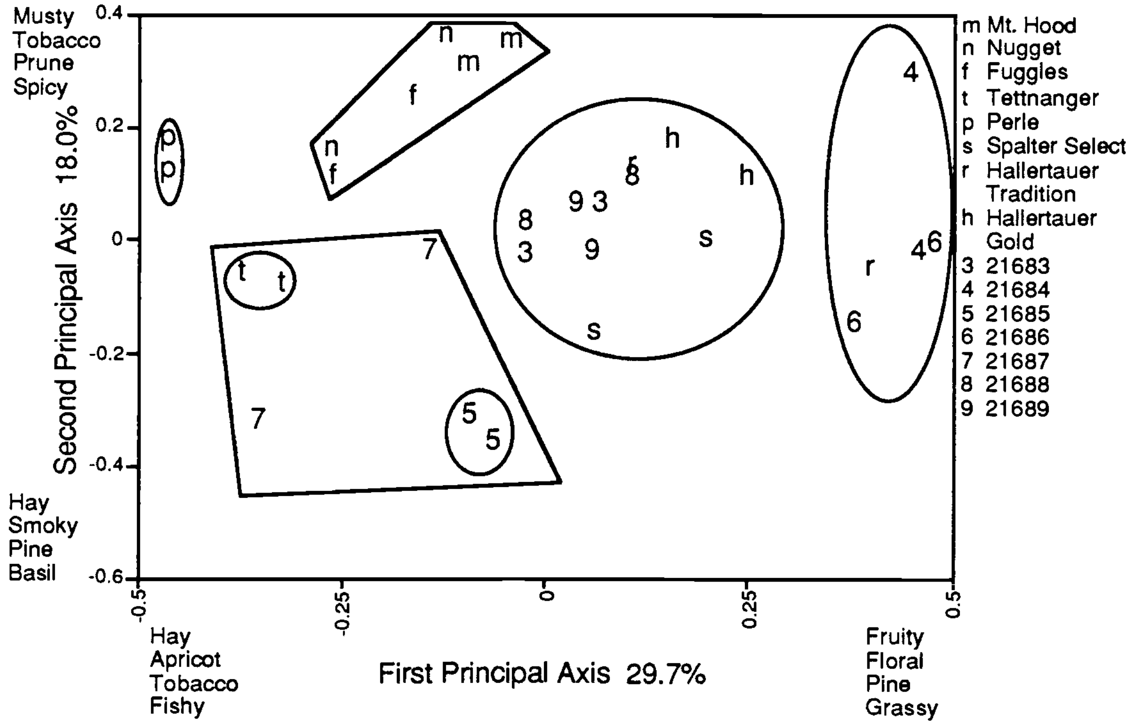

Figure 3-1: Separation of Commercial and Experimental Raw Hop Varieties by Free-Choice Profiling of Aroma Characteristics. Principal Axis one and two.

Figures 3-2 and 3-3 show the grouping and separation of two repetitions for the commercial samples for principal axis one and two (Figure 3-2) and principal axis one and three (Figure 3-3). There were five significantly different groupings for the commercial varieties. Group 1: Tettnanger; Group 2: Perle and Fuggles; Group 3: Fuggles, Nugget, and Mt. Hood; Group 4: Hallertauer Gold and Hallertauer Tradition; and Group 5: Spalter Select. Figure 3-2 shows the hops originally from Germany (Groups 4 and 5) were defined by the descriptors: fruity, floral, and spicy. Figure 3-3 shows that Spalter Select could be separated into a group by itself, described as having a more intense floral and green aroma than Hallertauer Gold and Hallertauer Tradition. Mt. Hood is genetically closely related to these varieties being a triploid seedling of a tetraploid Hallertauer Mittelfrüh, but did not group with the other German varieties. It had some of the same fruity character, but had more intense apricot, prune, and grassy notes. Tettnanger could be separated from the other varieties by a more intense tobacco, smoky, burnt match aroma. Perle could be separated from others by its fishy and green notes.

Figure 3-4 shows the grouping and separation of two repetitions for the experimental varieties for principal axis one and two. Principal axis two did not significantly separate the samples, so there are no descriptors associated with it. There were three groups which showed the same separation as Figure 3-1. Again samples 21683, 21688 and 21689 were centered at zero on the first principal axis. These samples had very low agreement between the panelists (Figure 3-5).

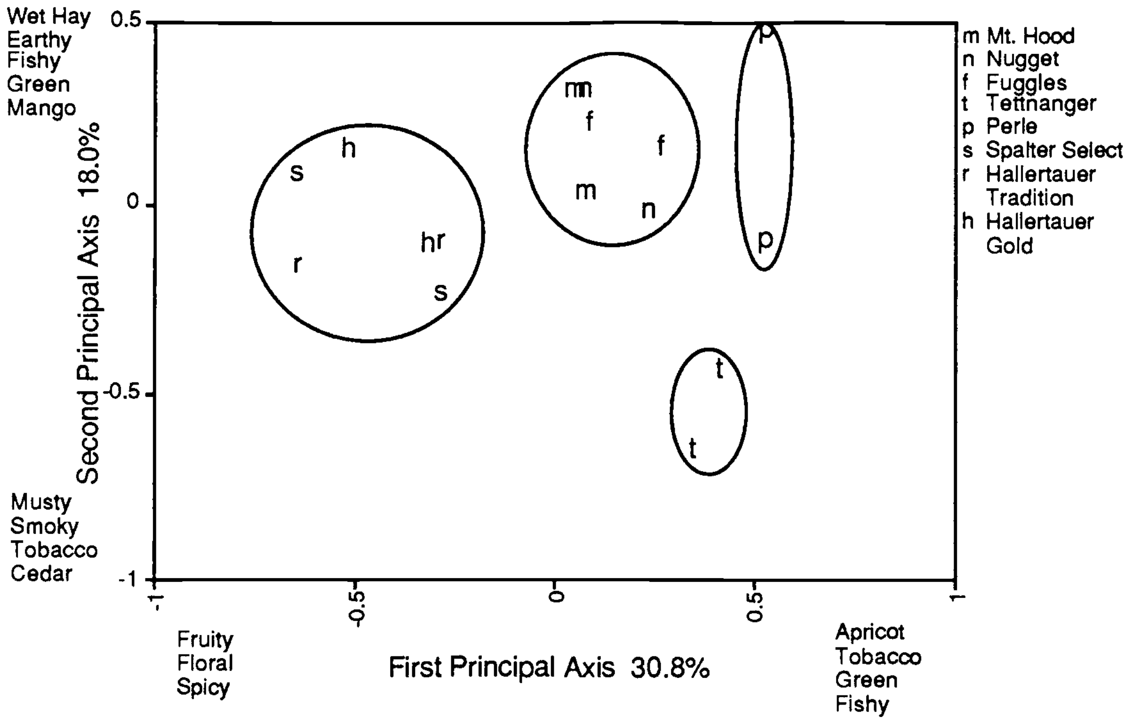

Figure 3-2: Separation of Commercial Raw Hop Varieties by Free-Choice Profiling of Aroma Characteristics. Principal Axis one and two.

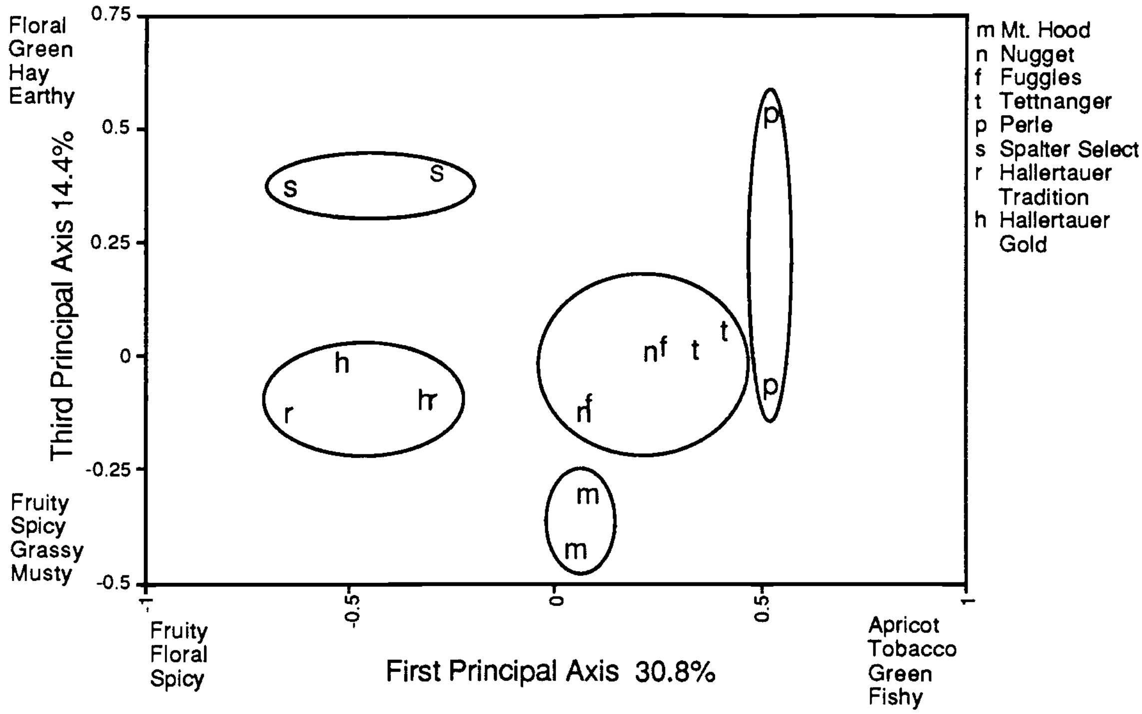

Figure 3-3: Separation of Commercial Raw Hop Varieties by Free-Choice Profiling of Aroma Characteristics. Principal Axis one and three.

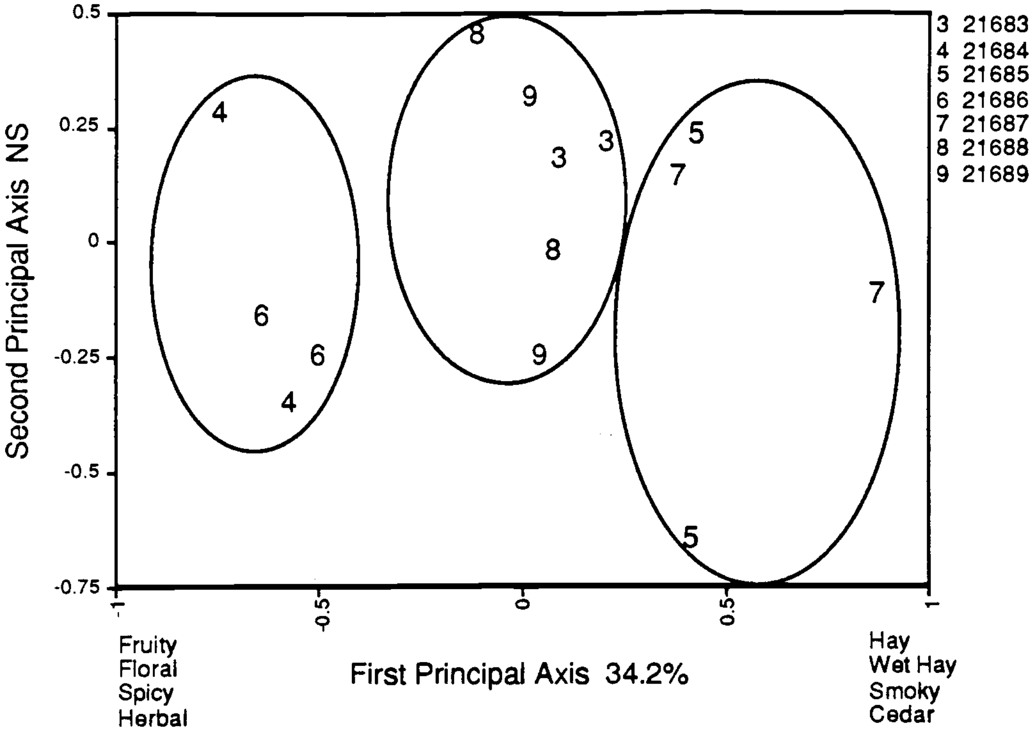

Figure 3-4: Separation of Experimental Raw Hop Varieties by Free-Choice Profiling of Aroma Characteristics, Principal Axis one and two.

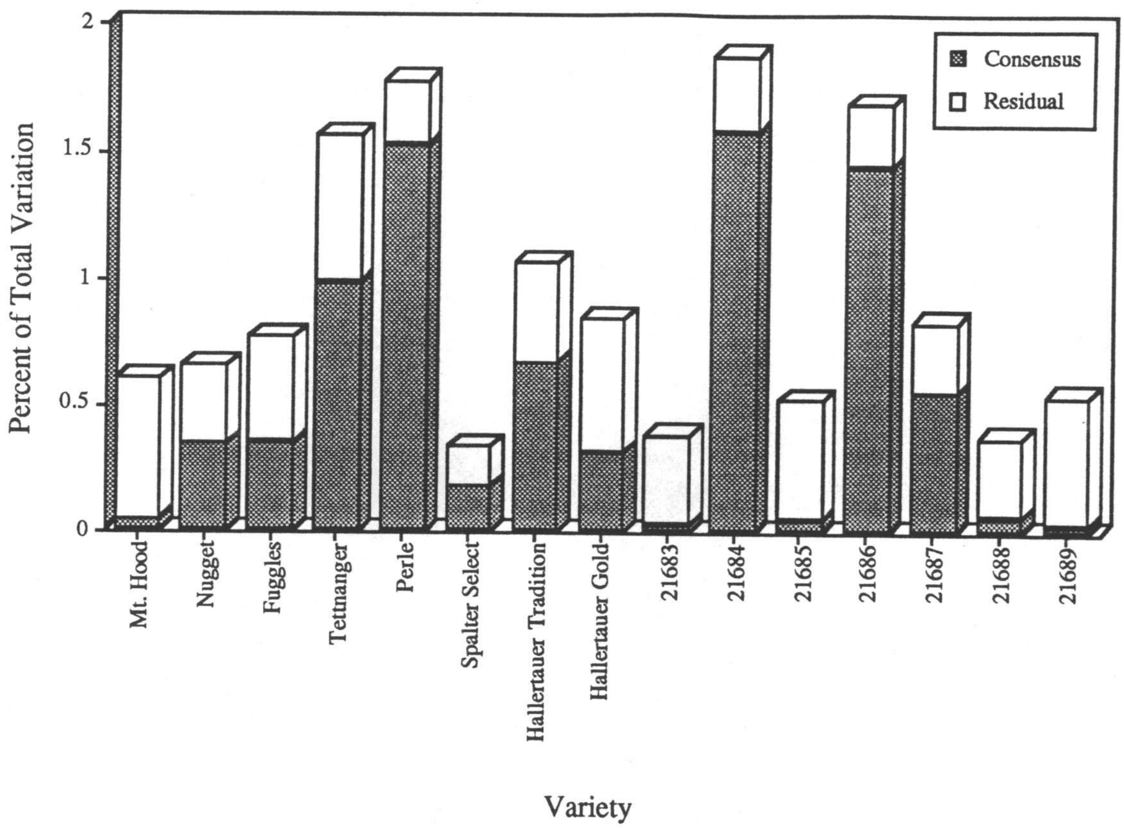

Figure 3-5: Percentages of consensus and residual (within) variation for eight commercial and seven experimental raw hop varieties.

3.4.4 *Chemical Correlations*

GC analysis of the hop oils of each variety resulted in 78 - 129 peaks with a mean of 97 peaks. Twenty-one peaks could be identified in each variety (Table 3-3). Correlation, regression analysis, and visual inspection of scatter plots of the concentration of each compound versus each of the principal axes identified myrcene, linalool, β-pinene, and limonene as the only compounds with high correlation to any of the principal axes. Figure 3-6 shows strong correlation (0.82) (p-value 0.0027) between the concentration of myrcene in the hop oils and the intensity of fruity, floral, pine, and sage aromas of principal axis one. The dashed line is the regression line. Myrcene was described by the panel as spicy, floral, prune and fruity. Figure 3-7 shows strong correlation (0.77) (p-value 0.0042) between the concentration of linalool in the hop oils and the intensity of fruity, floral, pine and sage aromas of principal axis one. The dashed regression line does not include experimental varieties 21684 and 21686 since they appeared to be outliers with low concentrations of linalool. It is not surprising that they could be outliers for linalool since their aroma characteristics indicate they had intense herbal characteristics and linalool has a floral aroma. Since each end of principal axis one was defined by a group of terms, samples with intense herbal characteristics were positioned with samples with intense floral and fruity characteristics. Linalool was described by the panel as lemon and floral. Correlation of the concentration of linalool in hop oil to the intensity of lemon and floral aromas in beer was demonstrated previously by Peacock et. al. in 1981 (13). Figure 3-8 shows the concentration of β-pinene in the hop oils correlated well (0.64) (p-value

0.0102) with the intensity of fruity, floral, pine and sage aromas on principal axis one. The dashed line is the regression line. The panel described the aroma of β-pinene as sage, musty and green beans. Figure 3-9 shows there was some correlation (0.51) (p-value 0.0504) between the concentration of limonene in the hop oils and the intensity of fruity, floral, pine and sage aromas on principal axis one. The dashed line is the regression line. The panel described the aroma of limonene as citrus and pine.

Table 3-3: Compounds identified by GC analysis of hop oils: Concentration in eight commercial and seven experimental varieties.

COMPOUND	CONCENTRATION IN nL/g FOR EACH VARIETY														
	21683	21684	21685	21686	21687	21688	21689	Hallertauer Gold	Hallertauer Tradition	Spalter Select	Fuggle	Mt. Hood	Nugget	Perle	US Tettnanger
beta-pinene	103	81	70	80	39	45	84	88	65	55	36	100	42	23	38
myrcene	8349	6453	5915	6111	3009	4064	7466	7870	6043	5256	2330	6383	3618	1756	2608
limonene	29	24	17	20	11	13	27	26	19	16	10	29	19	12	13
linalool	73	43	74	44	14	49	72	109	102	91	47	116	77	17	56
caryophyllene	585	191	310	446	202	176	640	586	472	192	679	1098	779	616	739
farnescene	1178	679	760	2236	800	667	2398	15	11	907	355	40	12	26	399
humulene	2173	667	1119	1564	775	639	2273	2208	1734	478	1910	2814	1856	2052	2261
muurolene	17	6	9	14	11	6	19	0	0	0	45	62	95	42	52
beta-selinene	18	6	8	30	0	0	29	21	15	70	24	28	84	22	24
delta-cadenine	93	34	44	77	33	25	110	96	72	0	121	171	95	105	136
gamma-cadinene	52	21	26	47	20	16	61	52	38	0	75	114	55	57	78
geranyl acetate	8	0	3	7	4	0	0	2	0	34	3	0	0	0	4
geranyl isobutyrate	40	22	22	44	19	41	35	3	4	7	14	18	0	0	12
geraniol	17	16	8	19	28	6	7	7	0	7	9	25	6	6	12
caryophyllene oxide	18	12	10	24	8	10	15	0	3	8	26	44	9	5	17
hum. epox I	30	11	31	30	24	10	27	28	0	3	14	24	9	6	15
hum. epox II	49	31	38	52	0	27	51	0	18	13	83	132	22	17	76
caryolan-1-ol	7	4	0	0	0	1	0	0	0	0	48	27	77	27	52
humulenol	17	8	13	23	9	13	10	6	4	8	12	16	17	5	12
humulenol II	10	4	0	0	4	4	1	6	5	0	18	33	17	8	27
h. diepox	9	7	4	5	3	0	0	0	0	0	7	7	5	4	7

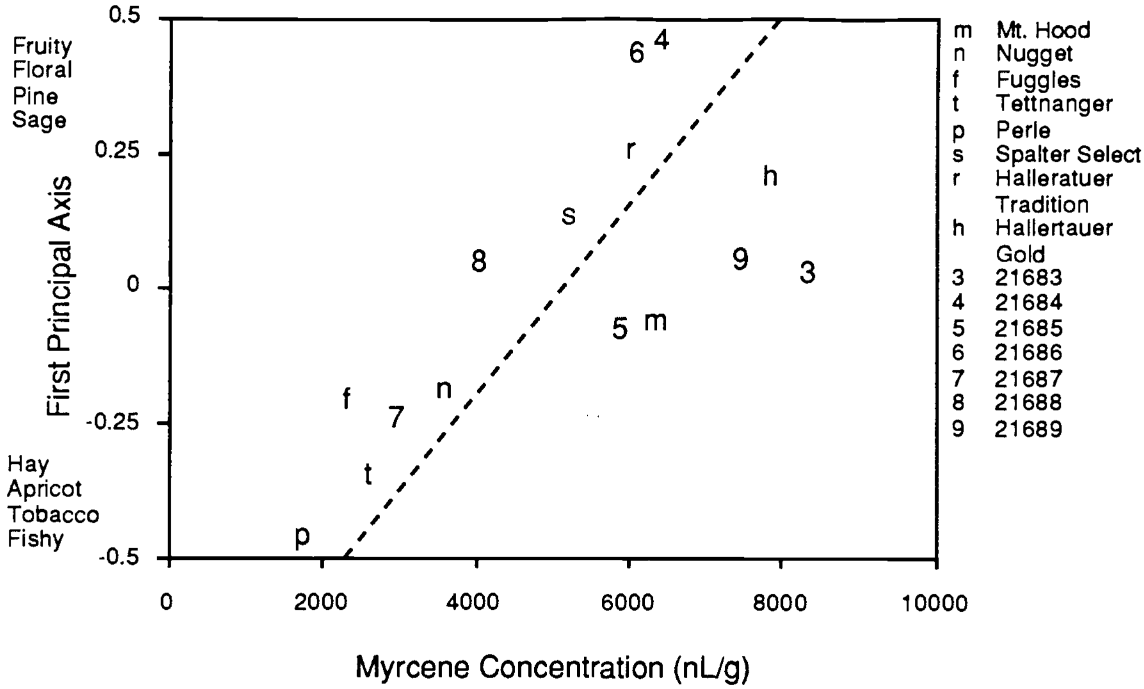

Figure 3-6: Correlation of Myrcene Concentration in the Hop Oils and Principal Axis One from Free-Choice Profiling of the Aroma Characteristics of Raw Hops.

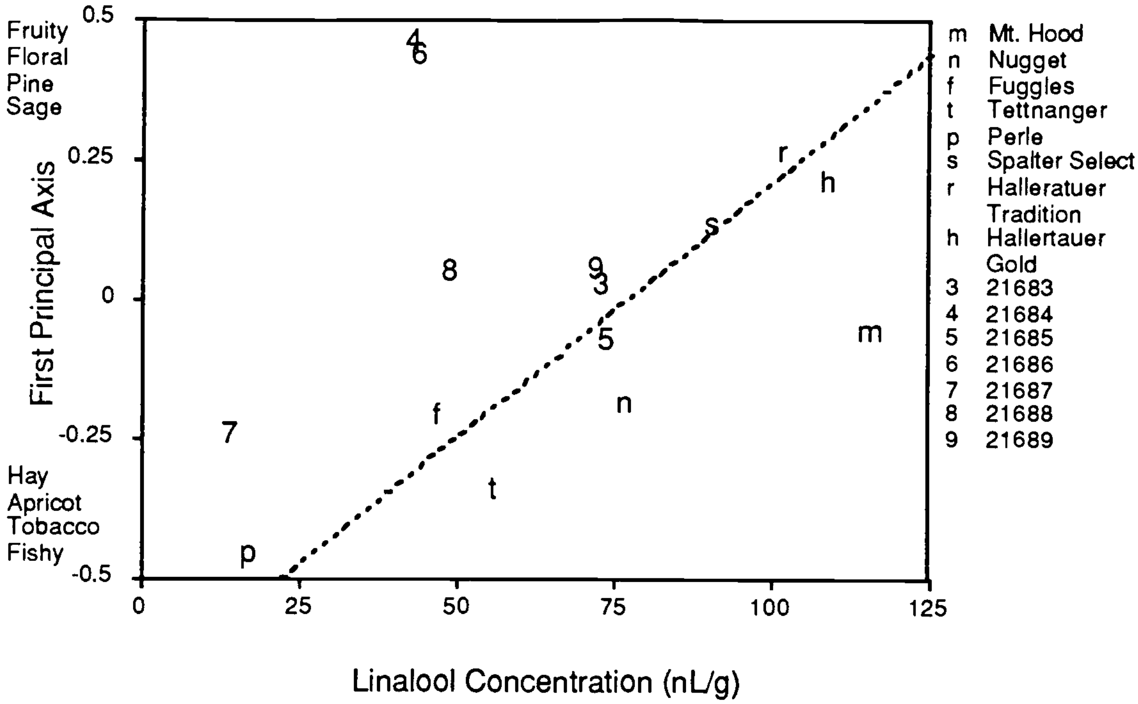

Figure 3-7: Correlation of Linalool Concentration in the Hop Oils and Principal Axis One from Free-Choice Profiling of the Aroma Characteristics of Raw Hops.

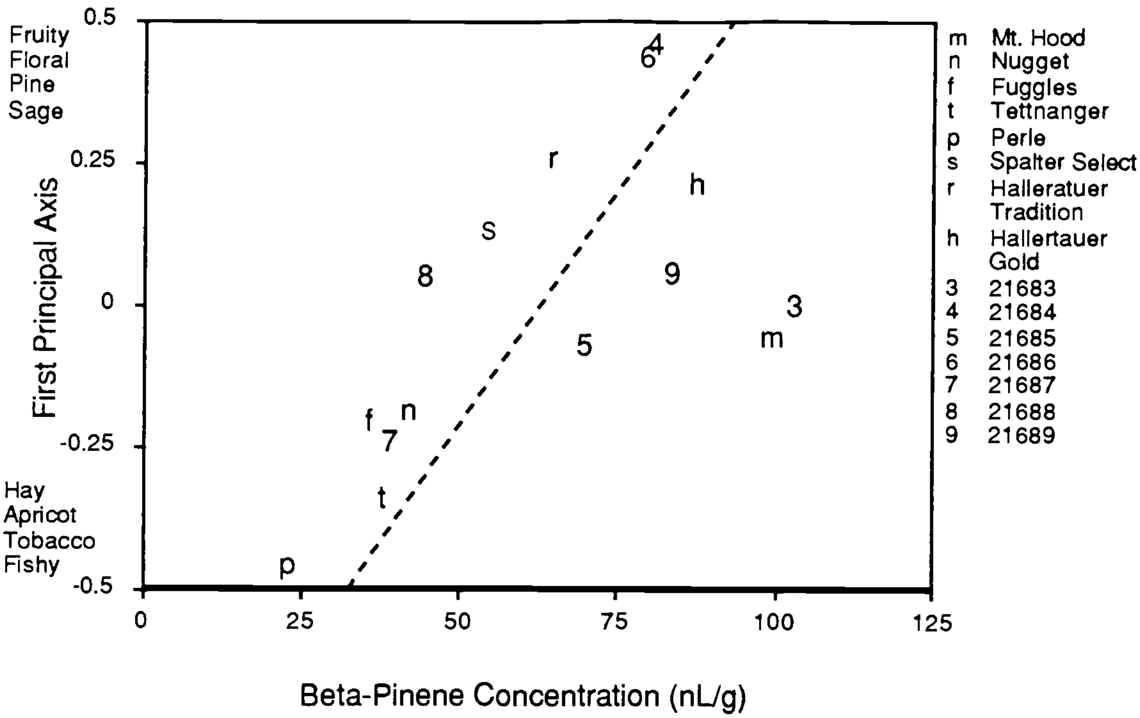

Figure 3-8: Correlation of β-pinene Concentration in the Hop Oils and Principal Axis One from Free-Choice Profiling of the Aroma Characteristics of Raw Hops.

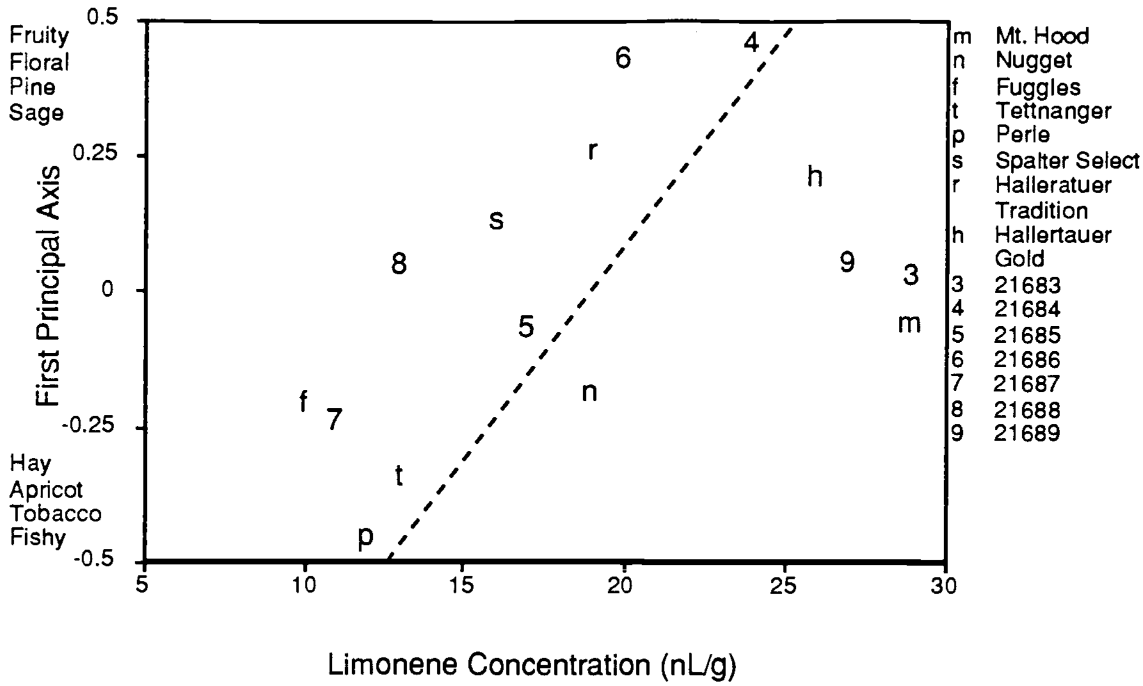

Figure 3-9: Correlation of Limonene Concentration in the Hop Oils and Principal Axis One from Free-Choice Profiling of the Aroma Characteristics of Raw Hops.

3.4.5 *Panelists*

Free-choice profiling of the 15 samples generated between 10 (panelist 1) and 22 (panelist 7) terms with an average of 14 terms per panelist (Table 3-4). As expected, not all individuals behaved similarly and the number of dimensions required to describe the differences varied from panelist to panelist. By examining how each panelist combined descriptors to define a principal axis one could get an overall interpretation of how they separated the samples and characterized the aroma of each variety. The definitions given for the descriptors by each panelist, helped explain which descriptors were important in differentiating the samples for each principal axis as summarized in Tables 3-5, 3-6, and 3-7. The more important attributes had higher loadings and are listed first for each panelist. The descriptors used by the panelists could be placed in groups with similar definitions. For instance all panelists used some type of "fruity", "floral" and "musty/dirty" descriptor. Knowing the definition of each of the descriptors used by the panelists allowed for grouping similarly defined descriptors and aided in developing a list of aroma qualities for each of the hop varieties.

Table 3-4: Descriptors generated by each panelist during free-choice profiling of hop aromas

Panelist 1	Panelist 2	Panelist 3	Panelist 4	Panelist 5	Panelist 6	Panelist 7	Panelist 8
Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity
Mango/Apricot	Apricot	Apricot/Prune	Apricot/Prune	Fruity	Prune	Prune	Apricot/Prune
Raisin/Prune	Honey/Prune	Honey	Lemon	Orange/Citrus	Apricot	Mango	Sweet
Honey	Orange Peel/	Apple	Linalool/	Floral/Violet	Floral	Honey	Fruity
Orange	Lemon	Lemon	Geraniol	Linalool	Linalool	Banana	Lemon
Mint	Apple	Floral	Mint	Mint	Mint	Fruity/Citrus	Floral
Pine/Cedar	Floral	Spices	Clove	Orange Tea	Sage	Floral	Mint/Pine
Herbal	Mint	Pine	Basil	Grassy	Black Tea	Minty	Spicy/Herbal
Wet Hay	Pine/Cedar	Cedar	Nutmeg	Hay/Alfalfa	Cedar	Spice	Grassy
Musty	Herbal	Hay	Green	Tobacco	Grassy	Green	Hay/Alfalfa
Smoky	Grassy	Wet Hay	Cedar	Musty	Hay	Grassy	Musty
	Hay	Tobacco	Alfalfa	Fishy	Fishy	Hay	Tobacco
	Musty	Burnt Match	Musty	Plastic	Burnt Match	Wet Hay	Fishy
	Tobacco	Fishy	Tobacco			Musty	Cheesy
	Earthy/Woody		Fishy			Smoky	
	Fishy		Rubber			Dirty	
	Cheesy					Meaty	
	Cat Pee					Damp Cloth	
						Rancid	
						Cheesy	
						Sweat	
						Glue/Vinyl	

Table 3-5: Loadings* of the attributes for the first three principal axes following free-choice profiling for All Samples

Panelist	Principal Axis 1	Principal Axis 2	Principal Axis 3
1	Mango/Apricot/ Raisin/Prune (0.70) + Orange (0.52) + OI[1] (0.34)	Wet Hay (0.61) + OI (0.47) + Smoky (-0.30) + Pine (-0.30)	Smoky (0.67) + Pine (-0.56)
2	Orange (0.52) + Hay (-0.51)	Earthy (0.40) + Pine/Cedar (0.39) + Apricot (-0.39) + Tobacco (0.37) + Musty (0.32)	Minty (0.59) + Herbal (0.48) + OI (0.42)
3	Pine (0.62) + Lemon (0.50)	Apricot (0.59) + Honey (0.56) + Wet Hay (-0.39)	Wet Hay (0.62) + Burnt Match (-0.44) + Honey (0.39) + Tobacco (-0.38)
4	Lemon (0.47) + Tobacco (-0.47) + Green (-0.43) + Apricot (-0.35) + Fishy (-0.30)	Green (0.51) + Nutmeg (0.34) + Basil (-0.31)	Musty (-0.72) + Alfalfa (-0.39)
5	Grassy (0.75) + Hay/Alfalfa (-0.47)	OI (-0.88) + Hay/Alfalfa (-0.30)	Hay/Alfalfa (0.69) + Grassy (0.45)
6	Apricot (-0.58) + Prune (-0.51) + Sage (0.49)	OI (0.63) + Sage (0.45) + Prune (0.38) + Grassy (-0.31)	Cedar (-0.57) + OI (-0.45) + Floral (0.37)
7	Mango (0.63) + Fruity/Citrus (0.39) + OI (0.32)	Wet Hay (-0.58) + Hay (-0.51) + Green (-0.31)	Mango (-0.62) + Meaty (-0.53)
8	Sweet (-0.55) + Spicy/Herbal (0.48) + Floral (0.43)	Spicy/Herbal (0.59) + Sweet (0.53) + Mint/Pine (0.33)	Mint/Pine (0.51) + Sweet (-0.37) + Hay/Alfalfa (0.35) + Fishy (-0.34) + Grassy (-0.31)

* Attributes with loadings <0.30 and >-0.30 were not included in the table.

1 Overall Intensity

Table 3-6: Loadings* of the attributes for the first three principal axes following free-choice profiling for Commercial Samples

Panelist	Principal Axis 1	Principal Axis 2	Principal Axis 3
1	Mango/Apricot/Raisin/Prune (-0.64) + Orange (-0.59)	Wet Hay (0.64) + Pine (-0.58) + Herbal (0.33)	Herbal (0.73) + OI (-0.47) + Wet Hay (-0.31) + Orange (0.31)
2	Orange (-0.49) + OI[1] (-0.45) + Minty (-0.32)	Earthy (0.63) + Orange (-0.41) + Cheesy (0.40)	Herbal (-0.54) Earthy (0.36) + Musty (-0.34)
3	Pine (-0.62) + Apricot (0.40) + Lemon (-0.35)	Honey (0.57) + Burnt Match (-0.52) + Tobacco (-0.52)	Cedar (-0.56) + Wet Hay (0.54) + Lemon (-0.37)
4	Tobacco (0.52) + Nutmeg (-0.41) + Green (0.37) + Lemon (-0.34) + Clove (-0.32)	Musty (-0.69) + Green (0.43) + Rubber (0.30)	Rubber (-0.61) + Mint (0.37) + Green (0.35) + OI (0.35) + Lemon (-0.32)
5	Fruity (-0.53) + Nutmeg (-0.41) + Green (0.37) + Lemon (-0.34) + Clove (-0.32)	Grassy (0.45) + OI (-0.44) + Fishy (0.42) + Tobacco (-0.38) + Musty (-0.34)	Fishy (0.56) + OI (0.51) + Grassy (-0.43) + Hay/Alfalfa (0.31)
6	Apricot (0.51) + prune (0.48) + Floral (-0.39) + Mint (-0.32) + Linalool (-0.30)	Cedar (-0.76)	Mint (0.48) + Sage (-0.48) + Floral (0.42) + Linalool (0.32) + Prune (0.31)
7	Mango (-0.55) + Fruity/Citrus (-0.38) + Grassy (-0.30)	Mango (-0.49) + OI (0.42) + Smoky (-0.40) + Banana (0.33)	Meaty (0.51) + OI (-0.46) + Honey (-0.34) + Floral (0.31) + Banana (0.30)
8	Sweet (0.62) + Spicy/Herbal (-0.42) + Floral (-0.32) + OI (-0.31)	Spicy/Herbal (0.54) + Mint/Pine (0.47) + Hay/Alfalfa (0.44)	Musty (0.51) + Grassy (-0.49) + Apricot (0.38) + Spicy/Herbal (-0.37)

* Attributes with loadings <0.30 and >-0.30 were not included in the table.

1 Overall Intensity

Table 3-7: Loadings* of the attributes for the first three principal axes following free-choice profiling for Experimental Samples

Panelist	Principal Axis 1	Principal Axis 2	Principal Axis 3
1	Mango/Apricot/Raisin/Prune (-0.56) + Orange (-0.50) + OI[1] (-0.47) + Smoky (0.39)	Pine (-0.73) + Smoky (0.44)	Smoky (-0.70) + Pine (-0.49) + Wet Hay (0.31)
2	Hay (0.66) + Orange (-0.42) + Honey (-0.31)	Apricot (-0.52) + Mint (0.50) + Apple (-0.34) + Herbal (0.31)	Earthy (0.61) + Herbal (-0.40) + Apple (-0.34) + Mint (-0.30)
3	Pine (-0.56) + Hay (0.45) + Lemon (-0.41) + Wet Hay (0.38)	Apricot (0.61) + Honey (0.57)	Cedar (0.67) + Hay (0.47) + Wet Hay (0.31)
4	Lemon (-0.54) + Apricot (0.44) + Fishy (0.31) + Green (0.31) + Cedar (-0.30)	Musty (0.75) + Alfalfa (-0.38)	Rubber (0.66) + Basil (-0.39) + Alfalfa (-0.35)
5	Hay/Alfalfa (0.71) + Grassy (-0.61)	Hay/Alfalfa (0.56) + Grassy (0.42) + OI (-0.40) + Fishy (0.34) + Mint (-0.34)	OI (0.80) + Grassy (-0.51)
6	Sage (-0.57) + OI (-0.57) + Apricot (0.40) + Prune (0.34)	Mint (-0.73) + Prune (0.42) + Cedar (-0.42)	Apricot (0.59) + OI (0.58) + Fishy (-0.38)
7	Mango (-0.63) + Wet Hay (0.44) + Fruity/Citrus (-0.37) + Hay (0.33)	Mango (-0.59) + OI (0.39) + Honey (0.32) + Green (-0.30)	Meaty (0.54) + Green (-0.46) + Cheesy (0.38) + Grassy (0.33)
8	Floral (-0.49) + Spicy/Herbal (-0.44) + Lemon (-0.42) + Fruity (-0.31)	Floral (-0.50) + Spicy/Herbal (0.38) + Grassy (-0.36) + Fishy (-0.36) + Cheesy (0.33)	Apricot (-0.50) + Grassy (0.48) + Spicy/Herbal (0.41)

* Attributes with loadings <0.30 and >-0.30 were not included in the table.
1 Overall Intensity

3.4.6 *Panelist Performance*

The amount of consensus between panelists, in describing each sample, could be visualized by looking at the residual variation divided into two parts, percentage consensus and percentage residual, obtained from the GPA of the samples (Figure 3-5). A high percentage of consensus in relation to the percentage residual indicates greater agreement between the panelists. Figure 3-5 shows the mean percentages for consensus and residual. There was high agreement for Nugget, Fuggles, Tettnanger, Perle, Spalter Select, Hallertauer Tradition, 21684, 21686, and 21687. There was low agreement for Mt. Hood, Hallertauer Gold, 21683, 21685, 21688 and 21689. These results suggest that some varieties were easier to describe than others. For instance, there was very high agreement for Perle, which had a distinctive fishy aroma. When a sample has an aroma that is very intense and distinctive, it is easier to replicate and obtain agreement between panelists.

Panelists' individual performance was examined by the percentage residual variation obtained from GPA. The percentage of residual variation ranged from 23.8% to 34.3% for principal axis one with about equal separation across the range, which indicates the panelists were about equal in separating the samples. By examining how each panelist separated varieties and replicate samples a visual measure of panelist performance could be obtained. All panelists were considered to have a reasonable to high level of performance. The gender of the panelist appeared to have no relationship with panelist performance, number of descriptors used, or choice of descriptors.

3.5 Conclusion

Most of the hop varieties were easily grouped and separated with the trained panel free-choice profiling technique. The varieties which had no distinguishing characteristic(s) in their complex aroma resulted in large residual variation for the panel. This variation indicates the panel disagreed on how to describe these samples and gives a plausible explanation for the inability of the panel to distinguish between these samples.

The consensus configurations will help researchers develop varieties which have aroma characteristics similar to their target variety, and brewers select appropriate hops for the aroma characteristics desired in brewing. The aroma characteristics of varieties are important for brewers who use fresh hops for dry-hopping beer. The fruity, citrus, floral and sage aromas which were correlated with hop oil compounds are highly volatile and would be blown off during the boil. However, they would be present if the hops were used for dry-hopping.

Future research to characterize all commercially available varieties is needed. Development of a list of aroma characteristics of beer brewed with each variety is the next logical step to learning more about the sensory characteristics of hop aromas and their changes during brewing. The hops used in this study were very fresh and contained low quantities of oxidation products. Since many hops are aged before used in brewing, further research is necessary to determine changes in sensory properties as oxidation products increase.

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4. AROMA QUALITIES OF DRY-HOPPED AND FINISH-HOPPED LAGERS BY TRAINED PANEL FREE-CHOICE PROFILING

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4.1 Abstract

The technique of trained panel free-choice profiling was applied to characterize the aromas of eight commercial and four experimental hop varieties used for dry-hopping and finish-hopping of American lagers. Analysis of the panelists' scores by Generalized Procrustes Analysis (GPA) provided information on the relationships between samples. The panelists separated the dry-hopped samples into three different groups: Group 1) 21689, Nugget, Hallertauer Tradition, Mt. Hood and Spalter Select; Group 2) Fuggles, Hallertauer Gold, Perle, 21686 and 21683; and Group 3)Tettnanger, 21685, and Control. The finish-hopped samples were also separated into three groups: Group 1) Tettnanger, Nugget, Fuggles, Perle, Mt. Hood, Hallertauer Tradition and Spalter Select; Group 2) 21685 and 21686; and Group 3) Hallertauer Gold, Control, 21683 and 21689. For both the dry-hopped and finish-hopped lagers the groups were characterized by the following aroma qualities: Group 1) Fruity and floral aroma qualities; Group 2)Both fruity, floral and musty, rubbery aroma qualities; and Group 3) Musty and rubbery aroma qualities.

4.2 Introduction

Many studies have focused on the chemical contribution of hops to beer (Buttery et al. 1965, Irwin 1987, Irwin 1989, Moir 1987, Peacock & Deinzer 1988, Peppard et al. 1989, Tressl et al. 1978). Many have conjectured as to the flavor that might be present in beer by determining sensory attributes and thresholds for chemicals present in beer (Fukuoka & Kowaka 1985, Meilgaard 1982, Peacock & Deinzer 1981a & b, Peacock et al. 1981, Peacock et al 1980, Sanchez et al. 1992a & b, Siebert 1994). Few have looked at the actual flavor contributed by the addition of hops (Peppard et al. 1989), or the flavor contribution of hops from different types of hopping regimes (Haley & Peppard 1983).

Free-choice profiling is a sensory method used for determining sample similarities, differences and characteristics. Originally it was designed to be used with untrained consumers (Gower 1975, Williams & Arnold 1985, Williams & Langron 1984), but was soon shown to be highly useful for separating samples when used with a trained panel (Jaime et al. 1993, Marshall & Kirby 1988, Rubico & McDaniel 1992). Free-choice profiling has been used to determine differences between samples in a variety of products (Dumont 1994, Jaime et al. 1993, Marshall & Kirby 1988, Williams & Langron 1984), and trained free-choice profiling panels have been able to separate samples were inter-sample differences were not apparent (Heymann 1994, Rubico & McDaniel 1992). Trained panel free-choice profiling was highly effective in previous work (Stucky & McDaniel 1996) for determining the aroma qualities and consensus configurations of some varieties of raw hops.

The primary aim of this research was to determine consensus configurations and a list of aroma qualities for the aroma of American lagers dry-hopped and finish-hopped with selected commercial and experimental hop varieties. Secondly, to investigate changes in the aroma qualities of the hops, produced by dry-hopping and finish-hopping, and determine if the aroma qualities of the raw hop (Stucky & McDaniel 1996) could be used to give insight into the aroma of the dry-hopped or finish-hopped beer. Thirdly, to determine if any of the lagers made with experimental hop varieties have aroma qualities similar to lagers made with commercial hop varieties. Lastly, to determine if trained panel free-choice profiling was a sufficient method for determining differences in the aromas of beers from a single style.

4.3 Experimental

4.3.1 *Samples*

From the 1995 crop, twelve raw hop samples, eight commercially available and four experimental varieties, were evaluated by a trained sensory panel. Mt. Hood, Nugget, Fuggles, Tettnanger, and Perle samples were obtained as cuts from full bales from the Oregon Hop Commission (OHC). Spalter Select, Hallertauer Tradition, Hallertauer Gold, and experimental varieties 21683, 21685, 21686, and 21689 were obtained as cuts from mini-bales from experimental plots in a commercial growers yard in Oregon. Samples from the OHC were stored at 1°C for a maximum of one week before receipt. The remaining samples were stored at -20°C before receipt. After receipt samples were stored separately, each sample in two vacuum sealed Ziploc® freezer bags, in a -34°C freezer one month before testing.

4.3.2 *Lager Ingredients*

- 36.32 kg (60 lbs) 2 row Harrington
- 6.81 kg (15 lbs) Rice Syrup Solids
- 57 g (2.0 oz) Galena hop pellets @11.7% Alpha Acids
- Gypsum treated (123ppm Ca^{++}) Filtered Water

4.3.3 *Brewing Procedure*

In an insulated steam jacketed 3.22 hl (85 gallon) mash kettle with false bottom, milled Harrington grains were added to 83.3 L (22 gallons) of gypsum treated (123ppm Ca^{++}) strike water at 56°C (133°F) to stabilize temperature at 51°C (124°F). The mash was held for 30 minutes stirring every five minutes. 37.85 L (10 gallons) of boiling water was added to bring mash temperature to 64°C (148°F). Steam was added to adjust temperature to 65.5°C (150°F). The mash was mixed and held for 15 minutes. Steam was added to bring temperature of mash to 70°C (158°F). Mash was held about ten minutes until starch test was negative. Temperature was raised to 76°C (168°F) and sparged with 113.6 L (30 gallons) of 76°C (168°F) sparge water. The wort was recirculated until nearly clear, then pumped into a 4.54 hl (120 gallon) jacketed boiling kettle. The kettle was filled to 3.22 hl (85 gallons) (to allow for 56.8 L (15 gallons) of evaporation). Rice syrup solids and hops were added. The wort was boiled for 90 minutes (80 minutes for finish-hopped lager). After boil the wort was stirred (gently, to avoid oxidation) to produce a whirlpool and pumped through a plate heat exchanger, with glycol and water cooling sections, which force cooled the sweet wort to 16.7°C (62°F). At the exit of the heat exchanger the wort was oxygenated with O_2 at 10 psi and a yeast slurry injected (for dry-hopped lager only) on the way to a jacketed 3.4 hl (90 gallon) conical fermentor. Temperature was stabilized at 15.5°C (60°F) in the fermentor. A batch replication was made for both the dry-hopped and finish-hopped lagers

4.3.4 *Yeast Preparation*

Brewers Choice© Liquid yeast for beer #2272 North American Lager (Wyeast Laboratories, Inc., Mt. Hood, OR) was used for the dry-hopped lager. Brewers Choice© Liquid yeast for beer #2247 Danish Lager II (Wyeast Laboratories, Inc., Mt. Hood, OR) was used for the finish-hopped lager. The yeast was changed for the finish-hopped lagers due to a faint sulfur aroma, most likely given by the yeast, in the dry-hopped lagers. The change was recommended by Wyeast Laboratories, Inc. (Mt. Hood, OR). Yeast growth was started per directions on package (seal broken, mixed, incubated at 21°C (70°F) for 1 day). Laaglander Light malt extract powder was used at 1 cup per 2 liters water to make 5 liters wort. The solution was autoclaved and cooled to 21°C (70°F). The growing yeast was added to 800ml wort. At 24 hour intervals the rapidly fermenting yeast solution was transferred to 4.2 liters and 10 liters of sweet wort at 21°C (70°F). The 10 liter slurry was allowed to begin fermenting (about 8 hours) then cooled to 4.4°C (40°F). The yeast slurry was warmed to 8.9°C (62°F) and mixed before transferring to cooled, oxygenated wort.

4.3.5 *Fermentation Procedure for Dry-Hopped Lager*

Initial temperature was set at 15.5°C (60°F). At first sign of fermentation (bubbles in oxygen trap) temperature was lowered to 13.3°C (56°F). As fermentation began termination, temperature was lowered to 11.7°C (53°F). When fermentation was very near the end, temperature was raised to 19.4°C (67°F) for a diacetyl rest. After 24 hours it was cooled to 7.2°C (45°F). The yeast was pumped off and saved for replicate batches. Beer was transferred to a bright beer tank in a 4.4°C (40°F) cold room. Cold room temperature was lowered to 1.1°C (34°F). The lager was force carbonated at 9 psi to obtain a theoretical 2.48 volumes of CO_2 based on the ASBC CO_2 chart (ASBC 1992b).

4.3.6 *Dry Hopping Procedure*

Hops were utilized based on oil volume (Table 4-1) as determined by the ASBC method (ASBC 1992a). Hops were weighed and placed in sanitized (boiled) hop bags. Bags were placed in the bottom of 19 liter stainless steel cornelious kegs. The keg was pressurized to 9 psi (same as bright beer tank). 18.2 kg (40 lbs) of beer was transferred under pressure to each keg. Pressure was maintained at 9 psi. Hops were allowed to steep for 14 days, at which point the pressure was released, the hops removed, and the keg repressurized to 9 psi. An empty hop bag was placed in the control keg, and removed when other hops were removed. Temperature was held at 1.1°C (34°F) during dry hopping.

4.3.7 *Finish Hopping Procedure*

Hops were utilized based on oil volume (Table 4-1) as determined by the ASBC method (ASBC 1992a). Hops were weighed and placed in sanitized (boiled) hop bags. Forty pounds of cooled sweet wort was transferred from the fermentor to a 189.3 L (50 gallon) steam jacketed boiling kettle. 3.785 L (1 gal.) of purified water was added, and the mixture boiled for 10 minutes. The steam was turned off and a bag of hops was added. After five minutes the hop bag was strained out, and the wort was pumped through a water cooled plate heat exchanger, which force cooled the wort to 15.5°C (60°F). The wort was pumped into a 5 gallon glass carboy containing two pounds of the yeast slurry. The carboy was placed in a 10°C (50°F) cooler for the duration of fermentation. This method was repeated for each variety, cleaning and sanitizing the equipment between varieties. The control beer used the same method with an empty hop bag. After fermentation the beer was racked off yeast lees into 19 liter cornelious kegs and pressurized to 9 psi in a 1.1°C (34°F) cooler to obtain a theoretical 2.48 volumes of CO_2, based on ASBC CO_2 chart (ASBC 1992b).

Table 4-1: Oil content and weight of hops added for Dry-Hopping and Finish-Hopping

Variety	mL oil/100g hops	Grams of Hops Added
21683	1.42	13.33
21685	0.95	19.92
21686	1.23	15.39
21689	1.45	13.05
Mt. Hood	1.28	14.79
Nugget	0.83	22.80
Fuggles	0.67	28.25
Perle	0.55	34.41
Tettnanger	0.77	24.58
Hallertauer Tradition	0.96	19.71
Hallertauer Gold	1.26	15.02
Spalter Select	0.85	22.27

4.3.8 *Panelists*

The panel consisted of five female and four male students and staff from Oregon State University. Ages ranged from 22-40. Two males and one female did not have prior experience as trained descriptive analysis panel members.

4.3.9 *Training and Standards*

The panel met for one-half hour five days a week, for a total of 31 panel sessions. The panel spent five days developing descriptors through the use of about sixty standards that had been chosen from previous hop aroma work (Sanchez et al 1992a & b, Stucky & McDaniel 1996), and new descriptors developed during training. After the panel had a solid word base, they were given samples of dry-hopped lager and asked to describe the aromas with any words. During the first three weeks of training the samples presented were bottled unhopped Budwieser lager (Anheuser-Busch, Inc., St. Louis, MO) that had been opened, then dry hopped with one of the twelve hop varieties and recapped at 1.1°C (34°F) to preserve the CO_2. The dry-hopped lager was allowed to steep for one week. The dry-hopped lagers to be tested were used the last three weeks of training. After testing the dry-hopped lagers, the panel was retrained for two weeks with the finished-hopped lagers. Standards were made to represent each of the terms used by the panelists (Table 4-2). To rate the intensity of each descriptor, the panel was trained to use a 16-point intensity scale (0 = none, 7 = moderate, and 15 = extreme). To anchor the intensity scale the panelists were provided with four intensity standards: 30 ml Saffola fresh safflower oil "3", 30 ml Hi-C orange juice "7", 30 ml Welches grape juice "11" and one stick Big Red cinnamon gum "15" (each in a 240ml teardrop wine glass). Each panelist had their own ballot with the descriptors listed that they previously used to describe the dry-hopped lager aromas. Panelists were able to add or delete terms from their ballot during any session. Panelist consistency was determined before testing to insure all panelists were reproducing ratings on replicate samples.

Table 4-2: Standards used for training and describing the aroma of Dry and Finish hopped lagers

Attribute	Reference (Company)
β-Caryophyllene	5µl in 20 ml water (Sigma® St. Louis, MO)
β-pinene	5µl in 20 ml water (Union Camp® Jacksonville, FL)
Alcohol	95% ethanol (Clear Spring®, Frankfort, KY)
Apple	Cubed fresh Jonathan red apple
Banana	Cubed fresh banana
Bubble Gum	Bazooka bubble gum (The Topps Company Inc. Duryea, PA)
Burned Match (sulfurous)	Tips of two burned matches (Diamond®, Minneapolis, MN)
Carmel	Kraft Carmels (Favorive Brands International Inc., Lincolnshire, IL)
Catty	No standard used
Cheesy	0.01% Valeric acid (K & K Lab)
Cider	Tree Top® Apple Cider (Tree Top, Inc., Selah, WA)
Chili Pepper/Spicy	Chili pepper (Spice Islands®, San Francisco, CA)
Cinnamon	Ground cinnamon (Spice Islands®, San Francisco, CA)
Clove	Ground clove (Spice Islands®, San Francisco, CA)
Cucumber	Sliced fresh cucumber
Diacetyl	Butter flavoring (Schilling®, Hunt Valley, MD)
Dirty/Soil/Earthy	Potting soil (Payless®, Wilsonville, OR)
DMS/Corn/Sulfur	Rolling Rock lager (Latrobe Brewing Co. Latrobe, PA)
Dusty	Paper from old book
Egg	Hard boiled egg, peeled
Floral	97% linalool on an aroma stick (Aldrich®, Milwaukie, WI)
Fishy	Tetra Fin fish food flakes (Tetra Sales, Blacksburg, VA)
Garlic	Garlic (Spice Islands®, San Francisco, CA)
Geraniol	98% geraniol on an aroma stick (Aldrich®, Milwaukie, WI)
Geranyl acetate	5µl in 20 ml water (Union Camp® Jacksonville, FL)
Grain	Harrington crystal malt
Grassy	0.01% cis-3-hexenal (Bedoukian Research, Inc., Danbury, CT)
Green Beans	Canned green beans (Del Monte, San Francisco, CA)
Hay	One long sprig cut into one inch pieces
Herbal	Oregano, thyme and rosemarry (Spice Islands®, San Francisco, CA)
Honey	Sweet Clover honey (Sue Bee®, Sioux City, IW)
Lactic	Lactic acid (Purac America, Inc. Lincolnshire, IL)
Lemon	Cubed fresh lemon
Lightstruck/Skunky	Corona Extra (Cerveceria Modelo, S.A. DE C.V., Mexico, D.F.)
Malty	Harrington crystal malt crushed and boiled
Mango	Dried mango slices
Metallic	Washed tin can
Methyl Nonal Ketal	5µl in 20 ml water (Aldrich® Milwaukie, WI)
Mushrooms	Cubed dried Picksweet mushrooms
Musty	Terpene-4-ol on aroma stick (Aldrich®, Milwaukie, WI)
Myrcene	5µl in 20 ml water (Union Camp® Jacksonville, FL)
Myrtenol	5µl in 20 ml water (Aldrich® Milwaukie, WI)
Nutmeg	Ground nutmeg (Spice Islands®, San Francisco, CA)
Nutty	Roasted diced hazelnuts
Orange	Cubed fresh orange
Peach	Canned peaches (Dole, San Jose, CA)
Pear	Cubed fresh pear
Perfume	Essence on aroma stick (Uncomon Scents®, Eugene, OR)
Perm Solution/Ammonia	Toni Silkwave® (The Gillette Company (USA) Inc., Boston, MA)
Pine/Evergreen	Macerated pine needles

Table 4-2 (Continued)

Attribute	Reference (Company)
Pineapple	Cubed fresh pineapple
Plastic	Sliced plastic contained
Popcorn	Air popped popcorn
Prunes	Cubed prunes (DelMonte®, Fullerton, CA)
Rose Petal	Essence on aroma stick (Uncomon Scents®, Eugene, OR)
Rancid	Rancid Canola oil (Wesson, Fullerton, CA)
Rubber	Sliced bicycle tube
Sage	Sage (Spice Islands®, San Francisco, CA)
Soap	Dawn® dishwashing detergent original scent (Proctor & Gamble, OH)
Strawberry	Cubed Fresh Strawberries
Tobacco	Tobacco from one Winston cigarette (Winston®, Winston-Salem, NC)
Vinegar/Wine	Heinz distilled white vinegar (H.J. Heinz Co., Pittsburgh, PA)
Woody	Pine board shavings
Yeasty	Yeast trub from fermented unhopped lager

4.3.10 *Sample Descriptors*

Free-choice profiling of the 13 samples generated between 19 (panelist 2) and 24 (panelists 5 & 8) terms with an average of 22 terms per panelist (Table 4-3) for the dry-hopping test, and between 16 (panelist 1) and 25 (panelist 9) terms with an average of 21 terms per panelist (Table 4-4) for the finish-hopping test.

Table 4-3: Descriptors generated by each panelist during free-choice profiling of aromas of dry-hopped American lager

Panelist 1	Panelist 2	Panelist 3	Panelist 4	Panelist 5	Panelist 6	Panelist 7	Panelist 8	Panelist 9
Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity
Pineapple	Pineapple	Pineapple	Pineapple	Pineapple	Pineapple	Pineapple/	Pineapple	Fruity
Orange	Strawberry	Peach	Fruity	Apple	Lemon	Banana	Apple	Apple
Lemon	Cider	Pear	Mango	Cider	Peach	Fruity	Pear	Lemon
Banana	Banana	Berry	Honey	Mango	Mango	Citrus	Peach	Banana
Mango	β-pinene/Myrcene	Prune	Floral	Floral	Honey	Prune	Fruity	Mango
Myrcene	Floral	Honey	Herbal	Methyl Nonal -	Geranyl Acetate	Honey	Banana	Prune
Roses	Pepper/Sage	Myrcene	Garlic	Ketal	Myrcene	Myrcene	Prune	Honey
Grassy	Tobacco	Geraniol/Floral	Malty	Herbal	Methyl Nonal -	Methyl Nonal -	Honey	Cider
Sage	DMS	Myrtenol	Grain	Spicy	Ketal	Ketal	Floral	Floral
Pine	Malty	Herbal	Yeasty/Malty	β-Caryophyllene	Geraniol	Herbal	Myrcene	Myrcene
DMS	Nutty	Clove/Nutmeg	Burnt	Sage/Musty/	Vegetative	Pine	Herbal	Herbal
Malty	Rubber	Cinnamon	Mushroom	Tobacco	DMS	Sage	Pine	Sage
Mushroom	Musty	Malty	Rubber	Malty	Nutmeg	Grassy	Cedar	Grassy
Rubber	Skunky	Hay	Musty	Woody	Clove	β-pinene	Grassy	Malty
Skunky	Yeasty	Mushroom	Dirty	Popcorn	Malty	Clove	β-pinene	Tobacco
Musty	Alcohol	Rubber	Alcohol	Rubber	Tobacco	Malty/Yeasty	Spicy	Yeasty
Burnt Match	Cheesy	Lightstruck	Cheesy	Skunky	Caramel	Mushroom	Malty	Rubber
Fishy	Soapy	Green Beans	Rancid	Dirty/Soil	Rubber	Tobacco	Yeasty	Musty
Alcohol		Alcohol	Metallic	Yeasty	Musty	Musty	Mushroom	Earthy
		Vinegar/Wine	Fishy	Alcohol	Lightstruck	Skunky	Tobacco	Burnt Match
				Dry Erase -	Lactic	Alcohol	Caramel	Ethanol
				Marker	Ester/	Fishy	Musty	Fishy
				Sharp	Bubble Gum		Skunky	
				Metallic				
				Bubble Gum				
				Fishy				

Table 4-4: Descriptors generated by each panelist during free-choice profiling of aromas of finish-hopped American lager

Panelist 1	Panelist 2	Panelist 3	Panelist 4	Panelist 6	Panelist 7	Panelist 9
Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity	Overall Intensity
Pineapple	Pineapple	Pineapple	Pineapple	Pineapple	Pineapple	Pineapple
Orange	Apple	Lemon	Fruity	Peach	Fruity	Fruity
Banana	Lemon	Pear	Cider	Mango	Lemon/Citrus	Apple
Mango	Banana	Peach	Prune	Perfume	Banana	Pear
Honey	Cider	Prune	Honey	Methyl Nonal-	Bubble Gum	Orange
Grassy	Honey	Honey	Floral	Ketal	Honey	Banana
Malty	Floral	Cucumber	Spicy	Geranyl Acetate	Corn	Bubble Gum
Rubber	Malty	Herbal	Chili Pepper	Ester/	Herbal	Honey
Musty	Nutty	Cinnamon	Malty	Bubble Gum	Sage	Herbal
Dusty	Diacetyl	Malty	Grain	Malty	Evergreen	Myrcene
Egg	Yeasty	Mushroom	Yeasty	Woody	Malty	Grassy
Perm Solution	Rubber	Yeasty	Rubber	Tobacco	Mushroom	Malty
Alcohol	Musty	Rubber	Musty	Caramel	Yeasty	Mushroom
Bubble Gum	Skunky	Musty/Dusty	Dirty	Yeast	Musty	Tobacco
Fishy	Dusty	Lightstruck	Sulfur	Rubber	Skunky	Yeasty
	Egg	Egg	Ammonia	Musty	Dirty	Rubber
	Alcohol	Alcohol	Pungent/Cheese	Skunky	Soil	Musty
	Soapy	Red Wine	Alcohol	Egg	Perm Solution	Skunky
	Vinegar	Fishy	Metallic	Lactic	Catty	Dirty
	Lobster		Fishy		Alcohol	Dusty
			Steamy		Plastic	Sulfur
					Soap	Perm Solution
					Fishy	Alcohol
						Fishy

4.3.11 *Presentation of Samples*

For assessment, the beer was poured from the keg into a glass pitcher, and from the pitcher 60ml was poured into a 240ml amber glass. An aluminum lid was placed on the glass to minimize the loss of volatiles. The glasses were coded with three digit random numbers. The samples were evaluated immediately after pouring. The temperature of the beer was 8.9°C $\pm$ 1°C. For testing, samples were presented in a (13 x 3) randomized incomplete-complete block design, using Cochran and Cox (1994) Table 11.21, as a basis for the pre-randomization order. Three replications of each hop variety were presented. Replications one and two were from the first batch of lager made, and replication three was from the second batch of lager made. Thirteen sessions were completed where three samples were presented at each session, and two sessions were completed each day. A minimum ten minute break was taken between sessions.

4.3.12 *Assessment Procedure*

A panelist removed the lid from the glass and took three short sniffs. The lid was replaced while the panelist rated the sample. If additional sniffs were required the samples were allowed to sit momentarily to recover the volatiles.

4.3.13 *Statistical Analysis*

Sensory data were analyzed by Generalized Procrustes Analysis using Procrustes-PC version 2.0 (Dijksterhuis 1989) and by Statistical Analysis System for Personal Computer (SAS 1987). Analysis of variance on the principal axes scores was used to ascertain differences among samples and, where appropriate, least significant difference using $p \leq 0.05$. The data were analyzed with all thirteen samples, then separately with only the commercial varieties, and with only the experimental varieties.

4.4 Results and Discussion

4.4.1 *Generalized Procrustes Consensus Configurations*

The final result of a Generalized Procrustes Analysis (GPA) is a consensus configuration of the samples for the different principal axis combinations, as presented in Figures 4-1 - 4-6. These figures illustrate the differences among samples. The first principal axis separates samples by the intensity of their aromas which give the highest percentage of separation. The second principal axis separates samples by the intensity of their aromas which give the next highest percentage. Figures 4-1 and 4-4 show the sample means from three replications. Figures 4-2, 4-3, 4-5 & 4-6 show the three replications with batch two underlined. Small letters and numbers are replications and large bold letters and numbers are sample means. The sample means are enclosed together to show significantly different sample groupings as determined by ANOVA of principal axis one values. Samples included in the overlap between two groups are members of both groups and are not significantly different from samples in either group. The descriptors used by each panelist which contributed most to each principal axis were summarized and are listed at the end of the axes. The farther along the axis a sample lies, the more intense the characteristics of that axis direction.

4.4.2 *Panelists*

As expected, not all individuals behaved similarly and the number of dimensions required to describe the differences varied from panelist to panelist. By examining how each panelist combined descriptors to define a principal axis one could get an overall interpretation of how they separated the samples and characterized the aroma of each variety. The descriptors for each panelist determined by GPA to have correlations ≥ 0.40 were most important in separating the samples and are listed in Tables 4-5 & 4-6. The more important attributes had higher correlation and are listed first for each panelist. The definitions given for the descriptors by each panelist, helped explain which descriptors were important in differentiating the samples for each principal axis. The descriptors used by the panelists could be placed in groups with similar definitions. For instance all panelists used some type of "fruity", "floral", "musty/dirty" and "rubbery" descriptors. Knowing the definition of each of the descriptors used by the panelists allowed for grouping similarly defined descriptors and aided in developing a list of aroma qualities for each of the hop varieties. The gender of the panelist appeared to have no relationship with panelist performance, number of descriptors used, or choice of descriptors with either the dry-hopped or finish-hopped lagers.

4.4.3 *Product Separation*

To supplement the graphical information from GPA, an analysis of variance (ANOVA) was completed on the sample values from each principal axes which had an eigenvalue greater than one. The summaries in Tables 4-7 and 4-8 were determined by comparing the ANOVA separation of each of the principal axes, giving the most weight to the first principal axis. In most cases only the first principal axis had an eigenvalue above one, thus the separation reflects the ANOVA of the first principal axis. The ANOVA on each of the principal axes gives only a guideline for the separation of the samples, since there is no control for the variability in scale usage by the panelists, and after GPA the samples are no longer considered independent. This separation was ultimately based on inspection of the ANOVA results and descriptor correlations (Tables 4-5 & 4-6) from each panelist.

Table 4-5: Correlations* of the attributes for the first principal axis following free-choice profiling for Dry-Hopped Samples

Panelist	All Samples Principal Axis 1	Commercial Samples Principal Axis 1	Experimental Samples Principal Axis 1
1	Pineapple(-0.54), OI[1](-0.51), Burnt Match(0.51), Alcohol(-0.48)	OI(0.55), Alcohol(0.51), Pineapple(0.50), Burnt Match(-0.49)	Pineapple(-0.85), OI(-0.57), Lemon(-0.57), Orange(-0.56), Mango(-0.54), Burnt Match(0.48)
2	Skunky(0.51), DMS(0.48), Rubber(0.41)	Herbal(-0.51), Rubber(-0.49), DMS(-0.44), Banana(0.41)	DMS(0.71), Musty(0.65), Pineapple(-0.60), Pepper/Sage(-0.50), Skunky(0.48), Nutty (-0.45), Rubber(0.40)
3	Cooked Green Beans(0.57), Mushroom(0.53), Honey(-0.52), Rubber(0.45), Hay(0.43), Herbal(0.41), Malty(0.40)	Hay(-0.65), Mushroom(-0.64), Herbal (-0.59), Pineapple(0.59), Cooked Green Bean(-0.57), Rubber(-0.49), Malt(-0.44), Prune(0.42), Pear(0.41)	Lightstruck(0.68), Honey(-0.56), Cinnamon(-0.52), Peach(-0.43)
4	Floral(-0.42), Grain(0.42)	Malty(-0.44), Grain(-0.44), Floral(0.41)	Grain(0.71), Fruity(-0.52), Dirty(-0.49), Pineapple(-0.47), Floral(-0.47), Metallic(0.46), Mango(-0.46), Honey(0.44), Herbal(-0.44)
5	Apple(-0.55), Rubber(0.53), Yeasty(0.52), DMS(0.46), Bubble Gum(-0.46), Mango (-0.41), Pineapple(-0.40)	Yeast(-0.64), Rubber(-0.60), Apple(0.58), Methyl Nonal Ketal(0.48), DMS(-0.40)	Popcorn(0.69), DMS(0.59), Bubble Gum (-0.45), Mango(-0.45), Herbal(0.44), Pineapple(-0.42), Apple(-0.40)
6	Lightstruck(0.71)	Lightstruck(-0.82), Rubber(-0.45), Malty (-0.41)	Lightstruck(0.65), Musty(0.63), Rubbery(0.42)
7	Fishy(0.81), Skunky(0.78), Alcohol(0.69), Musty(0.55), Fruity(-0.46), Honey(-0.46), Malty/Yeasty(0.43)	Fishy(-0.87), Skunky(-0.80), Alcohol (-0.76), Musty(-0.54), Mushroom(-0.41), Malty/Yeasty(-0.41), Sage(-0.40)	Fishy(0.80), Skunky(0.68), Sage(0.68), Alcohol(0.58), Fruity(-0.57), Banana/Pineapple(-0.56), Honey(-0.50), OI(-0.43), Pine(0.42)
8	Prune(0.65), Honey(0.54), Musty(0.53), Peach(-0.45)	Prune(-0.78), Musty(-0.62), Honey(-0.61), Peach(0.49), Herbal(0.46)	Prune(0.62), Fruity(-0.59), Musty(0.57), Pear(-0.54)
9	Rubber(0.66), Fruity(-0.62), Burnt Match(0.46), Yeasty(0.46)	Fruity(0.75), Rubber(-0.62), Yeasty(-0.61), Burnt Match(-0.48), Honey(0.41)	Grassy(-0.61), Musty(0.50), Rubber(0.46), Malty(-0.43)

* Attributes with correlations <0.40 and >-0.40 were not included in the table.

1 Overall Intensity

Table 4-6: Correlations* of the attributes for the first principal axis following free-choice profiling for Finish-Hopped Samples

Panelist	All Samples Principal Axis 1	Commercial Samples Principal Axis 1	Experimental Samples Principal Axis 1
1	Orange(0.61), Musty(-0.55), Rubber(-0.55), Pineapple(0.54), Fishy(-0.45), Perm Solution(-0.42), Dusty(-0.40)	Musty(0.66), Orange(-0.66), Rubber(0.64), Pineapple(-0.60), Fishy(0.58), Dusty(0.51), Perm Solution(0.50), Banana(-0.46), Bubble Gum(-0.42)	Alcohol(-0.63), Rubber(-0.62), Bubble Gum(0.55), Mango(-0.44), Grassy(0.42)
2	Lobster(-0.48), Egg(-0.41)	Lobster(0.55), Egg(0.50), Rubber(0.40)	Floral(-0.54), Diacetyl(-0.54), Soapy(0.51), Vinegar(0.47), Dusty(0.46), Rubber(0.44), Alcohol(-0.44)
3	Yeast(-0.51), Herbal(-0.48)	Herbal(0.64), Yeasty(0.55), Peach(-0.51), Pear(-0.49), Alcohol(-0.48), Mushroom(0.41)	Lemon(-0.74), Pear(-0.66), Peach(-0.64), Yeasty(0.61), Mushroom(0.55), OI(0.51), Pineapple(-0.45), Herbal(0.42)
4	Pineapple(0.61), Fruity(0.57), Ammonia(0.41)	Pineapple(-0.62), Ammonia(-0.59), Fruity (-0.56), OI[1](-0.49), Yeasty(-0.40)	Pungent/Cheese(-0.67), Chilipepper(-0.51), Ammonia(-0.49), OI(-0.48), Spicy(-0.47), Grain(-0.46), Honey(0.44)
6	Peach(0.52), Rubber(-0.51), Mango(0.42)	Rubber(0.52), Peach(-0.50), Mango(-0.45)	Tobacco(0.82), Geranyl Acetate(-0.72), Ester(0.41)
7	Musty(-0.48), Alcohol(0.44), Malty(0.43), Catty(-0.41), OI[1](0.40)	Malty(-0.42), Alcohol(-0.42)	Malty(-0.78), Yeasty(-0.70), Soapy(-0.47), Skunky(0.46)
9	No Terms ≥0.40 or ≤-0.40	Dirty(0.42), Yeasty(-0.40)	Rubber(-0.87), Fruity(-0.43)

* Attributes with correlations ≤0.40 and ≥-0.40 were not included in the table.

1 Overall Intensity

Table 4-7: Hop variety separation and aroma qualities for dry-hopped American lagers

Variety	Separation*	Aroma Qualities
All Samples		
21689	a	Fruity, Floral, Pineapple
Nugget	a	Fruity, Floral
Hallertauer Tradition	a	Fruity, Floral
Mt. Hood	a	Fruity, Floral
Spalter Select	a	Fruity, Floral
Perle	a b	Fruity, Floral, Musty, Rubbery
21683	a b	Fruity, Floral, Musty, Rubbery
21686	a b	Fruity, Floral, Musty, Rubbery
Hallertauer Gold	a b	Fruity, Floral, Musty, Rubbery
Fuggles	a b	Fruity, Floral, Musty, Rubbery
21685	b	Rubbery, Musty, Skunky
Control	b	Rubbery, Musty, Skunky, Malty, Yeasty
Tettnanger	b	Rubbery, Musty, Skunky, Malty, Yeasty

Commercial only		Experimental only	
Nugget	a	21689	a
Hallertauer Tradition	a	21686	a
Spalter Select	a	21683	a
Mt. Hood	a	21685	b
Perle	a b	Control	b
Hallertauer Gold	a b		
Fuggles	a b		
Control	b		
Tettnanger	b		

*Separation on first principal axis (different letters indicate a significant difference at $P \leq 0.05$)

Table 4-8: Hop variety separation and aroma qualities for finish-hopped American lagers

Variety	Separation*	Aroma Qualities
All Samples		
Tettnanger	a	Fruity, Alcohol, Malty
Nugget	a	Fruity, Alcohol, Malty
Perle	a	Fruity, Alcohol, Malty
Fuggles	a	Fruity, Alcohol, Malty
Mt. Hood	a	Fruity, Alcohol, Malty
Hallertauer Tradition	a	Fruity, Alcohol, Malty
Spalter Select	a	Fruity, Alcohol, Malty
21686	a b	Fruity, Alcohol, Malty, Musty, Rubber
21685	a b	Fruity, Alcohol, Malty, Musty, Rubber
21689	b	Musty, Rubber, Fishy
21683	b	Musty, Rubber, Fishy
Control	b	Musty, Rubber, Fishy
Hallertauer Gold	b	Musty, Rubber, Fishy

Commercial only		Experimental only	
Tettnanger	a	21685	a
Nugget	a	21686	a b
Fuggles	a	21689	a b
Perle	a	Control	b
Spalter Select	a	21683	b
Hallertauer Tradition	a		
Mt. Hood	a		
Control	b		
Hallertauer Gold	b		

*Separation on first principal axis (different letters indicate a significant difference at $P \leq 0.05$)

4.4.4 *Dry-Hopped Lagers*

The dry-hopped lagers were separated into three descriptive groups (Figure 4-1): Group 1) 21689, Nugget, Hallertauer Tradition, Mt. Hood and Spalter Select; Group 2) Fuggles, Hallertauer Gold, Perle, 21686 and 21683; and Group 3)Tettnanger, 21685, and Control. The three groups were characterized by the aroma qualities: Group 1) Fruity and floral aroma qualities; Group 2) Both fruity, floral and musty, rubbery aroma qualities; and Group 3) Musty, rubbery, skunky, yeasty and malty aroma qualities. The samples in groups one and three were significantly different ($p \leq 0.05$). Experimental variety 21685 is similar to the Control and Tettnanger, 21683 and 21686 are similar to Perle and Hallertauer Gold, and 21689 is similar to Nugget and Hallertauer Tradition.

The three replications of each variety are shown in Figures 4-2 and 4-3. There were no significant differences between the two batches or between the sample replications. However, for some varieties there appears to be a difference in the batches. For instance, for Tettnanger (Figure 4-3), the two replications from batch one were very similar, located at the negative end of principal axis one, but the batch replication is located at the far positive end of the axis. Since there were batch differences for only a few of the varieties, it is most likely that the differences stemmed from the dry-hopping procedure and not the brewing procedure. Analyzing the experimental varieties separately improved the separation between the samples (Figure 4-2). 21685 and Control were significantly more intense in musty, rubbery and sulfur aromas than 21683, 21686 and 21689. No difference in the separation of dry-hopped lagers was achieved by analyzing the commercial hop varieties separately.

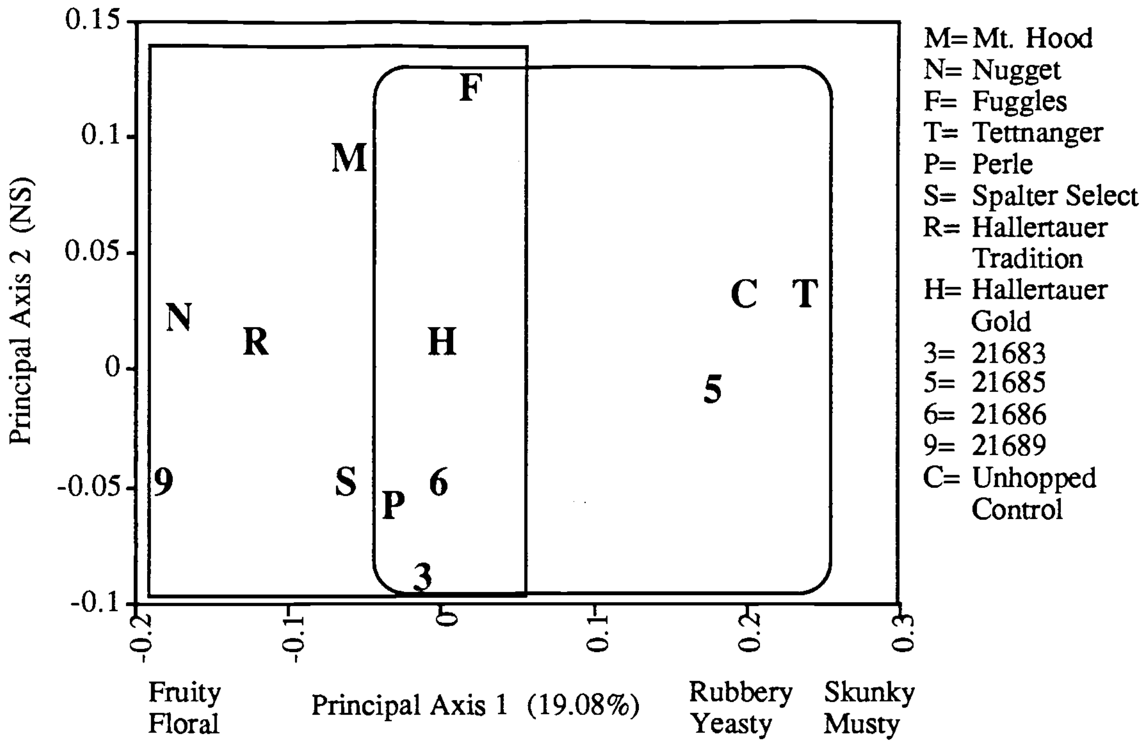

Figure 4-1: Separation of American Lagers Dry-Hopped with Commercial and Experimental Hop Varieties by Trained Panel Free-Choice Profiling of Aroma Characteristics. Principal Axes one and two.

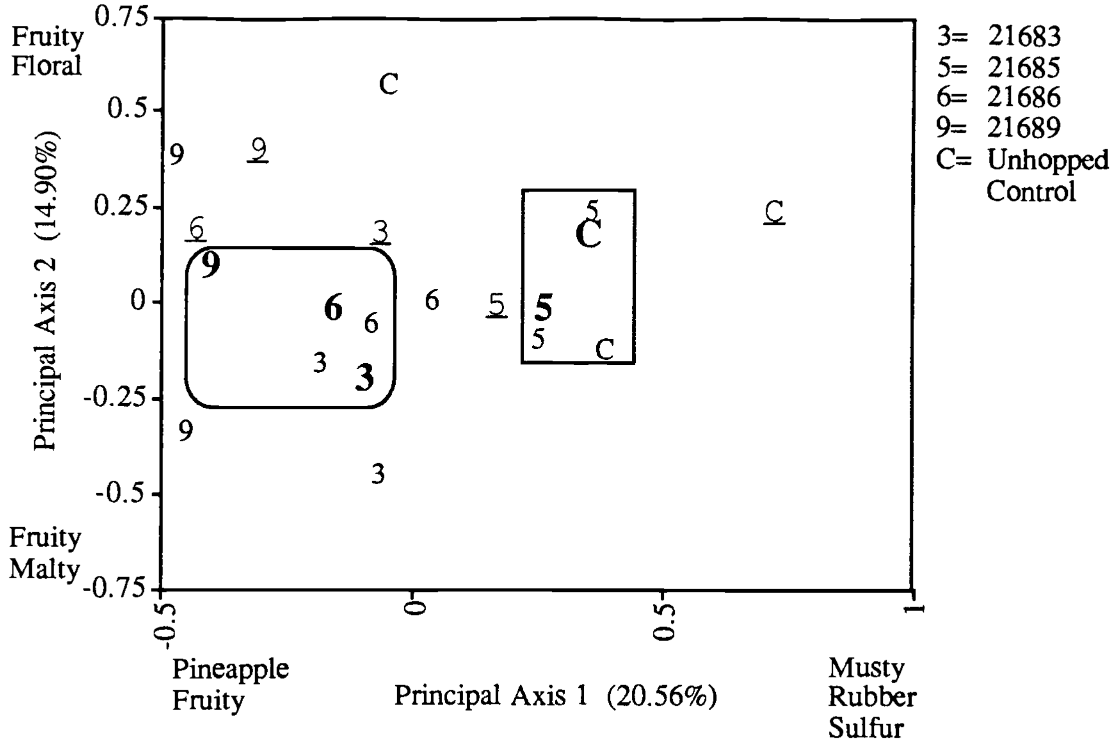

Figure 4-2: Separation of American Lagers Dry-Hopped with Commercial Hop Varieties by Trained Panel Free-Choice Profiling of Aroma Characteristics. Principal Axes one and two. Large bold letters are means. Small letters are replications from batch one. Underlined letters are replications from batch two.

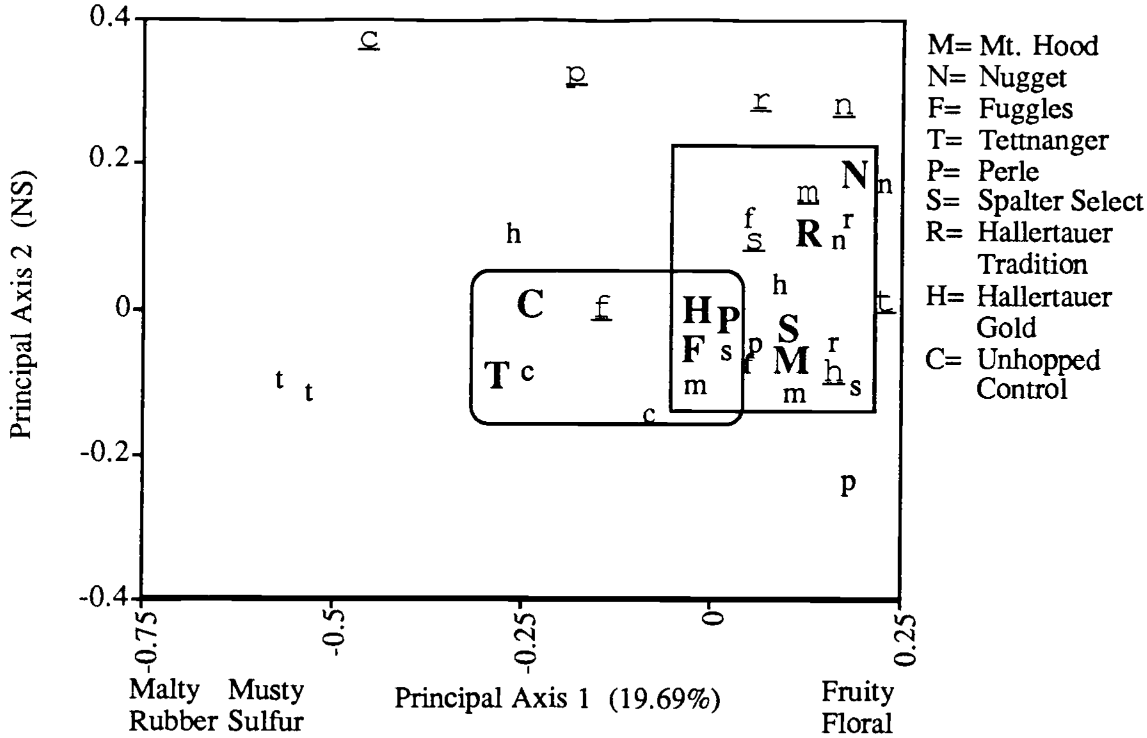

Figure 4-3: Separation of American Lagers Dry-Hopped with Experimental Hop Varieties by Trained Panel Free-Choice Profiling of Aroma Characteristics. Principal Axes one and two. Large bold numbers are means. Small numbers are replications from batch one. Underlined numbers are replications from batch two.

4.4.5 *Finish-Hopped Lagers*

The dry-hopped lagers were separated into three descriptive groups (Figure 4-4): Group 1) Hallertauer Gold, Control, 21683 and 21689; Group 2) 21685 and 21686; and Group 3) Tettnanger, Nugget, Fuggles, Perle, Mt. Hood, Hallertauer Tradition and Spalter Select. The three groups were characterized by the aroma qualities: Group 1) Musty, rubbery and fishy aroma qualities; Group 2)Both fruity, alcohol, malty and musty, rubbery, musty aroma qualities; and Group 3) Fruity, alcohol and malty aroma qualities. The samples in groups one and three were significantly different ($p \leq 0.05$). Experimental varieties 21683 and 21689 were similar to Hallertauer Gold, and varieties 21685 and 21686 were similar to Spalter Select and Hallertauer Tradition.

The three replications and means of each variety are shown in Figures 4-5 and 4-6. There were no significant differences between the two batches or between the sample replications. Analyzing the experimental varieties separately improved the separation between the samples (Figure 4-5). 21683 and the Control were significantly more intense in rubbery, musty, grassy and vinegar aromas than 21689, 21686 and 21685. No difference in the separation of dry-hopped lagers was achieved by analyzing the commercial hop varieties separately.

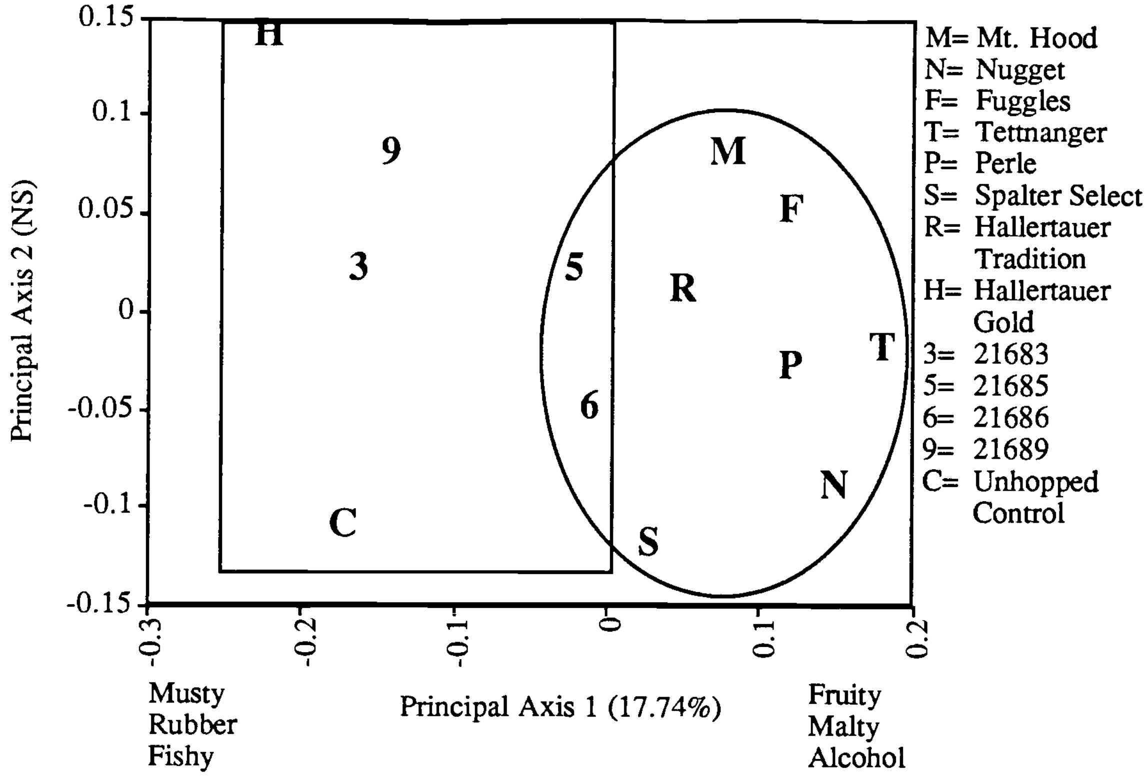

Figure 4-4: Separation of American Lagers Finish-Hopped with Commercial and Experimental Hop Varieties by Trained Panel Free-Choice Profiling of Aroma Characteristics. Principal Axes one and two.

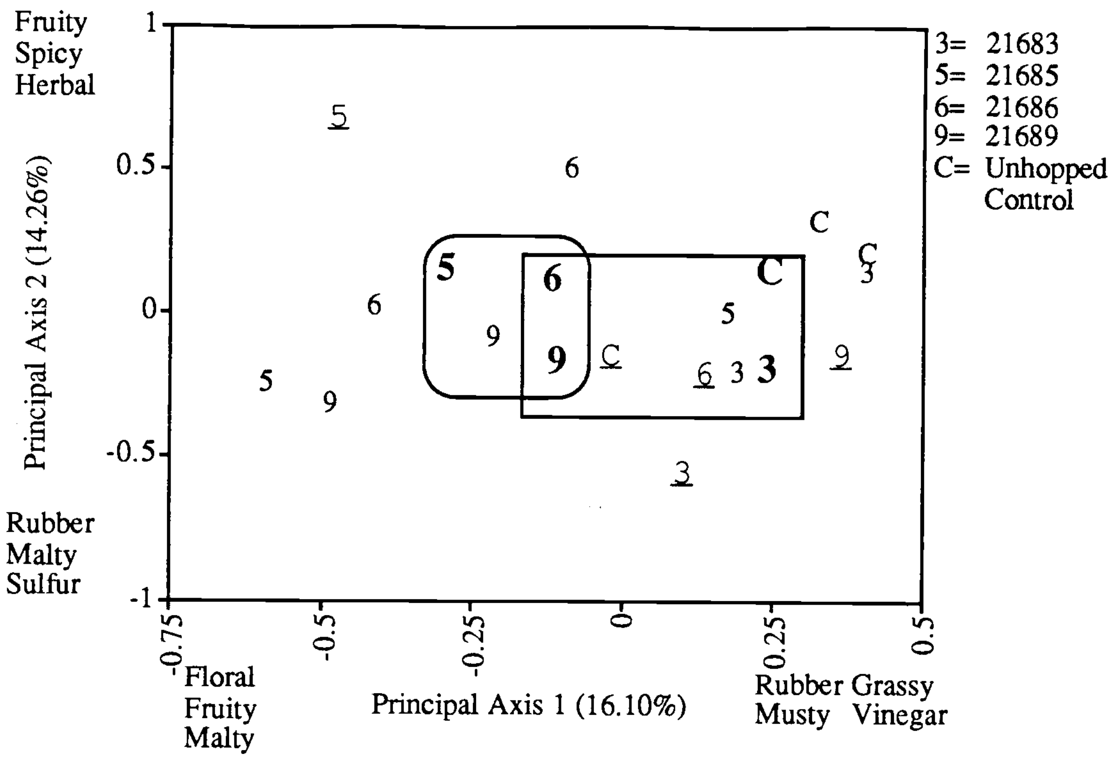

Figure 4-5: Separation of American Lagers Finish-Hopped with Commercial Hop Varieties by Trained Panel Free-Choice Profiling of Aroma Characteristics. Principal Axes one and two. Large bold letters are means Small letters are replications from batch one. Underlined letters are replications from batch two.

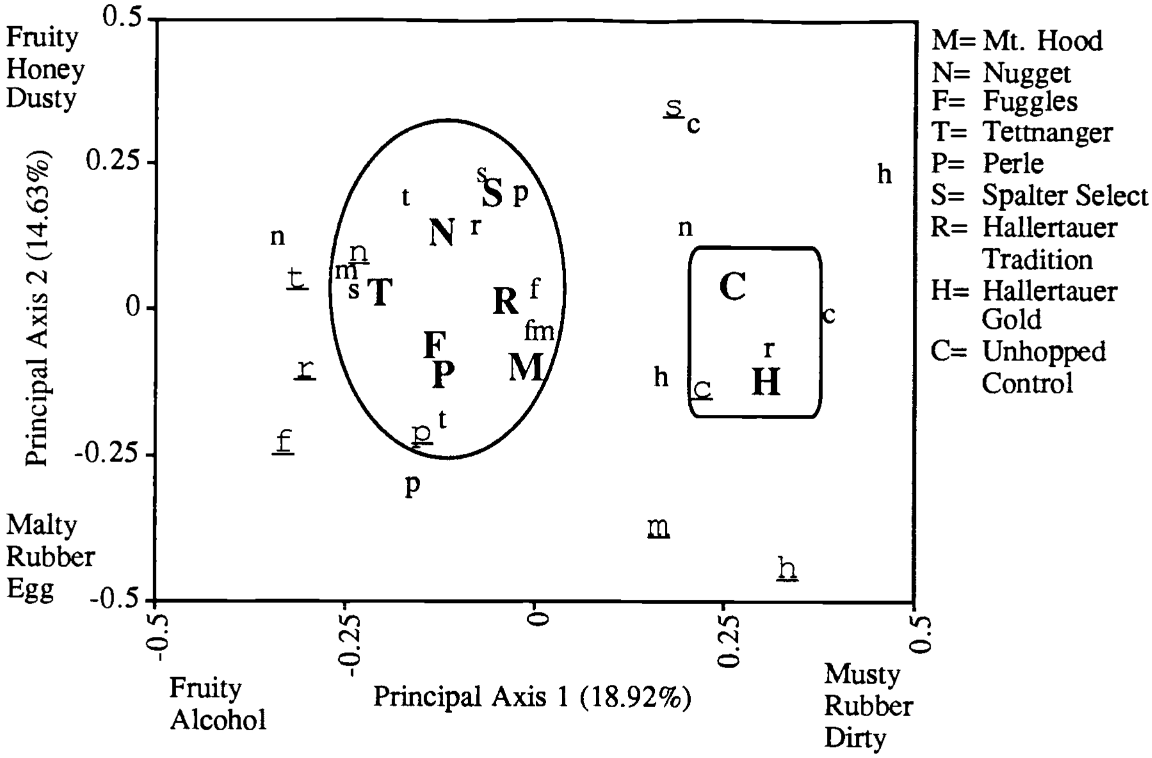

Figure 4-6: Separation of American Lagers Finish-Hopped with Experimental Hop Varieties by Trained Panel Free-Choice Profiling of Aroma Characteristics. Principal Axes one and two. Large bold numbers are means. Small numbers are replications from batch one. Underlined numbers are replications from batch two.

4.4.6 *Comparison of Dry and Finish-Hopped Lagers*

Comparing the samples from dry-hopping and finish-hopping, there was no relationship, that could be applied to all varieties, between the aroma qualities of a hop variety used for dry-hopping and the aroma qualities of a hop variety used for finish-hopping. Nugget, Mt. Hood, Hallertauer Tradition and Spalter Select were described as having fruity aroma characteristics for both processes. The control was described similarly for both processes. The remainder of the varieties were described differently when used for dry-hopping or finish-hopping. For instance 21689 was described as fruity, floral and pineapple in the dry-hopped lagers and musty, rubber, fishy in the finish-hopped lagers. The brewing process appears to effect the aroma of different varieties differently.

Comparing the varieties from dry and finish-hopping with the aroma of the raw hops (Stucky & McDaniel 1996) there are some varieties that have similar aromas. Hallertauer Tradition and Spalter Select had fruity and floral aroma characteristics in all three studies. Hallertauer Tradition, 21689 and Spalter Select had similar fruity and floral aromas in the raw and dry-hopped samples. Hallertauer Gold and 21683 had similar fruity, floral and musty aromas in the raw and dry-hopped samples. The remainder of the varieties were described differently in each of the studies. In general there appears to be no relationship, that could be applied to all varieties, between the aroma qualities of the raw hop and the lager dry or finish-hopped with that hop. Depending on the brewing process, the aroma qualities of certain raw hop varieties can be used to predict the aroma of the finished beer.

Experimental variety 21683 had similar aroma qualities to Hallertauer Gold in the dry-hopped and finish-hopped lagers, and in the raw form (Stucky & McDaniel 1996). 21689 was also similar to Hallertauer Gold in the raw hop and finish-hopped studies, but was given slightly but not significantly different, aroma qualities in the dry-hopped study.

4.4.7 *Panelist Performance for Dry-Hopped Lagers*

Panelists' individual performance was examined by the percentage residual variation obtained from GPA. The percentage residual variation for the dry-hopped lagers ranged from 33.0% to 65.4% of the total variation with approximately equal separation across the range, which indicates the panelists were about equal in separating the samples. By examining how each panelist separated varieties and replicate samples a visual measure of panelist performance was obtained. All panelists separated samples significantly and replicated samples well on the first principal axis.

The amount of consensus between panelists, in describing each sample, was visualized by looking at the residual variation divided into two parts, percentage consensus and percentage residual, obtained from the GPA of the samples (Figure 4-7). A high percentage of consensus in relation to the percentage residual indicates greater agreement between the panelists. Figure 4-7 contains the mean percentages for consensus and residual for the dry and finish-hopped samples. The dry-hopped lagers are the top bar graph and the finish-hopped lagers are the bottom graph. There was very high agreement between the panelists for Tettnanger. This unusually high agreement reflects the high similarity in the panelists ratings. Nugget, 21685, 21689 and Control also had high agreement between panelists. The remainder of the samples had low agreement between panelists and were samples located near zero on principal axis one (Figure 4-1). The samples with low agreement are located near zero since some of the panelists described them with the words at the left of the axis and some described them with the words at the right end of the axis. Samples with high agreement located near zero because they are described by the words at both ends of the axis.

4.4.8 *Panelist Performance for Finish-Hopped Lagers*

Panelists' individual performance was examined by the percentage residual variation obtained from GPA. The percentage residual variation for the finish-hopped lagers ranged from 42.6% to 93.0% of the total variation with panelists 5 & 8 having unusually high amount of residual variation. This is an indicator of poor panelist performance and indicates these panelists were not separating the samples in the same way as the rest of the panel. By examining how each panelist separated varieties and replicate samples a visual measure of panelist performance was obtained. Panelists 5 & 8 did not separate varieties and were unable to replicate most of the finish-hopped lagers. This was the first exposure to sensory analysis for both panelists 5 & 8. The remainder of the panelists all separated samples significantly and were able to replicate most samples accurately. Because of poor performance panelists 5 & 8 were removed from the data set for analysis of the finish-hopped lagers. Removal of panelists 5 & 8 from the data set improved the overall separation of samples, but did not change the sample order on principal axis one.

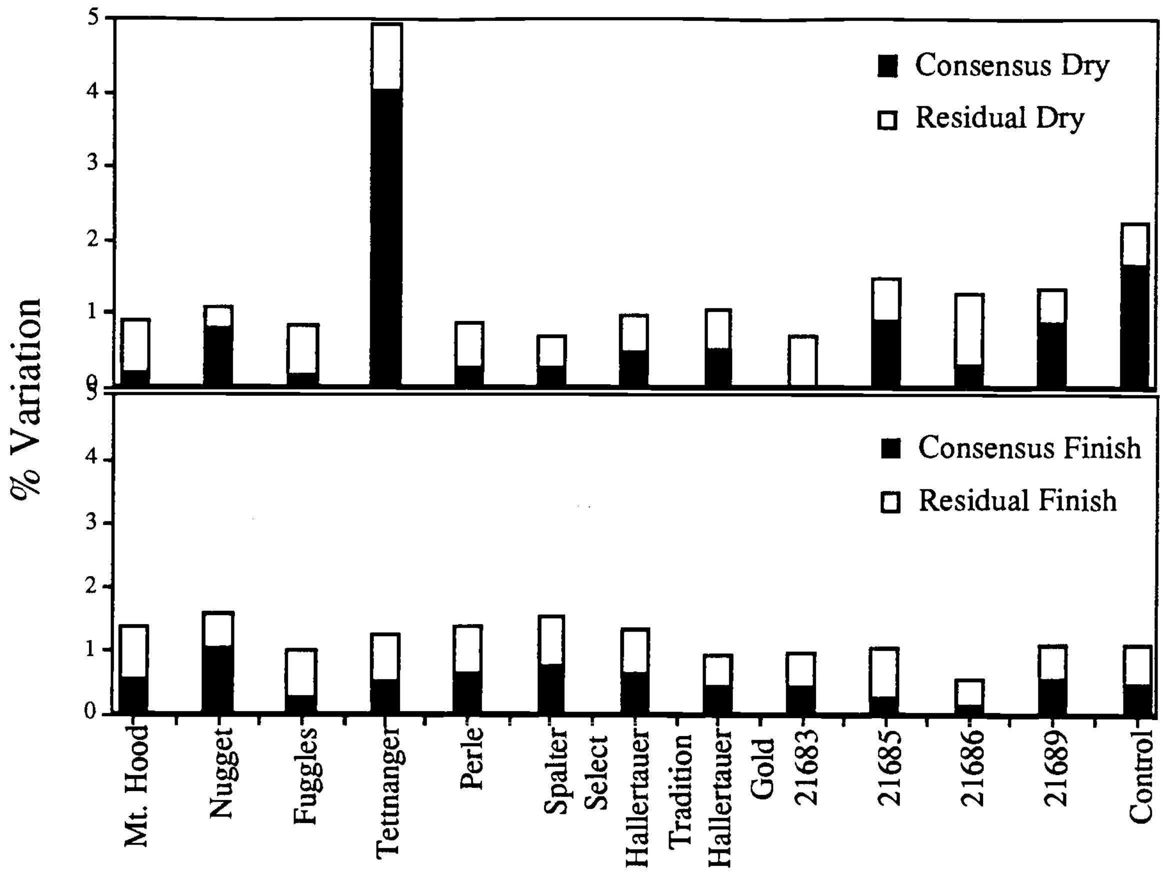

Figure 4-7: Percentages of Consensus and Residual (within) Variation for Trained Panel Free-Choice Profiling of Aroma Characteristics of American Lagers Dry-Hopped and Finish-Hopped with Commercial and Experimental Hop Varieties. The top graph is from dry-hopped lagers. The bottom graph is from finish-hopped lagers.

The amount of consensus between panelists, for the finish-hopped lagers is seen as the bottom graph in Figure 4-7. A high percentage of consensus in relation to the percentage residual indicates greater agreement between the panelists. There was high agreement between panelists for the Nugget variety. The remainder of the varieties had fair to low agreement between panelists. 21686, 21685 and Fuggles had very low agreement between panelists. These results suggest the lagers made with different finish hops had complex aromas which resulted in the generation of a wide variety of descriptors by the panelists. The low agreement between the panelists and the poor performance by panelists 5 and 8 suggest the finish-hopped lagers had very similar aromas which made them more difficult to separate than the dry-hopped lagers. However, even with the slightly poor performance, the panel was still able to significantly separate most of the samples. Which shows a trained free-choice profiling panel would be able to give a good separation of samples by aroma qualities using the free-choice profiling method.

4.5 Conclusion

Trained panel free-choice profiling methodology was highly effective for separating and describing the aroma qualities of lagers. The panelists separated both the dry-hopped and the finish-hopped lagers into three different groups. Fruity, floral, rubbery, and musty were the main aroma qualities by which the samples were separated.

There was a general trend for dry-hopped lagers to have similar aroma qualities to their respective raw hops. This is reasonable since the hops are added after fermentation, so a large amount of the hop oils, which were shown to have high correlation to the aroma qualities of the raw hops, are solubilized in the lager. There was no relationship, that could be applied to all hop varieties, between the aroma qualities of the dry-hopped lagers and the finish-hopped lagers. The brewing process appears to effect the aroma qualities of different hops differently.

Using a trained panel and determining standards and definitions for the descriptors of each panelist allowed for easy interpretation of GPA output. Trained panel free-choice profiling methodology is recommended for future studies where sample groupings and flavor qualities need to be determined.

Further research is necessary to determine how the taste qualities of hop varieties change between dry and finish-hopping, and the chemistry behind the changes in flavor. It is necessary to integrate research on chemical changes during brewing with the sensory characteristics associated with those changes. Since experimental variety 21683 had similar aroma qualities to Hallertauer Gold in both parts of this study and in the raw form, it would be interesting to determine if the taste profiles of these hops are also similar. If the chemical and agricultural characteristics of this variety are promising, then future research is appropriate.

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5. THESIS CONCLUSIONS

This research produced consensus configurations for some commercial and some experimental hop varieties based on their aroma qualities. Separate configurations were produced for the raw hops, dry-hopped lagers and finish-hopped lagers. There was no specific relationship for any of the varieties between the raw hops, dry-hopped lagers, and finish-hopped lagers. However there was a general trend for dry-hopped lagers to have similar aroma qualities to their respective raw hops. It is hypothesized that this is due to a low degree of chemical transformation of the hop oil since the hops were added after heating and after fermentation; two procedures known to change the composition of the hop oil.

Comparing previous research on hop oil chemistry in beer, and results of this study, it appears the aromas of the raw hop are primarily defined by the composition of the hop oil. Since dry-hopping retains the highest amount of oil from the hop, dry-hopped beers will have aromas more similar to the aroma of the raw hop used, than will finish-hopped beers. The more of the original oil compounds (non-transformed by heat or fermentation) the closer the aroma to the raw hop. However, this study showed there were exceptions to this rule. So there are other compounds not present in the oil (or present in the oil but not realized by this study) responsible, at least in part, for the aroma of hops in beer.

The results from each of the three panels showed trained panel free-choice profiling to be well suited for determining the aroma qualities of raw hops and hops in beer. This methodology is recommended for determining if experimental hop varieties have similar aroma qualities to commercial varieties. As well as determining the aroma qualities of other hop varieties.

More research is needed on hop varieties. If a consensus configuration could be made based on the aroma qualities of all commercial hop varieties, it would be a simple matter to determine where a new variety "fits" with all other varieties. Experimental variety 21683 had similar aroma qualities to Hallertauer Gold in all three parts of this study. It would be interesting to determine if the taste profiles of these hops are also similar. Continued research focused on the flavor changes of hop varieties during the brewing process would greatly benefit the brewing industry by allowing brewers to "predict" the flavor qualities in the finished beer.

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