Effects of Bitterness, Roughness, PROP Taster Status, and Fungiform Papillae Density on Bread Acceptance

A DISSERTATION
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA
BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Dr. Zata Vickers
January 2010

ACKNOWLEDGEMENTS

My sincerest thanks to Zata Vickers for her mentorship, guidance, and unwavering support and encouragement throughout my academic journey. I will carry her influence throughout my life and career.

Many thanks to the sensory panelists who participated in my studies.

I wish to also thank Gary Reineccius, Sanford Weisberg, James Anderson, and Len Marquart for providing advice and serving on my examining committee.

I would also like to acknowledge the Sensory Center, the Minnesota Agricultural Experiment Station, and the Joseph J. Warthesen 21st Century Fellowship for funding this research.

Thank you to my parents who inspired me to start this journey and provided gentle encouragement to see it through.

Finally, I would like to thank my husband, John Chilton, whose help, encouragement, and sacrifice went above and beyond. From collating ballots to volunteering to be a guinea pig for papillae counting experimentation, he was always willing to lend a hand (or tongue) when I needed it.

ABSTRACT

Consumption of whole grain foods, including whole wheat bread, has been linked to reduced risk of coronary heart disease, type II diabetes, certain cancers, and all cause mortality, but consumption falls far below recommended levels. Conventional wisdom dictates that refined bread is better liked than whole wheat bread, but support for this contention is scarce. If refined bread is preferred to whole wheat bread, determining the specific attributes or consumer characteristics that contribute to the disliking of whole wheat bread would provide food processors with the knowledge needed to develop technologies to improve the acceptability of whole wheat bread and to test acceptance of these products with consumers. In phase one of this study, we examined consumer preferences for refined and whole wheat breads. In phase two, we examined how two consumer characteristics, sensitivity to 6-*n*-propylthiouracil (PROP) and fungiform papillae density, affected perception of bitterness and roughness, two attributes that may contribute to whole wheat bread dislike. In phase three, we examined how three sensory properties, bitterness, roughness, and color and three consumer characteristics, bread type preference (whole or refined), perceived PROP intensity, and fungiform papillae density, affect bread liking.

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CHAPTER 1

INTRODUCTION

Literature Review

Whole grain benefits and consumption

Consumption of whole grain foods, including whole wheat bread, has been linked to reduced risk of coronary heart disease, type II diabetes, certain cancers, and all-cause mortality (Slavin, 2004). The Dietary Guidelines for Americans recommend consuming three servings of whole grain foods daily (U.S. Department of Health and Human Services, and U.S. Department of Agriculture, 2005). Currently, Americans consume nearly seven servings of grains a day with less than one serving coming from whole grain foods (Cook, and Friday, 2004). One of the most commonly eaten grain sources is bread. Americans consume nearly two servings of refined bread a day, but only 0.3 servings of whole grain bread (Cleveland, 2006). If consumers were to replace those two servings of refined bread with whole wheat bread, the American public would be much closer to meeting the dietary recommendations for whole grain consumption.

Consumer bread preferences

Consumer preference for refined breads is often cited as a reason for the relatively low consumption of whole wheat breads, but few studies have examined taste preferences between refined and whole wheat breads, and the results of those few studies have been inconclusive. Peryam and others (1960), in their examination of food preferences of men in the United States armed forces showed that white bread was preferred to whole wheat bread with scores of 7.7 and 6.8, respectively on a nine point hedonic scale (1= dislike extremely and 9 = like extremely). The survey was repeated eight times between 1950 and 1954 with more than 4,000 men taking the survey at each occasion. Soldiers preferred white bread to 89% of the foods surveyed, while they preferred whole wheat bread to 59% of the other foods surveyed. Taste preferences change over time, so these data may no longer apply to current consumers. The data are also limited to adult males in the US armed forces, so they may not be applicable to more diverse populations.

Vickers and others (1981) measured food preferences in a relatively older consumer population of cancer patients and age-matched controls (40-75 years). Their 205 subjects (controls) significantly preferred whole wheat bread to white bread (scores of 2.5 for whole wheat and 3.0 for white bread on a 9 pt hedonic scale with 1=like extremely and 9=dislike extremely). These data show the opposite trend to that observed by Peryam and others (1960), and like the Peryam study, may only apply to the relatively specific population included in the study at that time.

In a more recent study with children, Berg and others (2000) studied bread choices of 181 children. They asked the children to use pictures to construct three breakfasts: their usual breakfast, a tasty breakfast, and a healthy breakfast. The bread pictures, listed in order of increasing fiber content, included: white bread, a combination rye and white bread, rye bread, and crisp bread. Children's tasty breakfasts contained breads with less fiber than their usual breakfasts, which in turn contained breads with less fiber than their healthy breakfasts. Sixty-eight percent of the breads in the tasty breakfasts were white breads. Although this study included rye breads and not whole wheat breads, it supports the hypothesis that refined white breads are preferred by children.

These three studies suggest that younger consumers may generally prefer white breads to whole wheat breads, while the opposite may be true of older consumers. These three studies were based on responses to questionnaires, however, and not actual taste tests. Questionnaire data often do not predict liking ratings of actual food products when they are tasted (Cardello, and Maller, 1982).

The only taste test that was found in our literature review supported the hypothesis that refined breads are preferred to whole wheat breads. Mialon and others (2002) had 79 Chinese Malaysian and 82 Australian consumers (mean ages of the two ethnic groups were 19.3 and 18.5, respectively) rate their expected liking and actual liking of white and wholemeal breads. Consumers expected to like and actually did like the white bread better than the whole wheat bread. This study tested only one sample of each type of bread, so the results may not generalize to all refined and whole wheat breads. The results also may not apply to consumer preferences in the United States.

The type of wheat used to make both refined and whole wheat breads may also affect liking. Lukow and others (2004) examined whether children preferred whole wheat bread made from a white wheat variety to whole wheat bread made from a red wheat variety. One hundred thirty children rated both their visual and taste preferences between a red whole wheat bread and a white whole wheat bread. To rate visual and taste preference, children rated their liking on a 7 point facial hedonic scale anchored from 'super bad' to 'super good.' Children significantly preferred the appearance and taste of the white whole wheat bread to the red whole wheat bread. Forty five percent preferred the appearance of the white whole wheat bread, 17% preferred the appearance of the red whole wheat bread, while 38% of the children had no visual preference. Forty-eight percent of the children preferred the taste of white whole wheat bread, 27% preferred the red whole wheat bread, while 25% had no taste preference.

Sensory features of whole wheat bread that may contribute to dislike

Why would we like or dislike whole wheat bread? Eertmans and others (2001) divided food likes/dislikes into those that are innate (apparent at birth or universally expressed shortly after birth) and those that are acquired. Known innate likes include sweet, salty and umami tastes. Innate dislikes include bitter and sour tastes as well as strong irritants such as red pepper burn. No evidence exists for innate odor likes or dislikes in humans although several scientists have searched for them. Szczesniak and others (1971) noted that sharp painful textures or textures that were difficult to control tended to be disliked. We are unaware of any studies that specifically examined innate texture likes or dislikes in humans, but we assume that harsher, rougher textures would be innately less well liked. Liking or disliking of attributes other than these few innately liked or disliked ones are acquired. Acquired likes all arise by learning – either due to physiological consequences of consuming a food or evaluative conditioning, the pairing of the food with other liked or disliked stimuli. Examples of evaluative conditioning would be the pairing of food with admired people or fun situations that promotes liking, or the pairing of food with coercion or mealtime unpleasantness that promotes disliking (Eertmans, Baeyens, and Van den Bergh, 2001). In this research we concern ourselves with sensory attributes that may be innately disliked.

If whole wheat breads are less well liked than refined breads, what innately disliked attributes might be contributing to this dislike? Differences between whole wheat bread and refined bread can be traced back to the omission of bran and germ from refined flour. Whole wheat bread has more intense flavors and aromas, is less sweet, wheaty, toasted, and yeasty, and is more bitter, brown, burnt, and grain-like than refined bread (Chang and Chambers, 1992; Murray, Cox, Easton, and Mialon, 2002). The texture of whole wheat bread is more coarse, dense, chewy, and dry, while the aftertaste lasts longer and is more oily and drying. The appearance is darker with more visible grains (Murray, Cox, Easton, and Mialon, 2002). Of these attributes the ones most likely to tap into innate dislikes are the increased bitter taste (an innately disliked sensation), and possibly the coarser, rougher and harsher texture associated with wheat bran. Although innate texture likes/dislikes are unknown, one might expect the slightly painful harsh and rough sensations to be innately disliked.

We are not aware of any research identifying the compounds responsible for bitter taste in whole wheat. Phenolic acids in wheat bran could contribute to increased bitterness of whole wheat bread, because phenolic acids have been associated with bitter tastes in other food products (Mondy and Gosselin, 1988; Busch, Hrncirik, Bulukin, Boucon, and Mascini, 2006; Robichaud, and Noble, 1990). Preparation of breads with different milling fractions of rye revealed that bitter tastes and aftertastes were present in only the bread made with the bran fraction, and the bitterness was concentrated in the outermost bran layers (Heiniö, Liukkonen, Katina, Myllymäki, and Poutanen, 2003). This may or may not be the case for wheat. Wheat germ may also play a role in product bitterness, because both enzymatic and non-enzymatic lipid oxidation in oats have been linked to bitter tastes (Lehtinen, and Laakso, 2004). Jensen and others (personal communication, 2009) failed to find a relationship between free phenolic acid content and off flavor in bread but did find that an increase in lipid oxidation products accompanied an increase in bread off flavor over shelf life.

<u>Taste pathology that may contribute to whole wheat bread dislike</u>

People differ in their abilities to perceive tastes and textures, and these perception differences lead to variable preference. The best-known example is the bitterness perception of compounds like 6-*n*-propylthiouracil (PROP). These compounds taste bitter to people with functional TASR38 receptors (Dinehart, Hayes, Bartoshuk, Lanier, and Duffy, 2006), but have little or no taste to people without these receptors. Subjects are commonly divided into three PROP classification groups: nontasters who perceive little to no bitterness from low concentrations of PROP, medium tasters who perceive moderate bitterness, and supertaster who perceive intense bitterness from low concentrations of PROP. Several researchers have shown that one's ability to perceive PROP affects food preferences (Dinehart, Hayes, Bartoshuk, Lanier, and Duffy, 2006; Drewnowski, Henderson, Hann, Berg, and Ruffin, 2000; Keller, Steinmann, Nurse, and

Tepper, 2002; Keller, and Tepper, 2004; Lanier, Hayes, and Duffy, 2005; Pasquet, Oberti, El Ati, and Hladik, 2002).

Why does the ability to perceive PROP relate to perception of other food tastants? One popular explanation has been that PROP intensity is related to fungiform papillae density which in turn is related to trigeminal innervation. Fungiform papillae are taste structures on the tongue that house both taste cells and mechanoreceptors, and greater densities of fungiform papillae have been linked to increased perception of many sensations (Delwiche, Buletic, and Breslin, 2001; Hayes, and Duffy, 2007; Hayes, Bartoshuk, Kidd, and Duffy, 2008; Hayes, and Duffy, 2008). Several studies confirm that perceived PROP intensity and fungiform papillae density are positively correlated (Bartoshuk, 1994; Delwiche, Buletic, and Breslin, 2001; Essick, Chopra, Guest, and McGlone, 2003; Hayes, Bartoshuk, Kidd, and Duffy, 2008; Miller, and Reedy, 1990), but fungiform papillae density cannot fully predict supertaster status (Hayes, Bartoshuk, Kidd, and Duffy, 2008).

What makes a supertaster? Hayes and others (2008) showed that TAS2R38 genotype and fungiform papillae density provide independent contributions to increased perceived PROP intensity. For the three common TAS2R38 genotypes across the population, PAV homozygotes, AVI homozygotes, and heterzygotes, the researchers demonstrated that individuals who are AVI homozygotes tend to experience the lowest perceived PROP intensities, while PAV homozygotes tend to experience the greatest perceived PROP intensities. For the two homozygote groups, greater fungiform papillae density was related to increased PROP bitterness, but there was no relationship between fungiform papillae density and increased PROP bitterness for heterozygotes. The failure of fungiform papillae density to predict bitterness in heterozygotes may partially be explained by variability in receptor expression. Bufe and others (2005) found that heterozygotes could vary greatly in the amount of mRNA levels produced for each different allele, so some heterozygotes could behave more like PAV homozygotes and others more like AVI homozygotes. This additional source of variability may mute the contribution of fungiform papillae density to PROP bitterness in TAS2R38 heterozygotes. Hayes and others (2008) also found that PROP bitterness was able to predict perceived intensities of sucrose (sweet), citric acid (sour), salt (salty), and quinine (bitter) even when the effects of TAS2R38 genotype and fungiform papillae density were statistically controlled for, which suggests these two factors alone cannot fully explain supertasting phenomena. The researchers hypothesized that the following factors: taste bud density, taste damage, morphological differences in fungiform papillae, differences in central processing, and variable taste gene expression may also contribute to supertasting.

How might PROP taster status and fungiform density affect bread liking? If consumers with higher fungiform papillae density and perceived PROP intensity are more sensitive to unpleasant sensations like bitterness and roughness from whole wheat bread, it might logically follow that they would like these foods less. This relationship has been demonstrated in other food categories. Dinehart and others (2006) conducted a study in which 71 females and 39 males, rated bitterness and liking of three bitter vegetables, asparagus, Brussel sprouts, and kale. Subjects also rated the intensity of different concentrations of PROP and completed food frequency questionnaires to determine vegetable intake. The researchers found that PROP tasters perceived greater bitterness from the tasted vegetables. Increased bitterness from vegetables predicted vegetable dislike, and PROP bitterness was also correlated with lower vegetable consumption. Lanier and others (2005) studied the relationship between PROP bitterness, bitter taste, liking, and consumption in a variety of beverages. Forty-nine undergraduate students rated the bitterness from and their liking for Pilsner beer, blended scotch whiskey, instant espresso, and unsweetened grapefruit juice. Subjects also rated the intensity of PROP and reported the number of servings of alcohol consumed for each day in a typical week. Increased PROP bitterness was associated with increased bitterness ratings for all four beverages. Beverage bitterness was negatively associated with liking, and subjects who reported scotch as least bitter tended to consume more alcohol. In a study of 142 subjects, Zhao and Tepper (2007) showed that supertasters experienced greater bitterness and persistence of sweetness from model soft drinks made with high intensity sweeteners. Supertasters tended to like the persistence of bitterness less than nontasters did, but the effect was not significant.

Both PROP and fungiform papillae density also affect consumer texture perception. Essick and others (2003) measured the spatial resolution acuity of 83 young adult females (52 Asian and 31 Caucasian) by determining the threshold height for recognition of embossed plastic letters through an up-down tracking procedure. Subjects were recruited to ensure equivalent numbers of nontasters, medium tasters, and supertasters. Recognition threshold showed a strong negative correlation with perceived PROP intensity, although the acuity of nontasters tended to be quite variable. Measurements of fungiform papillae density and diameter were determined for the 52 Asian subjects. For these subjects, recognition threshold showed a strong negative correlation with fungiform papillae density and a strong positive correlation with fungiform papillae diameter. They hypothesized that the greater lingual acuity demonstrated by consumers with higher fungiform papillae densities and greater PROP sensitivities would affect both food perception and preference.

Several researchers have demonstrated that perceived PROP intensity and fungiform papillae density are related to perception of a variety of textural attributes. Hayes and Duffy (2007) found that both fungiform papillae density and perceived PROP intensity were positively correlated with creaminess ratings of water, milk, and heavy cream. Pickering and others (2004) showed that supertasters perceived increased astringency in wine. A similar study (Pickering, and Gordon, 2006), failed to show increased astringency perception in wine by supertasters, but did show supertasters perceived greater intensities for the following wine attributes: particulates after expectoration, smoothness after expectoration, grippy/adhesive, and mouthcoating. Tepper and Nurse (1997) showed medium tasters and supertasters were able to discriminate between 40% fat and 10% fat Italian salad dressings, while nontasters were not. Yackinous and Guinard (2001), however, found taster status was not related to perceptions of fattiness in potato chips, chocolate drink, mashed potatoes, and vanilla pudding, but they did find supertasters were more sensitive to stimulation on the medial tongue. De Wijk and others (2007) found greater custard discrimination abilities for supertasters but found inconsistent correlations between taster status and the intensity of ten texture attributes in vanilla custard with no apparent underlying relationship between attributes that were similarly affected by taster status. The failure of the Yackinous and Guinard (2001) and de Wijk and others (2007) to find clear relationships between perceived PROP intensity and texture perception may be explained by their use of 16 or

10 point category scales, respectively, to measure attribute intensities. Bartoshuk and others (2003) showed category scales can mask differences in perception between PROP taster status groups due to differences in meaning of the scale anchors to the separate taster groups.

We are aware of only one study that related fungiform papillae density, PROP taster status, texture perception, and food preference. Hayes and Duffy (2008) modeled optimal liking for milk and sugar mixtures in a group of 79 subjects with low dietary restraint. They found that consumers with greater perceived PROP intensity and higher fungiform papillae densities experienced greater creaminess from and liking for beverages with lower fat content than did consumers with lower perceived PROP intensities and fungiform papillae densities. They postulated that these differences in optimum fat content may have health implications for consumers.

Objectives and hypotheses

The objectives of this research are as follows:

Objective 1. Determine if refined wheat bread is preferred to whole wheat bread.

We hypothesize that consumers prefer refined wheat bread to whole wheat bread.

Objective 2. Determine how consumer differences in fungiform papillae density and PROP sensitivity relate to the ability to detect roughness and to the intensity of both bitterness and roughness in bread.

We hypothesize that consumers with higher fungiform papillae density will better discriminate differences in the roughness of breads, and that they will rate the bitterness and roughness of breads greater than will people with lower fungiform papillae density.

We hypothesize that consumers who are more sensitive to PROP will better discriminate differences in the roughness of breads and will rate the bitterness and roughness of breads higher than will consumers who are less sensitive to PROP.

Objective 3. Determine how bitterness and roughness affect bread liking and whether the effects differ depending on papillae density and PROP sensitivity of the panelist.

We hypothesize that both bitterness and roughness will adversely affect liking of whole wheat bread, and that these effects will be larger for PROP tasters and for people with higher fungiform papillae density.

CHAPTER 2

CONSUMER ACCEPTANCE OF REFINED AND WHOLE WHEAT BREADS

Preference for refined bread is often cited as a reason for the relatively low consumption of whole wheat bread; only a few studies, however, have examined consumer preferences between refined and whole wheat breads, and the results of these studies are inconclusive.

Our objective was to determine if refined wheat bread is preferred to whole wheat bread. We hypothesized that people would prefer refined wheat bread.

We conducted a taste test with 89 people. They rated their liking of nine different breads chosen to represent several comparisons between equivalent refined and whole wheat breads. Subjects also rated the intensity of 6-*n*-propylthiouracil (PROP) and completed a questionnaire about their bread preferences and purchasing habits. We classified subjects by their bread preference and their PROP taster status then examined the liking patterns of these subgroups.

People preferred refined bread to whole wheat bread when both were made using equivalent ingredients and procedures. They liked the commercial samples of refined and whole wheat breads equally well. When people were classified by their bread preference, those who preferred refined bread liked the refined bread better in all comparisons. PROP nontasters liked all refined and whole wheat breads equally.

Sensory preferences are a barrier to whole wheat bread consumption, but ingredient or processing modifications can improve liking of whole wheat bread to the level of refined bread.

Introduction

The goal of this study was to provide several comparisons between comparable refined and whole wheat breads to test the hypothesis that refined breads are better liked than whole wheat breads. We selected breads that provided the following four comparison sets between whole wheat and refined wheat:

1) Refined and whole wheat breads made from hard **red** spring wheat using equivalent ingredients and procedures, plus an additional whole wheat bread that had sodium stearoyl lactylate (SSL) added to achieve the same loaf volume as the refined wheat bread.
2) Refined and whole wheat breads made from hard **white** spring wheat using equivalent ingredients and procedures. In order to reduce the total number of

samples evaluated by the consumer, we did not include a sample of whole white wheat bread with SSL, as we assumed that any differences in liking seen between that sample and the regular whole white wheat sample would be similar to any liking differences between the whole red wheat bread and whole red wheat bread with added SSL.

3) The **top-selling** refined and whole wheat breads in Minneapolis and St. Paul, Minnesota, as determined by AC Nielsen ratings in March, 2005.
4) **Artisan** refined and whole wheat breads.

The first two comparisons provided a fair test between the two bread types; the breads in the third and fourth comparisons represented breads available to consumers. We also examined differences in refined and whole wheat bread liking between consumer groups based on three classifications: bread *preference*, bread *choice*, and PROP taster status.

Materials and Methods

Subjects

Participants from the University of Minnesota campus responded to an email solicitation. Interested individuals were asked whether they preferred whole wheat bread or refined bread. We were interested in the liking patterns of both consumers who preferred whole wheat bread and consumers who preferred refined bread, so we attempted to recruit equal proportions of each type of consumers. We were unable to recruit enough consumers who preferred refined bread, so we invited all the subjects that stated they preferred refined bread and 53% of the other subjects. A total of 89 people participated; 32 preferred refined bread; 57 preferred whole wheat bread. The University of Minnesota Institutional Review Board approved the procedures.

Bread Samples

Breads for the first two comparisons were prepared using AACC International Approved Method 10-10B ‘Optimized Straight-Dough Bread-Baking Method’ (AACC International, 1995). All flour samples were commercially available and provided gratis by Cargill, Inc. (Minneapolis, MN). The amount of water added depended on the flour type and was determined using a mixograph and the procedures outlined in AACC International Approved Method 54-40A (AACC International, 1995).

A model A-200 Hobart mixer (Troy, OH, United States) was used to combine ingredients and knead the dough. Sugar and salt were added to the flour dry, while the yeast was suspended in warm water (43°C) for five minutes prior to addition. The yeast suspension and remaining water were added just prior to mixing.

Optimal mixing time was estimated using a 10g mixograph (National Manufacturing Company, Lincoln, NE, United States) to be 3 minutes for the doughs made from hard red spring refined wheat flour, hard red spring whole wheat flour, and hard white refined wheat flour and 3.5 minutes for hard white whole wheat flour. Actual mixing times fell between 3 and 5 minutes and were determined by ending mixing at the point optimal dough development occurred, which was defined as the point of minimum mobility determined when the dough pulled completely away from the sides of the mixing bowl and visually had lost its rough, lumpy, wet appearance and instead appeared smooth, satiny, and not sticky (AACC International, 1995; Finney, 1984). The dough batches ranged in temperature from 30-32°C after mixing.

Each dough batch was scaled into five, 1 kg portions that were rounded and placed in bowls in a fermentation cabinet (National Manufacturing Company, Lincoln, NE, United States) at 30°C, 75% relative humidity and fermented for a total of 123 minutes. The first dough punch occurred after 52 minutes and the second after an additional 25 minutes. Molding and panning were performed after an additional 13 minutes. The final proof lasted 33 minutes. Punching and molding were done by hand. During punching, the dough was rolled out once in one direction and then rolled once again at a 90° angle to the first direction. Then it was turned over, folded end over end, and placed seam side down. During molding, the dough was rolled out again in the same manner, and then rolled up and placed seam side down in a baking pan that had been lightly greased with Crisco© shortening. After the final proof, the dough was baked for 24 minutes at 218.3°C in a revolving reel oven (Despatch, Minneapolis, MN, United States). The breads cooled completely before being sealed into polyethylene bread bags for storage. The breads were stored for approximately 18-20 hours before slicing.

Breads for the top selling and the artisan comparisons were purchased within 24 hours of tasting. The artisan breads had been baked the morning of purchase. The top-selling breads were likely delivered to the store the day of purchase, but may have sat on the shelf for up to 5 days prior to purchase.

About 3-8 hours before tasting, breads were cut into ½" slices. Each slice was then cut in half vertically, so that each half contained portions of both top and bottom crust. The half slices were then placed in small Ziploc© bags coded with three digit numbers. Full ingredient listings for each bread are provided in Table 1.

Table 1 Full ingredient listing and formulations, where known, for the nine breads included in the four comparison sets

Comparison	Bread	Bread Type	Ingredients	Proportion (%)
1. Refined and whole wheat breads made from **red** wheat using equivalent methods and ingredients.	Refined red wheat	Refined	Refined hard red spring wheat flour (13.1% protein, 13.7% moisture, 0.50% ash)	58.3
			Water	35.6
			Crystal® sugar	3.50
			Red Star® yeast	1.75
			Morton® salt	0.875
	Whole red wheat	Whole Wheat	Whole hard red spring wheat flour (14.6% protein, 12% moisture, 1.7% ash)	55.1
			Water	39.1
			Crystal® sugar	3.31
			Red Star® yeast	1.65
			Morton® salt	0.826
	Whole red wheat + sodium stearoyl lactylate (SSL)	Whole Wheat	Whole hard red spring wheat flour	54.8
			Water	38.9
			Crystal® sugar	3.29
			Red Star® yeast	1.64
			Morton® salt	0.821
			SSL	0.548
2. Refined and whole wheat breads made from **white** wheat using equivalent methods and ingredients.	Refined white wheat	Refined	Refined white wheat flour (12.2%, 14.5% moisture, 0.53%)	58.7
			Water	35.2
			Crystal® sugar	3.52
			Red Star® yeast	1.76
			Morton® salt	0.880
	Refined whole wheat	Whole Wheat	Whole white wheat flour (13.6% protein, 10.4% moisture, 1.7% ash)	56.0
			Water	38.1
			Crystal® sugar	3.36
			Red Star® yeast	1.68
			Morton® salt	0.840
3. **Top-selling** refined and whole wheat breads.	Country Hearth® Kids Choice	Refined	Enriched white flour, water, high fructose corn syrup, bleached oat fiber, yeast, sugar, vital wheat gluten, less than 2% white rye flour, calcium sulfate, liquid soybean oil, salt, calcium carbonate, dough conditioner, calcium propionate.	Unavailable
	Sara Lee® 100% Whole Wheat	Whole Wheat	Whole wheat flour, water, high fructose corn syrup, wheat gluten, yeast, less than 2% salt, soybean or cottonseed oil, brown sugar, vinegar, honey, wheat bran, soy lecithin, yeast nutrients, cornstarch, dough conditioners (may contain one or more of the following: mono and diglycerides, ethoxylated mono and diglycerides)calcium propionate.	Unavailable
4. **Artisan** refined and whole wheat breads.	Breadsmith® Country White	Refined	Refined white flour, water, sugar, margarine, eggs, salt, yeast.	Unavailable
	Breadsmith® 100% Whole Wheat, Whole grain	Whole Wheat	Whole wheat flour, water, honey, salt, yeast, wheat gluten.	Unavailable

Procedure for Sensory Test

Upon arrival at the testing location, subjects presented the label or a list of the first five ingredients of the bread they most commonly chose to eat to a greeter trained to classify the bread as 100% whole grain, 100% refined, or as a bread made from a mixture of refined and whole grain flours. The greeter then presented the subject with a slip of paper with an appropriate letter designation based on the bread information. The subject then handed this paper to the test attendant, signed a consent form, and indicated whether they wanted their samples served with butter, margarine, or nothing. The subjects were then allowed to taste the samples plain or with butter or margarine. If butter or margarine were used, subjects were asked to use approximately the same amount with each sample. Forty-four subjects used butter, nine used margarine, and 34 used no spread, two subjects did not provide this information.

In order to familiarize participants with the labeled affective magnitude (LAM) scale, subjects first used the scale to rate their liking of 13 disparate items, commonly liked and disliked foods and situations. Subjects then tasted each of the nine bread samples and rated their overall liking, flavor liking, texture liking, and appearance liking on LAM scales 120 mm in length (Schutz, and Cardello, 2001). The samples were presented in a balanced order according to a William's Latin Square design (MacFie, Bratchell, Greenhoff, and Vallis, 1989). Subjects first removed the samples from the bags to rate their liking of the appearance; then they tasted the samples to rate overall liking, flavor liking, and texture liking.

We evaluated subjects' perceived intensity of PROP using a general labeled magnitude scale 120 mm in length. Subjects first acclimated to the scale by using it to rate 17 sensations with varying intensity and modality. A subset of these sensations included: the brightness of the sun, the loudness of a whisper, and the oral burn of a carbonated beverage. Subjects then received a 10 ml sample of 3.2 mM PROP and were asked to swirl the entire sample in their mouth, expectorate it, and rate its intensity.
The subjects' final task was to complete a brief questionnaire in which they indicated their preference for either refined bread or whole wheat bread, selected reasons for their preference from a list (taste, smell, texture, nutrition, price, convenience, freshness, and

familiarity) and rated their liking of the best and the worst whole wheat and refined breads they had ever eaten.

Data Analysis

All data were compiled using SIMS® 2000 and analyzed using SAS® statistical software (version 9.1). A 0.05 alpha level was used for all statistical tests.

Subjects were classified into three different bread *choice* categories: refined, 100% whole grain, and mixed, based on the bread label or list of ingredients they brought to the testing session. If the bread contained only refined flours, the subject's bread choice was categorized as refined. If the bread contained only whole grain flours, the bread choice was categorized as whole grain. If the ingredients listed both refined and whole grain flours, the choice was classified as mixed.

We classified each subject as having a *preference* for refined or whole wheat bread using the following criteria: subjects who responded that they preferred a certain type of bread, refined or whole wheat, and gave an organoleptic reason for this preference, i.e. taste, smell, texture, etc. were classified as preferring this particular bread type. To classify subjects who did not state organoleptic qualities as reasons for their bread preference, we analyzed their liking scores for the best refined and whole wheat breads they had ever tasted. Subjects who rated the best refined bread more than 10 points higher than the best whole wheat bread were classified as preferring refined bread. Subjects who rated the best whole wheat bread more than 10 points higher than the best refined bread were classified as preferring whole wheat bread. Subjects who did not differ in their ratings of the best whole wheat bread and best refined bread by more than 10 points and did not give organoleptic reasons for their stated bread preference, were then classified according to what type of bread they most commonly chose to eat. Subjects who chose refined bread were classified as preferring refined bread and subjects who chose whole wheat bread were classified as preferring whole wheat bread. All subjects who chose mixed breads were classified by one of the preceding criterion.

Each subject's rating of the intensity of the 3.2 mM PROP sample was divided by the quotient of their rating of the brightness of the sun and the average rating for the brightness of the sun for all subjects (Porubcan and Vickers 2005). If this value fell below

13.0, the subject was classified as a PROP nontaster. If the value was above 72.3, the subject was classified as a PROP supertaster. If the value fell between 13.0 and 72.3, the subject was classified as a PROP medium taster.

To determine if refined breads were better liked than whole wheat breads, analyses of variance (ANOVA) using the PROC MIXED command were used. The model (liking rating = subject (random effect) + bread) was used to examine liking differences among all 9 bread samples for the panel as a whole. We also tested the following contrasts: 1) all refined bread samples vs. all whole wheat bread samples, 2) all laboratory refined bread samples vs. all laboratory whole wheat samples and 3) artisan and top-selling refined bread samples vs. artisan and top-selling whole wheat samples. Differences in liking of the bread samples among the subject classifications [bread *preference* (refined or whole wheat), bread *choice* (refined, mixed, or whole wheat), and taster status (nontaster, medium taster, or supertaster)] were determined using the following model (liking rating = subject (random effect nested in preference / choice / taster status) + bread sample + preference / choice / taster status + interaction (bread sample by preference / choice / taster status)). Serving order, spread type, and the interactions of serving order and bread and spread type and bread were originally included in the model but were never significant, so they were removed. We used the PDIFF statement to compute *t*-tests on the least square means for all pairwise comparisons.

Results

Of the 89 subjects, 32 preferred refined bread and 57 preferred whole wheat; 26 regularly chose refined bread, 22 chose whole grain, 39 chose mixed, and two provided no information; 16 were classified as PROP nontasters, 52 as medium tasters, and 21 as supertasters.

On average, refined breads were better liked than whole wheat breads for the panel as a whole ($F_{\text{all refined breads vs. all whole wheat breads}} = 6.7$, $p = 0.01$) (Table 2). This greater liking was primarily due to the comparisons between the laboratory produced breads. Refined breads were better liked in the comparisons with equivalent ingredients and processing steps ($F_{\text{all laboratory refined vs. all laboratory whole wheat}} = 44$, $p < 0.0001$). The panel liked the refined and whole wheat top-selling and artisan breads equally ($F_{\text{artisan and top-selling refined vs. artisan and top-selling whole wheat}} = 0.25$, $p = 0.62$). Consumers' bread *preference*, bread *choice*, and taster status affected their relative liking scores.

The following subsections are specific to each bread comparison (red wheat, white wheat, top-selling, and artisan). Within each section, the results of contrasts within each grouping (*preference*, *choice*, and PROP taster status) are reported. Significant differences, based on an alpha = 0.05 cutoff level, in overall liking for each of these contrasts are reported. In general the ratings for the flavor, texture, and appearance liking showed similar patterns to the overall liking ratings; therefore, those results will only be reported if they differ from the pattern of the overall liking results. Mean difference scores and statistics are presented in Tables 3, 4, and 5.

Table 2

Average liking ratings (standard errors) over all 89 subjects for the 9 bread samples broken into the 4 comparison sets described in the introduction. Ratings are on a 120 point labeled affective magnitude scale where 120 = greatest like imaginable, 60 = neutral, and 0 = greatest dislike imaginable.

Bread	**Overall Liking**	**Flavor Liking**	**Texture Liking**	**Appearance Liking**
Hard **red** spring wheat				
Red Refined	$77^{a,b}$ (1.8)	75^{b} (2.0)	77^{a} (1.8)	78^{a} (1.7)
Red Whole Wheat	63^{d} (2.2)	60^{c} (2.3)	64^{c} (2.6)	$74^{a,b,c}$ (2.1)
Red Whole Wheat + SSL	62^{d} (2.1)	58^{c} (2.3)	67^{c} (2.1)	$76^{a,b}$ (1.8)
Hard **white** spring wheat				
White Refined	73^{b} (1.9)	72^{b} (1.9)	$74^{a,b}$ (2.2)	77^{a} (1.6)
White Whole Wheat	64^{d} (2.2)	60^{c} (2.2)	66^{c} (2.3)	$70^{c,d}$ (2.0)
Top selling breads				
Kids Choice (refined)	70^{c} (2.1)	70^{b} (2.1)	66^{c} (2.5)	67^{d} (1.9)
Sara Lee Classic 100% Whole Wheat	69^{c} (1.7)	70^{b} (1.8)	$70^{b,c}$ (2.0)	$73^{a,b,c}$ (1.7)
Artisan				
Breadsmith Country White (refined)	80^{a} (1.5)	81^{a} (1.6)	78^{a} (1.6)	$74^{a,b,c}$ (1.5)
Breadsmith 100% whole grain, whole wheat	82^{a} (2.2)	82^{a} (2.5)	76^{a} (2.6)	$71^{b,c,d}$ (2.4)

[a,b,c,d] Values within a column that share letter designations do not significantly differ in liking ($p > 0.05$).

Table 3

Differences in liking and their significance within each consumer preference group for the 4 comparison sets described in the introduction. We classified each subject as having a *preference* for refined or whole wheat bread using the following criteria: subjects who responded that they preferred a certain type of bread, refined or whole wheat, and gave an organoleptic reason for this preference, i.e. taste, smell, texture, etc. were classified as preferring this particular bread type. To classify subjects who did not state organoleptic qualities as reasons for their bread preference, we analyzed their liking scores for the best whole wheat and refined breads they had ever tasted. Subjects who rated the best refined bread more than 10 points higher than the best whole wheat bread were classified as preferring refined bread. Subjects who rated the best whole wheat bread more than 10 points higher than the best refined bread were classified as preferring whole wheat bread. Subjects who did not differ in their ratings of the best whole wheat bread and best refined bread by more than 10 points and did not give organoleptic reasons for their stated bread preference, were then classified according to what type of bread they most commonly chose to eat. Subjects who chose refined bread were classified as preferring refined bread and subjects who chose whole wheat bread were classified as preferring whole wheat bread. All subjects who chose mixed breads were classified by one of the preceding criterion. Liking ratings are on a 120 point labeled affective magnitude scale where 120 = greatest like imaginable, 60 = neutral, and 0 = greatest dislike imaginable.

Comparison set	***Preference* Group**	**Difference in Overall Liking Ratings[a] (std error of the difference)**	**Difference in Flavor Liking Ratings**	**Difference in Texture Liking Ratings**	**Difference in Appearance Liking Ratings**
Red refined vs. whole red wheat	Refined	26* (4.5)	23* (4.8)	25* (5.1)	23* (4.0)
	Whole wheat	7.2* (3.4)	9.5* (3.6)	5.1 (3.8)	-6.3* (3.0)
Red refined vs. whole red wheat + SSL	Refined	23* (4.5)	29* (4.8)	19* (5.1)	18* (4.0)
	Whole wheat	9.9* (3.4)	10.1* (3.6)	4.0 (3.8)	-6.2* (3.0)
White refined vs. white whole wheat	Refined	17* (4.5)	20* (4.8)	15* (5)	20* (4.0)
	Whole wheat	5.0 (3.4)	8.5* (3.6)	4.0 (3.8)	-0.18 (3.0)
Top-selling refined vs. top-selling whole wheat	Refined	9.9* (4.5)	11* (4.8)	0.07 (5.5)	2.9 (4.0)
	Whole wheat	-5.1 (3.4)	-6.8 (3.6)	-5.8 (3.8)	-18* (3.0)
Artisan refined vs. artisan whole wheat	Refined	12* (4.5)	13* (4.8)	19* (5.0)	24* (4.0)
	Whole wheat	-10* (3.4)	-9.5* (3.6)	-8.2* (3.8)	-8.9* (3.0)

[a] Difference in liking ratings is the rating for the first listed bread minus the rating of the second listed bread. E.g. for the comparison 'Red refined vs. whole red wheat' the difference is (red refined – red whole wheat).

* Values marked by an asterisk are significantly greater or less than zero ($p < 0.05$).

Table 4

Differences in liking and their significance within each consumer *choice* group for the 4 comparison sets described in the introduction. Subjects were classified into three different bread *choice* categories: refined, 100% whole grain, and mixed, based on the bread label or list of ingredients they brought to the testing session. If the bread contained only refined flours, the subject's bread choice was categorized as refined. If the bread contained only whole grain flours, the bread choice was categorized as whole grain. If the ingredients listed both refined and whole grain flours, the choice was classified as mixed. Liking ratings are on a 120 point labeled affective magnitude scale where 120 = greatest like imaginable, 60 = neutral, and 0 = greatest dislike imaginable.

Comparison Set	*Choice* Group	Difference in Overall Liking Ratings[a] (std error of the difference)	Difference in Flavor Liking Ratings	Difference in Texture Liking Ratings	Difference in Appearance Liking Ratings
Red refined vs. whole red wheat	Refined	23* (5.1)	19* (5.4)	22* (5.8)	22* (4.7)
	Mixed	11* (4.2)	13* (4.4)	6.3 (4.7)	-2.8 (3.8)
	Whole	7.3 (5.6)	11 (5.9)	9.8 (6.3)	-5.8 (5.1)
Red refined vs. whole red wheat + SSL	Refined	23* (5.1)	28* (5.4)	20* (5.8)	18* (4.7)
	Mixed	13* (4.2)	15* (4.5)	4.6 (4.7)	-2.8 (3.9)
	Whole	9.5 (5.6)	7.6 (5.9)	6.3 (6.3)	-6.6 (5.1)
White refined vs. white whole wheat	Refined	16* (5.1)	20* (5.4)	12* (5.8)	16* (4.7)
	Mixed	7.1 (4.2)	9.0* (4.4)	4.7 (4.7)	4.1 (3.8)
	Whole	7.0 (5.6)	10 (5.9)	9.4 (6.3)	0.52 (5.1)
Top-selling refined vs. top-selling whole wheat	Refined	13* (5.1)	15* (5.4)	2.3 (5.8)	6.1 (4.7)
	Mixed	-2.3 (4.2)	-5.8 (4.4)	-5.5 (4.7)	-10* (3.8)
	Whole	-9.8 (5.6)	-7.3 (5.9)	-7.9 (6.3)	-13* (5.1)
Artisan refined vs. artisan whole wheat	Refined	10* (5.1)	11* (5.4)	15* (5.8)	21* (4.7)
	Mixed	-6.6 (4.2)	-5.7 (4.4)	-3.3 (4.7)	-4.7 (3.8)
	Whole	-11.1* (5.6)	-9.8 (5.9)	-8.4 (6.3)	-7.2 (5.1)

[a] Difference in liking ratings is the rating for the first listed bread minus the rating of the second listed bread. E.g. for the comparison 'Red refined vs. whole red wheat' the difference is (red refined – red whole wheat).

* Values marked by an asterisk are significantly greater or less than zero ($p < 0.05$).

Table 5

Differences in liking and their significance within each consumer taster status group for the 4 comparison sets described in the introduction. To determine taster status, subjects rated the intensity of 3.2 mM PROP, and each subject's intensity rating of the sample was divided by the quotient of their rating of the brightness of the sun and the average rating for the brightness of the sun for all subjects. If this value fell below 13.0, the subject was classified as a PROP nontaster. If the value was above 72.3, the subject was classified as a PROP supertaster. If the value fell between 13.0 and 72.3, the subject was classified as a PROP medium taster. Liking ratings are on a 120 point labeled affective magnitude scale where 120 = greatest like imaginable, 60 = neutral, and 0 = greatest dislike imaginable.

Comparison Sets	Taster status	Difference in Overall Liking Ratings[a] (std error of the difference)	Difference in Flavor Liking Ratings	Difference in Texture Liking Ratings	Difference in Appearance Liking Ratings
Red refined vs. whole red wheat	Nontaster	6.3 (6.3)	10 (6.7)	0.93 (7.1)	-5.1 (6.0)
	Medium	12* (3.7)	13* (3.9)	11.6* (4.1)	4.2 (3.5)
	Supertaster	25* (5.7)	21* (6.0)	22* (6.4)	12* (5.4)
Red refined vs. whole red wheat + SSL	Nontaster	9.2 (6.3)	11 (6.7)	3.8 (7.1)	-0.77 (6.0)
	Medium	15* (3.7)	16* (3.9)	11* (4.1)	2.7 (3.5)
	Supertaster	18* (5.7)	22* (6.0)	9.5 (6.4)	5.0 (5.4)
White refined vs. white whole wheat	Nontaster	-0.024 (6.3)	0.73 (6.7)	4.7 (7.1)	-2.4 (6.0)
	Medium	11* (3.7)	16* (3.9)	9.4* (4.1)	6.6* (3.5)
	Supertaster	14* (5.7)	15* (6.0)	7.5 (6.4)	16* (5.4)
Top-selling refined vs. top-selling whole wheat	Nontaster	-2.1 (6.4)	-0.29 (6.7)	-6.7 (7.1)	-4.1 (6.0)
	Medium	0.36 (3.7)	-2.1 (3.9)	-2.8 (4.1)	-9.3* (3.5)
	Supertaster	2.5 (5.7)	3.9 (6.0)	-3.3 (6.4)	0.53 (5.4)
Artisan refined vs. artisan whole wheat	Nontaster	-1.6 (6.3)	-2.3 (6.7)	3.3 (7.1)	0.52 (6.0)
	Medium	-5.8 (3.7)	-4.5 (3.9)	-1.6 (4.1)	-0.28 (3.5)
	Supertaster	5.5 (5.7)	7.3 (6.0)	7.9 (6.4)	12* (5.4)

[a] Difference in liking ratings is the rating for the first listed bread minus the rating of the second listed bread. E.g. for the comparison 'Red refined vs. whole red wheat' the difference is (red refined – red whole wheat).

* Values marked by an asterisk are significantly greater or less than zero ($p < 0.05$).

Laboratory Red Wheat Breads

Subjects with a refined bread *preference* liked the refined red wheat bread better than both versions of the whole red wheat bread (Table 3). Subjects with a whole wheat bread *preference* also liked the refined red wheat bread better than both versions of the whole red wheat bread (Table 3). Subjects with a whole wheat bread *preference* liked the appearance of both versions of the whole red wheat bread better than the appearance of the refined red wheat bread (Table 3).

Subjects who regularly *chose* refined bread or mixed bread liked the refined red wheat bread better than both versions of the whole red wheat bread (Table 4). Subjects who regularly *chose* mixed breads liked the appearance of the breads equally well (Table 4). Subjects who regularly *chose* whole grain bread liked all three breads equally well (Table 4).

PROP nontasters liked all nine bread samples equally well (Table 5). Both medium tasters and supertasters liked the refined red wheat bread better than both versions of the whole red wheat bread (Table 5). Supertasters were the only group to like the texture of the whole red wheat bread with added SSL better than the texture of the regular whole red wheat bread ($t = 2.0$, $p = 0.05$). In all other comparisons for all liking measures the whole red wheat bread and whole red wheat bread with SSL were liked equally well ($p > 0.22$).

Laboratory White Wheat Breads

Subjects with a refined bread *preference* liked the refined white wheat bread better than the whole white wheat bread (Table 3). Subjects with a whole wheat bread *preference* like the two breads equally well, but they did rate the flavor of the refined white wheat bread better than the flavor of whole white wheat bread (Table 3).

Subjects who regularly *chose* refined bread liked the refined white wheat bread better than the whole white wheat bread (Table 4). Subjects who regularly *chose* mixed or whole grain bread liked the refined white wheat bread and the whole white wheat bread equally well (Table 4). Subjects who *chose* mixed grain bread liked the flavor of the refined white wheat bread better than the flavor of the whole white wheat bread (Table 4).

Medium tasters and supertasters liked the refined white wheat bread better than the whole white wheat bread (Table 5).

Top-Selling Breads

Subjects with a refined bread *preference* liked the top-selling refined bread (Kids Choice) better than the top-selling whole wheat bread (Sara Lee) (Table 3). Subjects with a whole wheat bread *preference* liked these two breads equally well, but they rated the appearance of the top-selling whole wheat bread better than the appearance of the top-selling refined bread (Table 3).

Subjects who regularly *chose* refined bread liked top-selling refined bread better than the top-selling whole wheat bread (Table 4). Subjects who regularly *chose* mixed bread and whole grain bread liked the breads equally well; however, both of these *choice* groups (mixed and whole grain) rated the appearance of the top-selling whole wheat bread better than the appearance of the top-selling refined bread (Table 4).

Medium tasters rated the appearance of the top-selling whole wheat bread better than the appearance of the top-selling refined bread, otherwise the taster groups did not differ in their ratings of these breads (Table 5).

Artisan Breads

Subjects with a refined bread *preference* liked the artisan refined bread better than the artisan whole wheat bread (Table 3). Subjects with a whole wheat bread *preference* liked the artisan whole wheat bread more than the artisan refined bread (Table 3).

Subjects who regularly *chose* refined bread liked the artisan refined bread better than the artisan whole wheat bread (Table 4). Subjects who regularly *chose* mixed bread or whole grain bread liked the two samples equally well (Table 4).

Supertasters liked the appearance of artisan refined bread better than the appearance of the artisan whole wheat bread, otherwise the taster groups did not differ in their ratings of these two breads (Table 5).

Questionnaire

Taste was the most commonly cited reason for *preferring* one type of bread (either whole wheat or refined) (Table 6). Other commonly cited reasons were texture and nutrition. Fewer subjects cited smell and familiarity. Nutrition was cited more frequently by subjects with a whole wheat bread *preference* than by subjects with a refined bread *preference*. Price and familiarity were cited more frequently by those subjects with a refined bread *preference* than by those with a whole wheat bread *preference*. Seventy-five percent of the subjects with a refined bread *preference* also *chose* to consume refined bread most frequently, but only one-third of subjects with whole wheat bread *preference* chose to consume whole wheat bread most frequently (data not shown).

Table 6

The percentage of subjects who cited a particular reason for their stated preference between refined and whole wheat bread. Chi-square and p values represent the comparison between subjects with a refined bread *preference* and subjects with a whole wheat bread *preference*.

Reason for Bread Preference	**Percentage of subjects who cited this reason**		**Chi-square value**	**p-value**
	Prefer refined	*Prefer* whole wheat		
Taste	73	82	0.76	0.41
Texture	60	70	0.93	0.47
Nutrition	13	94	56	<0.0001
Smell	30	35	0.23	0.81
Familiarity	47	13	12	0.001
Price	20	4	5.9	0.02
Freshness	7	7	0.016	1.0
Convenience	10	2	2.8	0.13

Discussion

Bitterness may be a sensory barrier to whole wheat bread acceptance. Nontasters and medium tasters liked the laboratory red and white whole wheat breads better than the supertasters liked these breads ($t_{\text{supertasters vs. nontasters}} = -3.2$, $p = 0.001$) ($t_{\text{supertasters vs. medium tasters}} = -2.7$, $p = 0.008$), which may be attributed to a number of factors. One contributing factor could be supertasters' enhanced bitterness perception. Although, we did not measure bread bitterness in our study, previous research has shown both that supertasters experience greater bitterness from foods (Dinehart, Hayes, Bartoshuk, Lanier, and Duffy, 2006) and that whole wheat breads are more bitter than their refined counterparts (Chang, and Chambers, 1992). The presence of wheat bran, which contains high levels of phenolic acids, could contribute to increased bitterness in whole wheat bread, as phenolic acids have been associated with bitter tastes in other food products (Busch, Hrncirik, Bulukin, Boucon, and Mascini, 2006; Mondy, and Gosselin, 1988; Robichaud, and Noble, 1990). Preparation of breads with different milling fractions of rye revealed that bitter tastes and aftertastes were present only in breads that included bran fractions and the bitterness was concentrated in the outermost bran layers (Heiniö, Liukkonen, Katina, Myllymäki, and Poutanen, 2003). This may or may not be the case for wheat. The presence of wheat germ may also play a role in product bitterness, as both enzymatic and non-enzymatic lipid oxidation in oats have been linked to bitter tastes (Lehtinen, and Laakso, 2004).

The addition of SSL to whole wheat bread did not improve its liking with the exception that supertasters liked the texture of the whole wheat bread with added SSL better than the texture of the regular whole wheat bread. The SSL produced a less dense, less rough, and softer bread. Essick and others (2003) found that supertasters, on average, had higher densities of fungiform papillae, which were related to greater lingual acuity. These differences in fungiform papillae density and lingual acuity may affect food preferences. Supertasters and other people with high papillae densities may sense rough textures more intensely and like them less.

The top-selling and artisan whole wheat breads were better liked than the laboratory whole wheat breads indicating that bakers and food manufacturers have already found ways to increase consumer acceptability of whole wheat breads. Both the top-selling whole wheat bread and the artisan whole wheat bread contained approximately 2 grams of sugar per slice, which would both add sweetness and suppress bitterness in the breads. The dough for the laboratory whole wheat breads contained the equivalent of 2 grams of sugar per slice prior to fermentation, so the actual amount of sugar in the bread was likely much smaller. The artisan whole wheat bread also contained wheat gluten and the top-selling whole wheat bread contained both wheat gluten and dough conditioners that can increase specific loaf volume and soften texture.

Many subjects with a whole wheat bread *preference* did not actually choose to consume whole wheat bread. Sales of the top-selling refined bread vastly exceed those of the top-selling whole wheat bread (U.S. Census Bureau, 2002), so it is likely that consumers who like both refined and whole wheat breads equally well are still choosing to buy and consume refined wheat bread despite the nutritional superiority of the whole wheat bread. This represents a missed opportunity to incorporate whole grain breads into the diet. This disconnect may be explained by the nearly universal appeal of refined bread. Individuals or institutions may serve only refined bread products because nearly all consumers will accept the product, whereas whole wheat bread products will be disliked by some. The food dislikes of a minority of consumers may dictate the eating behavior of the rest. Other reasons for this disconnect could be that whole wheat breads are less available, perceived as more expensive, and consumers have a difficult time identifying whole grains (Burgess-Champoux, Marquart, Vickers, and Reicks, 2006; Chase, Reicks, Smith, Henry, and Reimer, 2003; Kantor, Variyam, Allshouse, Putnam, and Lin, 2001).

CHAPTER 3

RELATIONSHIPS BETWEEN FUNGIFORM PAPILLAE DENSITY, PROP SENSITIVITY, AND BREAD ROUGHNESS PERCEPTION

The purpose of this study was to determine if fungiform papillae density and 6-*n*-propylthiouracil (PROP) sensitivity were correlated with bread roughness intensity and discrimination. We hypothesized individuals more sensitive to PROP and with higher fungiform papillae densities would perceive enhanced bread roughness and would have better roughness discrimination abilities. Thirty-seven panelists rated the roughness of bread samples that had been differentially staled to manipulate roughness. Panelists also rated bitterness and sweetness intensities. The samples included series of 100% whole wheat and 100% refined wheat breads that had been staled for 0-5 days. We measured each subject's fungiform papillae density and perceived PROP intensity. Contrary to our hypothesis, panelists with greater papillae densities did not perceive greater roughness intensities and were not better at discriminating roughness differences. Panelists who perceived greater PROP intensity, however, perceived greater roughness, bitterness, and sweetness intensities and were better able to discriminate roughness differences.

Introduction

In this study, we tested the hypothesis that individuals who experience PROP more intensely and have greater fungiform papillae densities experience increased roughness from bread and are also be better able to discriminate differences in bread roughness. We also measured bread sweetness and bitterness, since these attributes are known to vary with both perceived PROP intensity and fungiform papillae density.

Materials and Methods

Panelists

Thirty-seven panelists (29 female, aged 19 to 60, mean age 38) participated in the study. All panelists were students or staff on the University of Minnesota campus and were chosen based on their interest and availability as determined by email solicitation. The University of Minnesota Institutional Review Board approved all procedures of the study.

Samples

Bread samples included 100% whole wheat and 100% refined wheat breads that had been aged for zero, one, three or five days (eight samples in total). All breads were purchased at Breadsmith® bakery at approximately the same time of day. Breads that were aged for more than one day were refrigerated until the day of testing to maximize staling and minimize microbial growth. All breads were sliced upon purchase and stored in sealed polyethylene bags. The day of the test, individual bread slices were further sliced both vertically and horizontally creating one-fourth slices. Each one-fourth slice was immediately sealed in a zippered plastic bag (Target Corporation, Minneapolis, MN) coded with a three digit number.

Testing Procedure

Panelists were seated in individual booths and provided informed consent prior to participation. They then received a tray containing all eight samples. Samples were presented in balanced order according to a Williams' Latin Square design (MacFie, Bratchell, Greenhoff, and Vallis, 1989). Panelists were first acclimated to the general labeled magnitude (gLM) scale, a semi-logarithmic scale anchored at “no sensation on the left” and “greatest imaginable sensation” on the right, by using it to rate 17 sensations with varying intensity and modality. A subset of these sensations included: the brightness of the sun, the loudness of a whisper, and the oral burn of a carbonated beverage. Panelists rated each sample's roughness, sweetness, and bitterness intensity on 120 mm gLM scales. They were instructed to take a large bite of the bread sample (avoiding the crust), to use their tongue to touch the bread to the roof of their mouth, and to then immediately rate how rough the sample felt. They were then instructed to chew, swallow, and rate the sample's sweetness and bitterness.

Panelists then received a 10 ml sample of 3.2 mM PROP and were asked to swirl the entire sample in their mouth, expectorate it, and rate its intensity on a 120 mm gLM scale.

To measure panelists' fungiform papillae densities, their tongues were stained with FD&C Blue #1 neon food coloring (McCormick & Co, Inc., Hunt Valley, MD) and placed between two plastic microscope slides that were fastened together with three screws, one on either end and another at the center front. Panelists were asked to touch the tip of their tongue to the center front screw to keep placement consistent. The slide device was mounted on a flat surface under a Sony Cybershot® DSC-P200 digital camera (Sony Electronics Inc., San Diego, CA) stabilized on a tripod. Several photos of the tongue were taken in a brightly lit room using the camera's macro mode with no flash. The best photograph was used to count the number of fungiform papillae within a 5 millimeter by 5 millimeter square that had been traced on the top slide directly behind the center front screw, bisecting the midline of the tip of the tongue.

Data Analysis

All data were compiled using SIMS® 2000 (Sensory Computer Systems, Morristown, N.J.) and analyzed using SAS® statistical software ((version 9.1 (SAS Inst., Cary, N.C.)) and a 0.05 level of significance. Roughness, bitterness, and sweetness ratings were log normally distributed, which is often the case for data on gLM scales, so the ratings were transformed using the natural logarithm. Prior to the transformation, zero values were assigned a value of 0.1, the lowest non-zero value on the scale.

In order to confirm that breads increased in roughness over staling time, an analysis of variance (ANOVA) was performed using the PROC MIXED command with the model:

ln roughness = judge (random effect) + taste position + age + gender + bread type + staling time + bread type* staling time.

A significant, positive effect for staling time would confirm that roughness increased over staling time. A significant effect for bread type would indicate that refined and whole wheat breads differed in roughness, and a significant effect for the interaction of bread type and staling time would indicate that the change in roughness over time was not identical for the two bread types. We also performed the same ANOVA on the natural logs of the bitterness and sweetness scores to examine how these attributes changed over staling time. The PDIFF statement was used to compute *t*-tests on the least squares means of the interaction of bread type and staling time to determine which breads differed significantly in roughness, bitterness, and sweetness.

To determine how papillae count and perceived PROP intensity affected perceived intensities, regression analyses were performed with the model:

ln (roughness / bitterness / sweetness rating) = age + gender + bread type + staling time + ln papillae + ln PROP + ln papillae * bread type + ln PROP * bread type

Significant, positive coefficients for the predictors ln papillae and ln PROP would support our hypothesis that individuals with increased fungiform papillae density and perceived PROP intensity would experience greater perception of the attribute. Significant coefficients for the interactions between bread type and ln PROP and bread type and ln papillae would indicate that any differences in perception caused by perceived PROP intensity or papillae count were not identical for whole wheat and refined breads. Taste position was initially included in the model, but was never significant, so it was removed. The interactions between ln papillae and bread type and ln PROP and bread type were also removed, because they were never significant.

To determine how papillae count and perceived PROP intensity affected roughness discrimination, the slopes of the psychophysical functions of roughness vs. staling time were calculated for each bread type for each panelist from the untransformed data. These slopes were then regressed against papillae count and perceived PROP intensity using the following model:

roughness vs. staling time slope (roughness discrimination) = papillae + PROP

Significant, positive coefficients for the predictors papillae and PROP would support our hypothesis that individuals with increased fungiform papillae density and perceived PROP intensity would be better at discriminating roughness differences between samples. Serving order, age, gender, and bread type were initially included in the model, but they were not significant, so they were removed.

Results

Roughness ratings increased with staling time ($F = 40.17$, $p < 0.0001$) (Table 1). Fresh bread and day-old bread were significantly less rough than breads that had been aged for three or five days ($t > 2.5$, $p < 0.013$). Roughness ratings did not differ for the fresh and day old breads ($t < 0.52$, $p > 0.60$), nor for the five day old bread and three day old bread ($t < 1.9$, $p > 0.056$). Whole wheat breads were significantly rougher than refined breads ($F = 352$, $p < 0.0001$) with the five day old refined bread significantly less rough than the fresh whole wheat bread ($t = 2.9$, $p = 0.0038$). Bitterness ratings also increased with staling time ($F = 4.8$, $p = 0.0028$), but sweetness ratings did not ($F = 2.2$, $p = 0.085$) (Table 1).

Table 7

Thirty-seven panelists rated intensities on 120 mm generalized labeled magnitude scales anchored at no sensation of the left end of the scale and strongest imaginable sensation on the right end of the scale. Panelists were previously acclimated to the scale by practicing rating sensations that varied in intensity and modality. Intensity ratings were log normally distributed, so analyses were performed on transformed data.

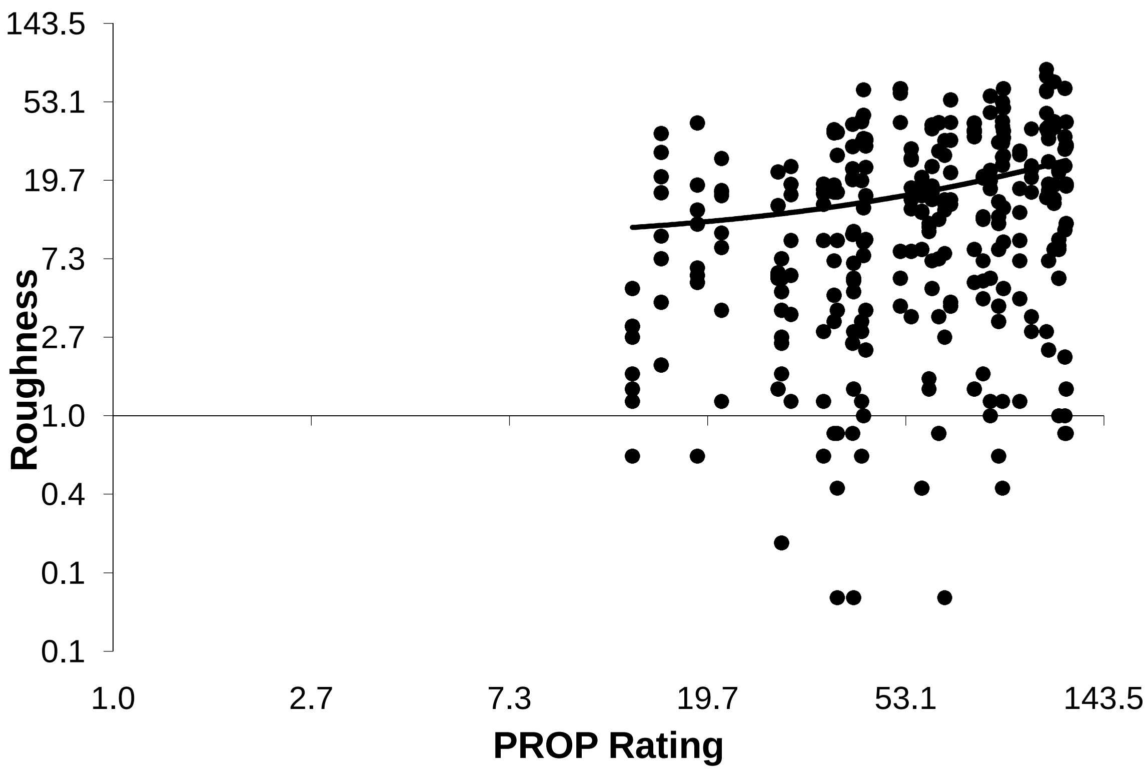
Bread type	**Staling time (days)**	**Mean Roughness (std error of the mean)**	**Mean Bitterness**	**Mean Sweetness**
Refined Wheat	0	2.3 (1.2)[a]	2.0 (1.3)[a]	10 (1.2)[a]
Refined	1	2.5[a]	2.6[a]	12[a]
Refined	3	8.2[b]	3.9[b]	7.8[a]
Refined	5	11[b]	3.9[b]	8.7[a]
Whole Wheat	0	19[c]	6.3[c]	11[a]
Whole	1	19[c]	7.2[c]	10[a]
Whole	3	30[d]	7.7[c]	9.3[a]
Whole	5	32[d]	8.7[c]	9.4[a]

[a,b,c,d] Values within a column that share letter designations do not significantly differ in intensity ($p > 0.05$).

Contrary to our hypothesis, panelists with higher papillae counts did not perceive greater roughness intensities from the breads (t=1.0, p = 0.31). Panelists who perceived greater PROP intensity did perceive greater roughness from the breads (t = 5.5, p < 0.0001) (Figure 1). Men perceived greater bread roughness than women (t = 3.7, p = 0.0003).

Figure 1

Thirty-seven panelists rated, on 120 mm generalized labeled magnitude scales anchored at no sensation of the left end of the scale and strongest imaginable sensation on the right end of the scale, roughness intensity of eight bread samples and bitterness intensity of 3.2 mM PROP. Panelists were previously acclimated to the scale by practicing rating sensations that varied in intensity and modality. Intensity ratings and papillae counts were log normally distributed, distributed, so analyses were performed on transformed data.



Contrary to our hypothesis, panelists with higher papillae counts were not significantly better at discriminating roughness differences among the bread samples (t= 1.3, p = 0.19), although a trend was observed (Figure 2). Panelists who experienced greater PROP intensity were better at discriminating differences with marginal significance (t=1.9, p = 0.056) (Figure 3).

Figure 2

Thirty-seven panelists rated , on 120 mm generalized labeled magnitude scales, roughness intensity of eight bread samples that had been staled for 0, 1, 3, or 5 day to manipulate roughness. The slopes of the psychophysical function of roughness vs. staling time were calculated for each bread type for each panelist. These values represent each panelist's discrimination ability. Open circles and the gray trend line represent the refined bread series, while black circles and the black trend line represent the whole wheat bread series.

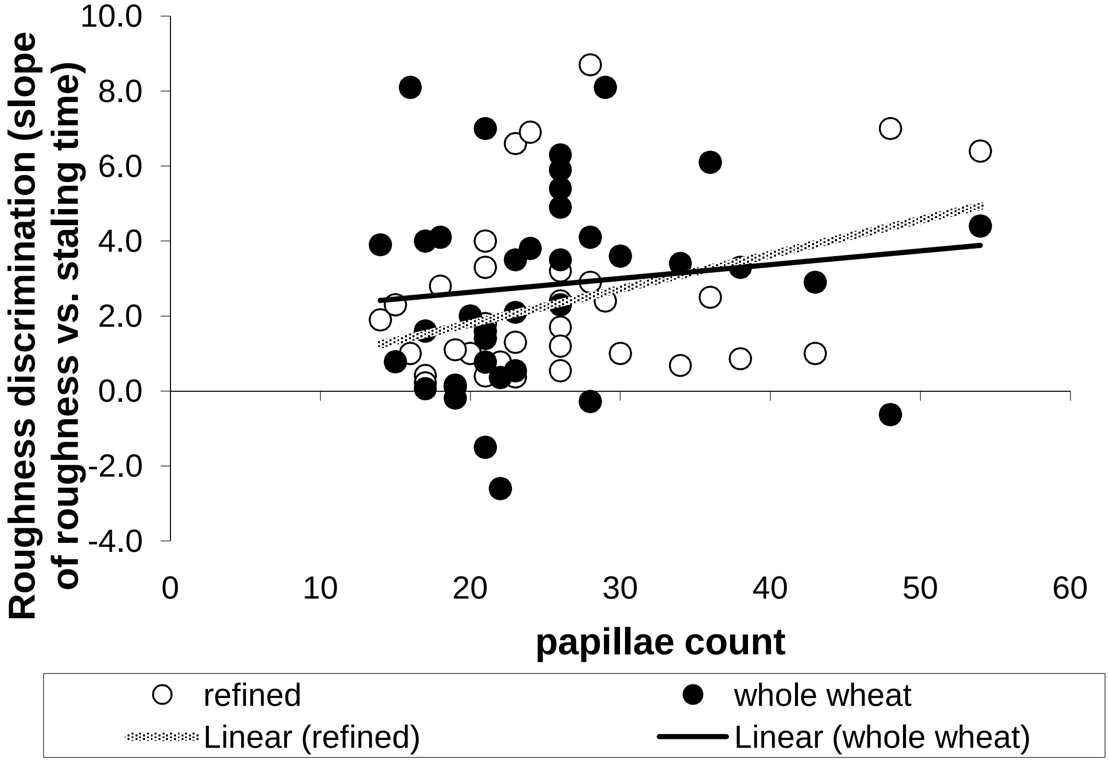
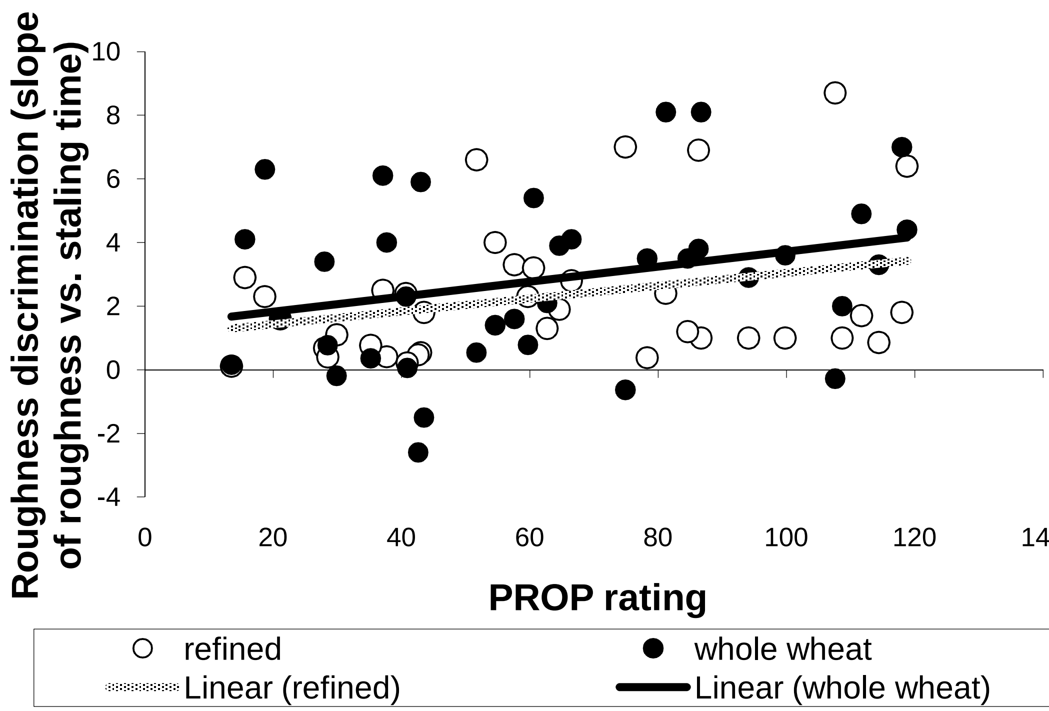


Figure 3

Thirty-seven panelists rated , on 120 mm generalized labeled magnitude (gLM) scales, roughness intensity of eight bread samples that had been staled for 0, 1, 3, or 5 day to manipulate roughness. PROP intensity was also scaled on a120 mm gLM scale. The slopes of the psychophysical function of roughness vs. staling time were calculated for each bread type for each panelist. These values represent each panelist's discrimination ability. Open circles and the gray trend line represent the refined bread series, while black circles and the black trend line represent the whole wheat bread series.



Fungiform papillae density was not a significant contributor to differences in bitterness ratings (t= 0.88, p = 0.38). Panelists who perceived greater PROP intensity also perceived greater bread bitterness (t=6.7, p<0.0001). Whole wheat breads were more bitter than refined breads (t=6.4, p < 0.0001), and bitterness increased over staling time (t=2.8, p = 0.0064). Men found the breads more bitter (t = 3.5, p = 0.0006), and bitterness intensity decreased with panelist age (t=3.3, p = 0.0012).

Fungiform papillae density was not a significant contributor to differences in sweetness ratings (t= 0.20, p = 0.83). Panelists who perceived greater PROP intensity also perceived greater bread sweetness (t=6.7, p<0.0001). Men found the breads sweeter (t = 3.9, p = 0.0001), and sweetness intensity decreased with panelist age (t=2.8, p = 0.0064).

Discussion

Trigeminal fibers innervate mechanoreceptors, which play important functions in texture perception. Fungiform papillae are heavily innervated with trigeminal fibers, which is why we predicted fungiform papillae density would predict roughness intensity and discrimination. Several studies have found correlations between PROP intensity and texture perception (de Wijk, Dijksterhuis, Vereijkena, Prinz, and Weenen, 2007; Hayes, and Duffy, 2007; Pickering, and Gordon, 2006; Pickering, Simunkova, and DiBattista, 2004; Tepper, and Nurse, 1997), and a popular explanation has been that PROP intensity is related to fungiform papillae density which in turn is related to trigeminal innervation. Consistent with previous research, we found fungiform papillae density and perceived PROP intensity were correlated with each other ($t=4.7$, $p<0.0001$). However, fungiform papillae density did not predict differences in roughness ratings while PROP did. Trigeminal fibers are widely dispersed on the tongue, so fungiform papillae density may not be a good measure of overall trigeminal innervation. Why PROP intensity would better predict texture perceptions is unclear to us at this time. The ability to taste PROP has been associated with a specific gene (Bufe, et al, 2005), but it may be possible for this gene to be linked to another gene that encodes trigeminal innervation of the tongue. Hayes and Duffy (2007) found both perceived PROP intensity and fungiform papillae density predicted creaminess and sweetness ratings, but concluded PROP intensity was a better predictor of those attributes. Essick, Chopra, Guest, and McGlone (2003) found strong correlations between both PROP intensity and lingual acuity and fungiform papillae density and lingual acuity, but the tasks they used to measure lingual acuity may be very different than the task of sensing roughness in bread. They measured lingual acuity by having subjects identify molded plastic letters ranging from 2.5–8 mm in height. Roughness cues in bread likely originate from smaller structures and particles and may be sensed quite differently than molded letters.

As far as we know this is the first study to indicate increases in bread bitterness over shelf life. Pasqualone, Summo, Bilancia, and Caponio (2007) used a trained panel to study sensory changes in Altamura durum wheat sourdough bread over a six day shelf life and found no changes in crumb bitterness and a decrease in crust bitterness. There is very little published research on the causes of bread bitterness, so it is difficult to speculate what may be causing changes in bitterness seen over shelf life. One possible explanation is that bitterness may become more apparent in bread as it loses some of its characteristic flavors and aromas over shelf life. The formation of free fatty acids and other fat oxidation products over shelf life may also contribute to increased bitterness. Jensen and others (personal communication, 2009) found that an increase in lipid oxidation products accompanied an increase in bread off flavor over shelf life. While sweetness did not vary significantly over shelf life, the older breads tended to be less sweet, which could explain the greater bitterness ratings for those breads. It is also possible that bitterness did not actually increase over shelf life, but rather the increase represents a "horns" effect. Panelists may have rated the older breads as more bitter, if they liked the older breads less.

There is little support for our finding that men experience these sensations more intensely than do women. Bartoshuk (1994) showed women perceive increased bitterness intensity from suprathreshold PROP concentrations, and PROP bitterness has been correlated to increased bitterness (Lanier, Hayes, and Duffy, 2005; Pickering, Simunkova, and DiBattista, 2004; Prutkin, et al, 2000) and sweetness (Pasquet, Oberti, El Ati, and Hladik, 2002; Prutkin, et al, 2000) perception in other taste solutions and food, so one might expect men to perceive less bitterness and sweetness than do women. While some studies have found increased sweetness (Holt, Cobiac, Beaumont-Smith, Easton, and Best, 2000; Hong, Chung, Kim, Chung, Lee, and Kho, 2005; Laeng, Berridge, and Butter, 1993) and bitterness (Lanier, Hayes, and Duffy, 2005) perception for women, others have failed to find any gender differences in bitterness or sweetness perception (Chang, Chung, Kim, Chung, and Kho, 2006; Dinehart, Hayes, Bartoshuk, Lanier, and Duffy, 2006; Drewnowski, Kristal, and Cohen, 2001; James, 1999). Age may also affect differences in taste perception between genders. Mojet (2001) found lower taste thresholds for elderly men but did not find differences in younger populations. Our sex effect may have been due to the small sample of men in our study (eight), who were probably not representative of the larger population of men as a whole. The average age of the male panelists (35) was also lower than the average age of the female panelists (39), which may help explain this finding.

Differences in roughness and bitterness intensity among breads may partially explain differences in liking seen between refined and whole wheat breads see in our earlier study. The importance of roughness and bitterness differences may be related to PROP sensitivity. Those individuals with greater PROP sensitivity may be more aware of bread differences and may perceive increased roughness and bitterness in whole wheat bread. Our previous study found supertasters showed greater dislike for whole wheat breads than did other consumers, while nontasters had no preferences between refined and whole wheat breads. These differences between individuals may affect bread choices and consumer health, as consumption of whole grain foods, including whole wheat bread, has been linked to reduced risk of coronary heart disease, type II diabetes, certain cancers, and all-cause mortality (Slavin, 2004).

CHAPTER 4

RELATIONSHIPS BETWEEN ROUGHNESS, BITTERNESS, PROP SENSITIVITY, FUNGIFORM PAPILLAE DENSITY, AND BREAD ACCEPTANCE

The purpose of this study was to determine how bitterness, roughness, color, perceived PROP intensity, and fungiform papillae density affect bread liking. To accomplish this, 78 subjects from the University of Minnesota campus (61 female) rated their liking of bread samples that were manipulated to vary independently in bitterness, roughness, and darkness. The roughness of the bread was manipulated by adding bleached bran. Bitterness was manipulated by adding aqueous wheat germ extract. Color was manipulated by adding caramel color.

As expected, added bitterness decreased bread liking. This decrease tended to be larger for subjects with higher perceived PROP intensity. Fungiform papillae density had little impact on the liking changes due to added bitterness.

Surprisingly, added roughness increased bread liking. This increase was significantly larger for subjects with higher fungiform papillae density than those with lower densities and was significantly larger for subjects with lower perceived PROP intensity than those with higher perceived PROP intensity.

The effects of added color on bread liking depended on subjects' stated preference for either 100% refined bread or 100% whole wheat bread. Added color decreased liking of subjects with a stated preference for refined bread and increased liking of subjects with a stated preference for whole wheat bread.

This study substantiates the widespread assertion that bitterness and dark color may contribute to lower liking of whole grain bread and provides the surprising result that rough texture may positively impact bread liking. This study also adds to the growing body of research into how consumer perceived PROP intensity affects food acceptance and the relatively scant body of research into how consumer fungiform papillae density impacts food acceptance

Introduction

The purpose of this study was to determine how three sensory properties, bitterness, roughness, and color and three consumer characteristics, bread type preference (whole or refined), perceived PROP intensity, and fungiform papillae density, affect bread liking. To accomplish this, consumers rated their liking of bread samples that were manipulated to vary independently in bitterness, roughness, and darkness. The roughness of the bread was manipulated by adding bleached bran at three levels. Bitterness was manipulated by adding aqueous wheat germ extract at three levels. Color was manipulated by adding caramel coloring at three levels. In order to keep the number of samples at a reasonable number, a 1/3 fractional factorial Taguchi design was employed (see Table 8) (Oehlert, 2000).

Table 8

The sample identification system follows this pattern: added bitter germ extract level (B)- low (l), medium (m), high (h), added rough bleached bran level (R)- low (l), medium (m), high (h), and added caramel color level (C)- low (l), medium (m), high (h). e.g. BhRmCl has a high bitterness level, a medium roughness level, and no added color.

Sample #	Sample ID	Bitter Germ Extract	Rough Bleached Bran	Caramel Color
1	BhRmCl	1	0	-1
2	BlRmCm	-1	0	0
3	BmRhCl	0	1	-1
4	BlRhCh	-1	1	1
5	BmRlCm	0	-1	0
6	BlRlCl	-1	-1	-1
7	BhRhCm	1	1	0
8	BmRmCh	0	0	1
9	BhRlCh	1	-1	1

We also measured subjects' perceived PROP intensities and fungiform papillae densities to relate these measures to liking of the manipulated bread samples.

We hypothesized that increased bitterness, roughness, and darkness will have negative effects on overall liking of bread. We also predicted that the impact of bitterness and roughness on liking will be greater for those consumers who have higher fungiform papillae densities and perceive greater PROP intensities.

Materials and methods

Bleached wheat bran preparation

Bran was bleached according to United States Patent 6899907 (Monsalve-Gonzalez, Metzger, Prakash, Valanju, and Roufs, 2005). Red Wheat Bran (Bob's Red Mill Natural Foods, Milwaukie, OR, USA) was sized using a RO-TAP sieve shaker (W.S. Tyler, Inc., Gastonia, N.C., USA), and bran that did not pass through a #20 sieve was collected for further processing. This bran was heated at 70°C for 15 minutes in a 0.06% disodium EDTA (Spectrum Chemical Manufacturing Corp., Gardena, CA, USA) solution to remove any transition metals. The bran was then rinsed with deionized water, blanched at 75°C for 10 minutes to denature any native peroxidase, and rinsed again with deionized water. Sodium hydroxide (NaOH) was added to the bran at a level of 0.83% (wt NaOH/ wt bran) and peroxide (H_2O_2) was added at a level of 14.4% (wt H_2O_2/ wt bran). Excess deionized water was added to create a 15% bran in water solution. The bran, NaOH, and H_2O_2 solution was then heated to 85°C for 40 minutes. Bran was then drained and thoroughly rinsed with deionized water. The bleached bran was then spread thinly on aluminum foil to air dry for 24 hours. The dried rough bleached bran was then passed through a burr mill grinder (Black and Decker, Towson, Maryland) set on the finest setting three times. To determine bran size, samples were evaluated with a RO-TAP sieve shaker with #20 (largest openings), #30, #45, #60, #80, and #120 (smallest openings) sieves (W.S. Tyler, Inc., Gastonia, N.C., USA). The majority of the bran did not pass through a #30 sieve (see Table 9).

Table 9

Dried rough bleached bran was passed through a burr mill grinder to reduce particle size and improve bread baking properties. To determine bran size, 100 grams of the ground, rough bleached bran was placed in a RO-TAP sieve shaker with #20, #30, #45, #60, #80, and #120 sieves. The percentage of bran that remained on each sieve and passed through all sieves is reported.

Size	Percentage
Not through #20	34.9
Through #20 but not #30	39.9
Through #30 but not #45	19.3
Through #45 but not #60	3.0
Through #60 but not #80	1.1
Through #80 but not #120	0.44
Through #120	1.3

Bitter wheat germ extract preparation

To prepare bitter germ extract, one part raw wheat germ (Bob's Red Mill Natural Foods, Milwaukie, OR, USA) was added to two parts deionized water and allowed to sit at room temperature for 30 minutes. The germ slurry was then centrifuged at 4,750 rpm for 40 minutes at 23°C. The supernatant was collected and the germ solids were discarded. The bitter germ extract was kept refrigerated for up to 24 hours until added to the bread dough.

Bread preparation

Breads were prepared using AACC International Approved Method 10-10B 'Optimized Straight-Dough Bread-Baking Method' (AACC International, 1995). The formulations are provided in Table 10. The flour used was commercially available and provided gratis by Cargill, Inc. (Minneapolis, MN, USA). The amount of water added depended on the amount of rough bleached bran and bitter germ extract in the formulation and was determined using a mixograph and the procedures outlined in AACC International Approved Method 54-40A (AACC International, 1995).

Table 10

Breads were prepared using AACC International Approved Method 10-10B 'Optimized Straight-Dough Bread-Baking Method.' Rough bleached bran was added at three levels: 0, 7, or 14% of the flour weight. Bitter germ extract was added at 0, 35, or 50% of the flour weight, and caramel color at 0, 0.4, or 0.8% of the flour weight. Sugar was added at 2%, yeast at 3%, and salt at 1.5% of the flour + rough bleached bran weight. The amount of added liquid (combination of water and bitter germ extract) was 62% of the flour weight for breads with no added rough bleached bran, was 72% of the flour + rough bleached bran weight for breads with 7% added rough bleached bran, and was 82% of the flour + rough bleached bran weight for breads with 14% added rough bleached bran. In order to increase loaf volume of the breads containing bitter germ extract and/or rough bleached bran, sodium stearoyl lactylate (SSL) was added at a level of 0.5% (wt SSL/ wt flour + rough bleached bran) to all breads containing rough bleached bran, and gluten was added at a level of 2% (wt gluten/ wt flour + rough bleached bran) to all breads containing bitter germ extract and/or rough bleached bran. The sample identification system follows this pattern: Bitterness level (B)- low (l), medium (m), high (h), Roughness level (R)- low (l), medium (m), high H), and Color level (C)- low (l), medium (m), high (h). e.g. BhRmCl has a high bitterness level, a medium roughness level, and no added caramel color.

Ingredient	**Proportion each ingredient (%)**								
	Sample								
	1 BhRmCl	**2 BlRmCm**	**3 BmRhCl**	**4 BlRhCh**	**5 BmRlCm**	**6 BlRlCl**	**7 BhRhCm**	**8 BmRmCh**	**9 BhRlCh**
Rough Bleached Bran	3.9	3.9	7.3	7.3	0.0	0.0	7.3	3.9	0.0
Bitter Germ Extract	27.6	0.0	18.3	0.0	20.5	0.0	26.1	19.3	29.1
Caramel Color	0.0	0.2	0.0	0.4	0.2	0.0	0.2	0.4	0.5
Flour	51.4	51.3	45.0	44.8	58.8	59.3	44.9	51.2	58.2
Water	12.2	39.7	24.6	42.8	15.8	36.8	16.7	20.4	7.0
Sugar	1.1	1.1	1.0	1.0	1.2	1.2	1.0	1.1	1.2
Yeast	1.7	1.7	1.6	1.6	1.8	1.8	1.6	1.7	1.7
Salt	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.9
Gluten	1.1	1.1	1.0	1.0	1.2	0.0	1.0	1.1	1.2
Sodium Stearoyl Lactylate	0.3	0.3	0.3	0.3	0.0	0.0	0.3	0.3	0.3

We wanted all breads to have equivalent loaf volumes, so that each sample would have the same slice area. It was therefore necessary to add sodium stearoyl lactylate

(SSL) at a level of 0.5% (wt SSL/ (wt flour + rough bleached bran)) to all breads containing rough bleached bran, and gluten at a level of 2% (wt gluten/ (wt flour + rough bleached bran)) to all breads containing bitter germ extract and/or rough bleached bran.

Approximately 12-24 hours before bread making, the rough bleached bran, bitter germ extract, and caramel color for each sample were combined in order to allow the caramel color to stain the rough bleached bran. Because the amounts of rough bleached bran and amounts of bitter germ extract differed for every sample, water was added to this mixture for samples 2, 3, 4, and 8 (see Table 1) to keep the liquid to rough bleached bran ratio consistent during presoaking. To compensate for this additional water, less water was added when making the dough.

A model A-200 Hobart mixer (Troy, OH, United States) was used to combine ingredients and knead the dough. Sugar (Crystal United Sugars, Inc., Minneapolis, MN, USA), salt (Morton International Inc., Chicago, IL, USA), SSL (Spectrum Chemical Manufacturing Corp., Gardena, CA, USA), and vital wheat gluten (Bob's Red Mill Natural Foods, Milwaukie, OR, USA) were added to the flour dry. Yeast (Red Star, Milwaukie, WI, USA) was suspended in warm water (43°C +/- 2°C) for five minutes prior to addition. The yeast suspension and remaining liquids were added just prior to mixing. Doughs were mixed for one minute. The sides of the bowl were scraped down, and then the dough was mixed for an additional five minutes.

Each dough batch was scaled into seven portions. With the exception of portions of sample 6, each portion was scaled to contain approximately 100 grams of flour (samples 5, 6, and 9) or 100 grams of flour combined with rough bleached bran (samples 1-4, 7, 8). Sample 6 was scaled into portions containing only 86 grams of flour, because, despite the additions of SSL and gluten to the other samples, sample 6 still had a higher baked specific volume than all other samples, and we wanted all of the bread loaves to be approximately the same size.

After scaling, the dough portions were rounded and placed bowls greased with shortening (Crisco®, The J.M. Smucker Company, Orrville, OH, USA) and fermented in a fermentation cabinet (National Manufacturing Company, Lincoln, NE, USA) at 30°C, 75% relative humidity for a total of 123 minutes. The first dough punch occurred after 52 minutes and the second after an additional 25 minutes. Molding and panning were performed 13 minutes after the second punch. Punching and molding were performed with a sheeter roll and molder (National Manufacturing Company, Lincoln, NE, USA). The molded dough was placed seam side down in a loaf pan that had been lightly greased with shortening (Crisco®, The J.M. Smucker Company, Orrville, OH, USA). The final proof lasted 33 minutes. After the final proof, the dough was baked for 24 minutes at 218.3°C in a revolving reel oven (Despatch, Minneapolis, MN, United States). The breads cooled completely before being wrapped in aluminum foil (Handi-Foil®, Wheeling, IL, USA) and sealed into zippered polyethylene bags (S.C. Johnson & Son, Inc., Racine, WI, USA) for storage. The breads were stored for approximately 16-20 hours before slicing.

About 3-8 hours before tasting, breads were cut into ½" slices using a bread slicing guide (Progressive International, Inc., Kent, WA, USA). Each slice was then cut in half vertically, so that each half contained portions of both top and bottom crust. The half slices were then placed in small zippered polyethylene bags (S.C. Johnson & Son, Inc., Racine, WI, USA) coded with three digit numbers.

Subjects

Participants from the University of Minnesota campus responded to an email solicitation for people willing to taste bread and have their fungiform papillae density measured. A total of 80 people participated in the study, but the data for two subjects were not included in the analysis because they failed to complete all portions of the study. Of the 78 panelists remaining, 61 were female. All interested parties except those with food allergies were included in the study. The University of Minnesota Institutional Review Board approved the procedures.

Procedure for sensory test

Subjects were first familiarized with the Labeled Affective Magnitude (LAM) scale by using the scale to rate their liking of 13 disparate items, including commonly liked and disliked foods and situations. Subjects then removed the samples from the bags to rate their liking of the bread’s appearance; then they tasted the samples, taking at least two bites, to rate overall liking, taste liking, and texture liking on 120 point LAM scales (Schutz, and Cardello, 2001). To mask any aroma differences caused by the added rough bleached bran and bitter germ extract, subjects wore nose clips while tasting all samples.

The samples were presented in a balanced order according to a William's Latin Square design (MacFie, Bratchell, Greenhoff, and Vallis, 1989).

We evaluated subjects' perceived intensity of PROP using a 120 point general labeled magnitude (gLM) scale. Subjects first acclimated to the scale by using it to rate 17 sensations with varying intensity and modality. A subset of these sensations included the brightness of the sun, the loudness of a whisper, and the oral burn of a carbonated beverage. Subjects then received a 10 ml sample of 3.2 mM PROP and were asked to swirl the entire sample in their mouth, expectorate it, and rate its intensity.

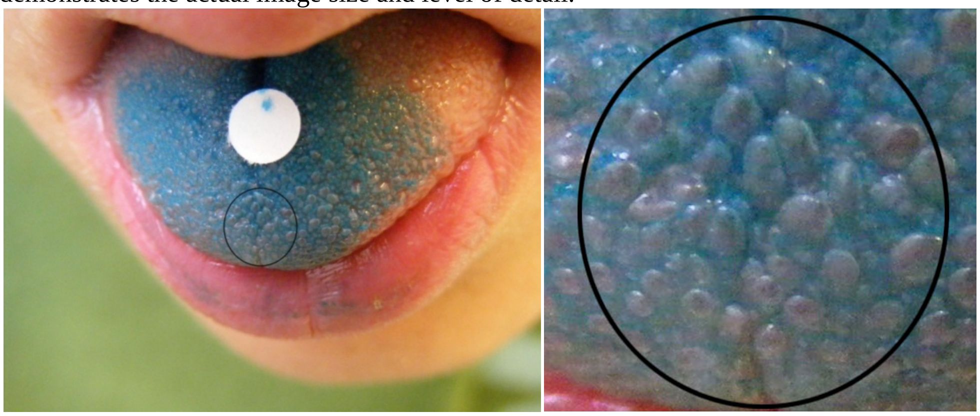
Subjects then completed a brief questionnaire in which they were asked to indicate their bread type preference (either refined bread or whole wheat bread) 'based on only the sensory qualities of the bread (i.e. taste, flavor, texture, smell, appearance, touch, etc…) disregarding all other factors". They also rated, on 120 point LAM scales, their liking of the texture of 6 different foods (cream of wheat cereal, popcorn, dry cornflakes, instant oatmeal, corn tortilla chips, and cooked white rice) and rated, on 100 point unstructured line scales labeled with 'Not at all Important' on the left end and 'Very Important' on the right end, how important flavor, smell, texture, appearance, and nutritional value were to them when selecting foods.

Subjects returned on a separate day to have their fungiform papillae density measured. Subjects' tongues were stained with FD&C Blue #1 neon food coloring (McCormick & Co, Inc., Hunt Valley, MD). A circle of filter paper (7 mm diameter) was placed on the center of their tongue approximately 1-2 cm from the tip of their tongue. Several photos of the tongue were taken using a 7.1 megapixel digital camera (FUJIFILM U.S.A., Inc., Hollywood, CA, USA) in a brightly lit room using the camera's macro mode with no flash.

To measure papillae density, the best photograph was selected, and Adobe Photoshop was used to mark the area in which papillae were to be counted. To do this, the elliptical marquee tool was used to draw an outlined circle the same size as the filter paper circle that had been placed on the tongue. This outlined circle was then moved on the image to the very tip of the tongue, marking the boundary of the area in which fungiform papillae were counted (see Figure 4). All papillae that fell within the boundaries of the outlined circle were counted. Those papillae that were in contact with the outlined circle were counted if more than 50% of those individual papillae were within the boundary.

Figure 4

The left image shows a compact version of the entire image taken, including the filter paper, and shows placement of the outlined circle on the photograph. The right image is the same photograph cropped and demonstrates the actual image size and level of detail.



Data analysis

All data were compiled using SIMS® 2000 (Sensory Computer Systems, Morristown, N.J., USA) and analyzed using SAS® statistical software ((version 9.1 (SAS Inst., Cary, N.C., USA)). A 0.05 level of significance was used for all statistical tests.

Intensity ratings of 3.2 mM PROP were used to classify subjects into three taster status groups. Those who rated the PROP solution below 25 were classified as nontasters and those who rated the PROP solution greater than 85 were classified as supertasters. All others were classified as medium tasters. The cut off values were set by the natural breaks in the histogram of PROP scores. Twenty-three subjects were classified as nontasters, 39 as medium tasters, and 13 as supertasters

Subjects were also classified by papillae count. Papillae counts ranged from 20 to 74 with a median papillae count of 39 and a mean papillae count of 40.4. The 42 subjects with papillae counts less than or equal to 39 were classified as having a low density, and the other 36 subjects with densities greater than 39 were classified as having a high density.

Subjects were also classified by their preference for refined or whole wheat bread based on their response to the questionnaire completed after the taste test. Sixty-two subjects responded that they preferred whole wheat bread and 18 subjects responded that they preferred refined wheat bread.

To test how added bitter germ extract, added rough bleached bran, and added caramel color levels, and consumer classification groups affected bread liking an analysis of variance (ANOVA) was performed using the PROC MIXED command with Sattherwaite degrees of freedom and the following model:

> Liking measure (overall, appearance, taste, or texture) = judge (random effect) + breadtypepreference (refined or whole wheat) + tasterstatus (non, med, or super) + papillaedensity (low, high) + addedgermextract (-1, 0, 1) + addedbleachedbran (-1, 0, 1) + addedcaramelcolor (-1, 0, 1) + taster*germextract + papillae density*germextract + preference*germextract + taster*bleachedbran + papillaedensity*bleachedbran + preference*bleachedbran + taster*caramelcolor + papillaedensity*caramelcolor + preference*caramelcolor

Taste position, gender, age, the interaction between papillae density and taster status, the interaction between papillae density, taster status, and added bitter germ extract, the interaction between papillae density, taster status, and added rough bleached bran, and the interaction between papillae density, taster status, and added caramel color were initially included in the model, but were never significant, so they were removed. Multiple comparison tests were performed using the PDIFF statement to compute *t*-tests on the least squares means.

To test whether consumer classification groups affected liking of 6 cereal food items with varying textures, ANOVA with multiple comparison *t*-tests were performed using the PROC ANOVA statement and the following model:

> Cereal item (cream of wheat, popcorn, dry cornflakes, oatmeal, corn chips, or rice) liking = bread type preference (refined or whole wheat) + taster status (non, med, or super) + papillae density (low, high)

To test how consumer classification groups affected the importance of flavor, smell, texture, appearance, and nutritional value when selecting foods, ANOVA with multiple comparison *t*-tests were performed using the PROC ANOVA statement and the following model:

> Attribute (appearance, smell, texture, taste, or nutrition) importance = bread type preference (refined or whole wheat) + taster status (non, med, or super) + papillae density (low or high)

To test whether subject classification factors were related, exact Pearson's Chi-square tests were performed using the PROC FREQ procedure with EXACT PCHI statement on the following factors: papillae density, bread type preference, and taster status.

Results

F and p-values for all ANOVA are presented in Table 11 and will not be referred to further in the text. Subjects with high fungiform papillae density had significantly lower liking ratings compared to subjects with low fungiform papillae densities (all $F > 7.8$, all $p < 0.0068$).

Table 11

F and p-values are given for design factors, and their interactions with consumer classification groups for the following measures: overall liking, appearance liking, taste liking, and texture liking. Design factors were the level of caramel color, bitter germ extract, and rough bleached bran. Classification groups included bread type preference, taster status, and papillae density. Within a cell, the F and p-values presented correspond to the liking measures listed in the first cell of the column and the effect listed in the first cell of that row. For instance, the F and p-values listed in the bottom right cell correspond to the interaction of the amount of rough bleached bran and papillae density group on texture liking scores.

Effect	Overall Liking	Taste Liking	Appearance Liking	Texture Liking
Main Effect of Caramel Color	F=1.6, p=0.21	F=1.1, p=0.34	F=2.5, p=0.081	F=0.34, p=0.71
Interaction of Caramel Color with Bread Type Preference	**F=7.5, p=0.0006**	**F=6.8, p=0.0012**	**F=15, p=<.0001**	**F=5.0, p=0.0072**
Interaction of Caramel Color with Taster Status	F=0.84, p=0.50	F=0.38, p=0.82	F=0.58, p=0.68	F=0.78, p=0.54
Interaction of Caramel Color with Papillae Density	F=0.70, p=0.50	F=2.1, p=0.12	F=0.02, p=0.98	F=0.44, p=0.65
Main Effect of Bitter Germ Extract	**F=14, p<0.0001**	**F=15, p<0.0001**	**F=4.2, p=0.015**	**F=17, p<.0001**
Interaction of Bitter Germ Extract with Bread Type Preference	F=0.73, p=0.48	F=1.7, p=0.19	**F=3.4, p=0.033**	F=0.96, p=0.38
Interaction of Bitter Germ Extract with Taster Status	F=0.58, p=0.68	F=0.42, p=0.80	F=2.0, p=0.089	F=0.86, p=0.49
Interaction of Bitter Germ Extract with Papillae Density	F=2.5, p=0.079	F=2.0, p=0.14	F=0.24, p=0.79	F=0.65, p=0.52
Main Effect of Rough Bleached Bran	**F=13, p<0.0001**	**F=3.6, p=0.027**	F=0.62, p=0.54	**F=16, p<.0001**
Interaction of Rough Bleached Bran with Bread Type Preference	F=2.8, p=0.062	F=0.87, p=0.42	**F=9.7, p<0.0001**	F=3.7, p=0.027
Interaction of Rough Bleached with Taster Status	**F=2.5, p=0.043**	F=1.1, p=0.34	F=2.0, p=0.089	**F=4.6, p=0.0011**
Interaction of Rough Bleached Bran with Papillae Density	**F=6.7, p=0.0014**	**F=3.1, p=0.045**	**F=4.3, p=0.014**	**F=11, p<0.0001**

Effect of caramel color addition on liking

The effects of caramel color on liking depended on consumer bread type preference. In general, added caramel color decreased liking for subjects whose bread type preference was refined bread and increased liking for subjects whose bread type preference was whole wheat bread. Subjects whose bread type preference was refined bread liked breads without caramel color significantly better than breads with caramel color overall (both $t > 2.0$, $p < 0.043$). Trends were similar for taste, appearance, and texture liking (Figure 5). Subjects whose bread type preference was whole wheat liked breads with caramel color added significantly more for appearance and taste liking ($t > 2.2$, $p < 0.031$). Trends for texture liking and overall liking were similar (Figure 5). The effect of added caramel color on liking did not depend on fungiform papillae density (Figure 6) or taster status (Figure 7).

Figure 5

Average liking ratings for the three levels of added caramel color for the two bread type preference groups. The left most set of bars represents overall liking scores, the next set of bars to the right represents taste liking scores, the set of bars second to the right represents appearance liking scores, and the right most set of bars represents texture liking scores. White bars represent samples with no added caramel color, grey bars represent samples with the medium level of added caramel color, and black bars represent samples with the highest level of added caramel color; solid bars represent consumers whose bread type preference was refined wheat (21%) and dotted bars represent consumers who bread type preference was whole wheat (79%). Seventy-eight subjects rated nine bread samples on 120 point LAM scales, where a rating of 60 corresponded to the descriptor 'neither like or dislike,' a rating of 67 corresponded to the descriptor 'like slightly', and a rating of 82 corresponded to the descriptor 'like moderately'. Bars within a liking measure grouping that share a letter designation do not significantly differ in liking.

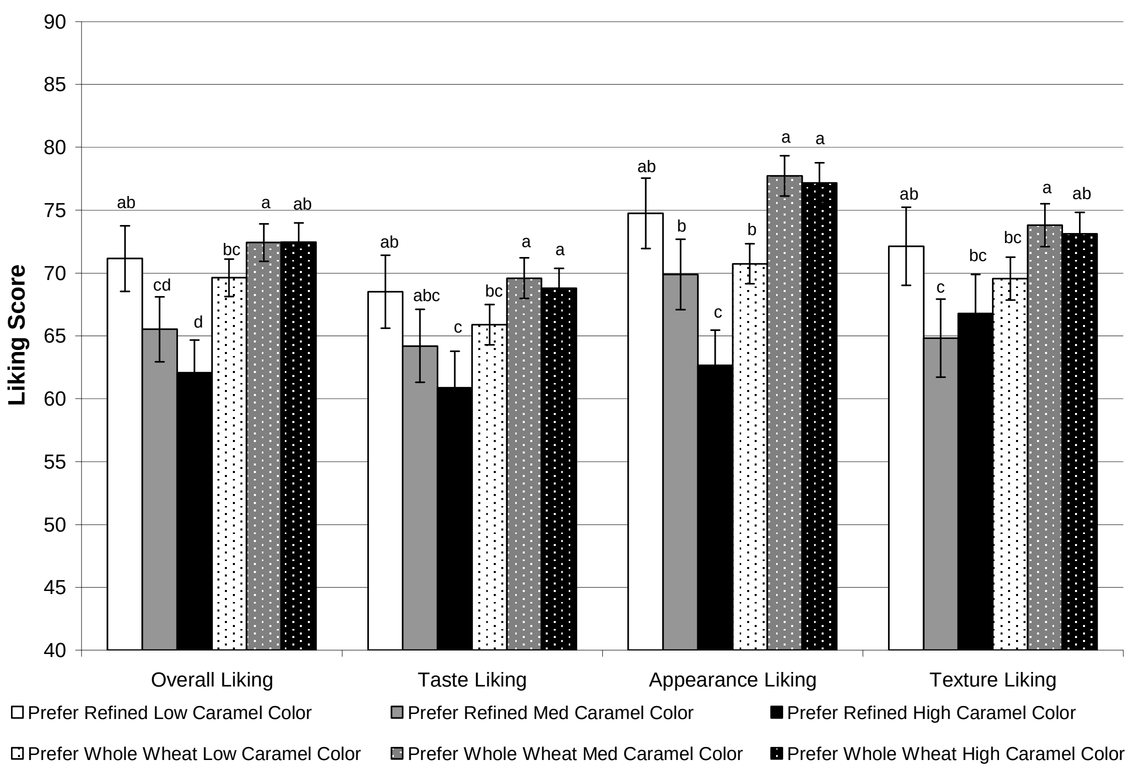


Figure 6

Average liking ratings for the three levels of added caramel color for the two papillae density groups. The left most set of bars represents overall liking scores, the next set of bars to the right represents taste liking scores, the set of bars second to the right represents appearance liking scores, and the right most set of bars represents texture liking scores. White bars represent samples with no added caramel color, grey bars represent samples with the medium level of added caramel color, and black bars represent samples with the highest level of added caramel color; sparsely dotted bars represent consumers with low papillae densities (54%) and densely dotted bars represent consumers with high papillae densities (46%). Seventy-eight subjects rated nine bread samples on 120 point LAM scales, where a rating of 60 corresponded to the descriptor 'neither like or dislike,' a rating of 67 corresponded to the descriptor 'like slightly', and a rating of 82 corresponded to the descriptor 'like moderately'.

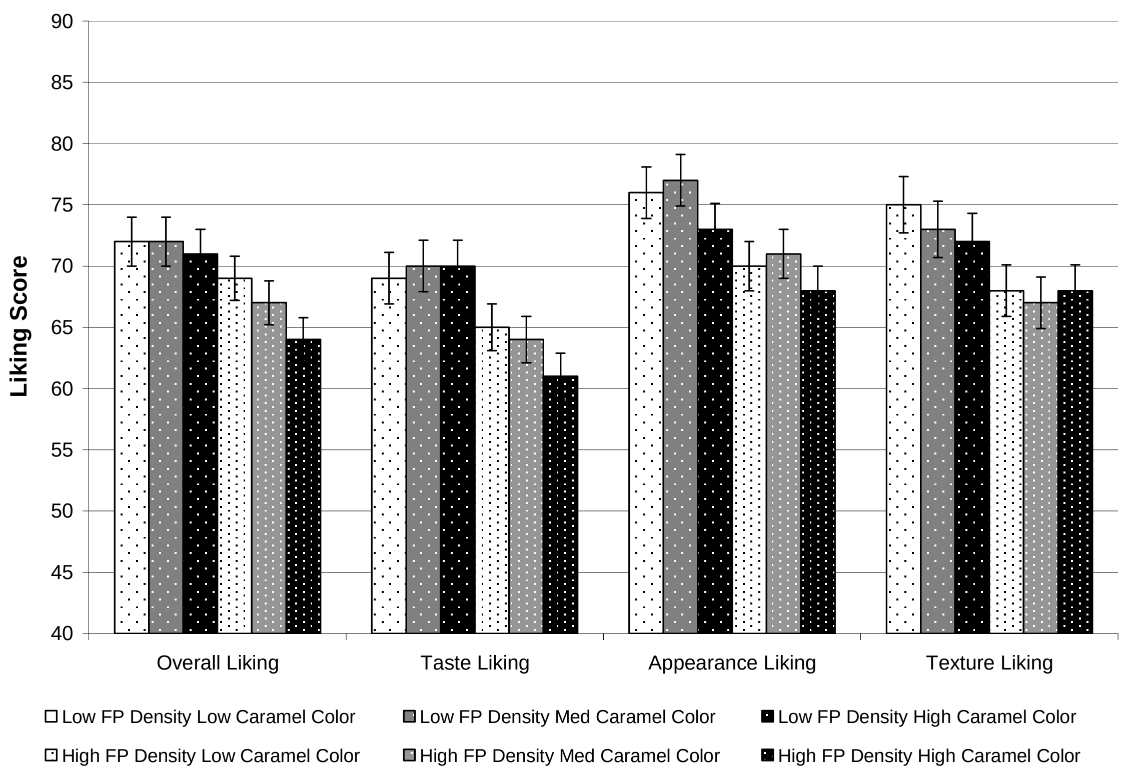
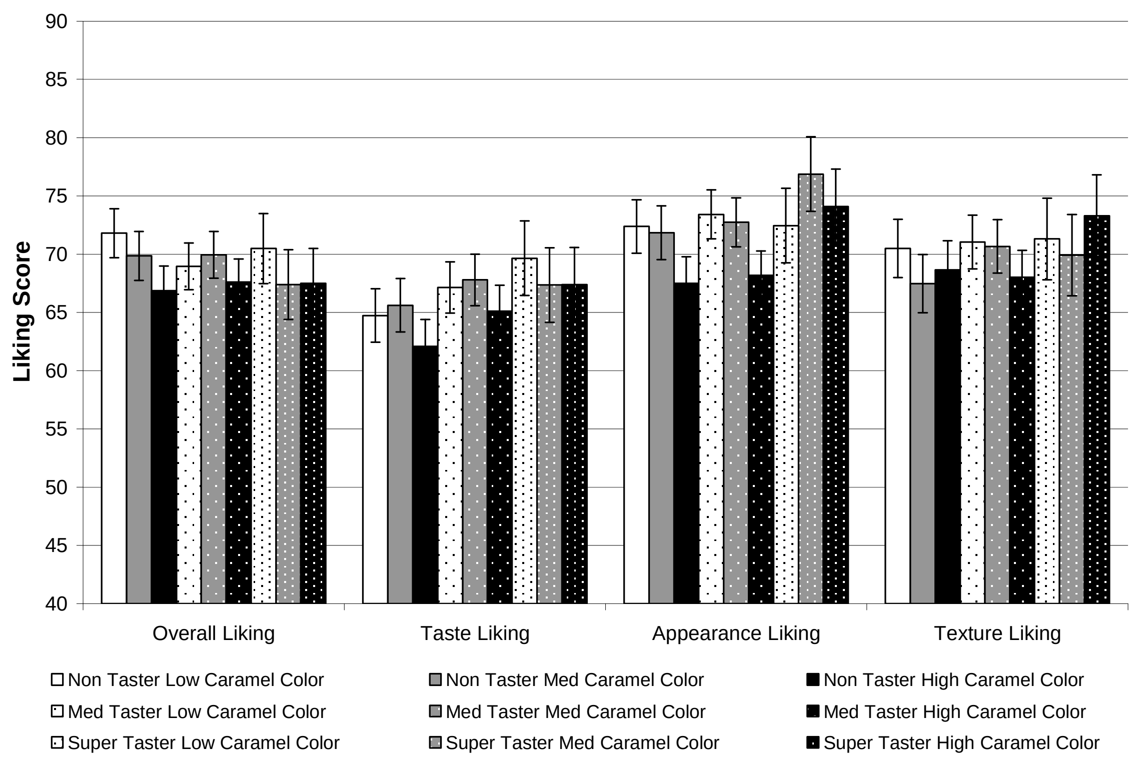


Figure 7

Average liking ratings for the three levels of added caramel color for the three taster status groups. The left most set of bars represents overall liking scores, the next set of bars to the right represents taste liking scores, the set of bars second to the right represents appearance liking scores, and the right most set of bars represents texture liking scores. White bars represent samples with no added caramel color, grey bars represent samples with the medium level of added caramel color, and black bars represent samples with the highest level of added caramel color; solid bars represent nontasters (33%), sparsely dotted bars represent medium tasters (50%), and densely spotted bars represent super tasters (17%). Seventy-eight subjects rated nine bread samples on 120 point LAM scales, where a rating of 60 corresponded to the descriptor 'neither like or dislike,' a rating of 67 corresponded to the descriptor 'like slightly', and a rating of 82 corresponded to the descriptor 'like moderately'.

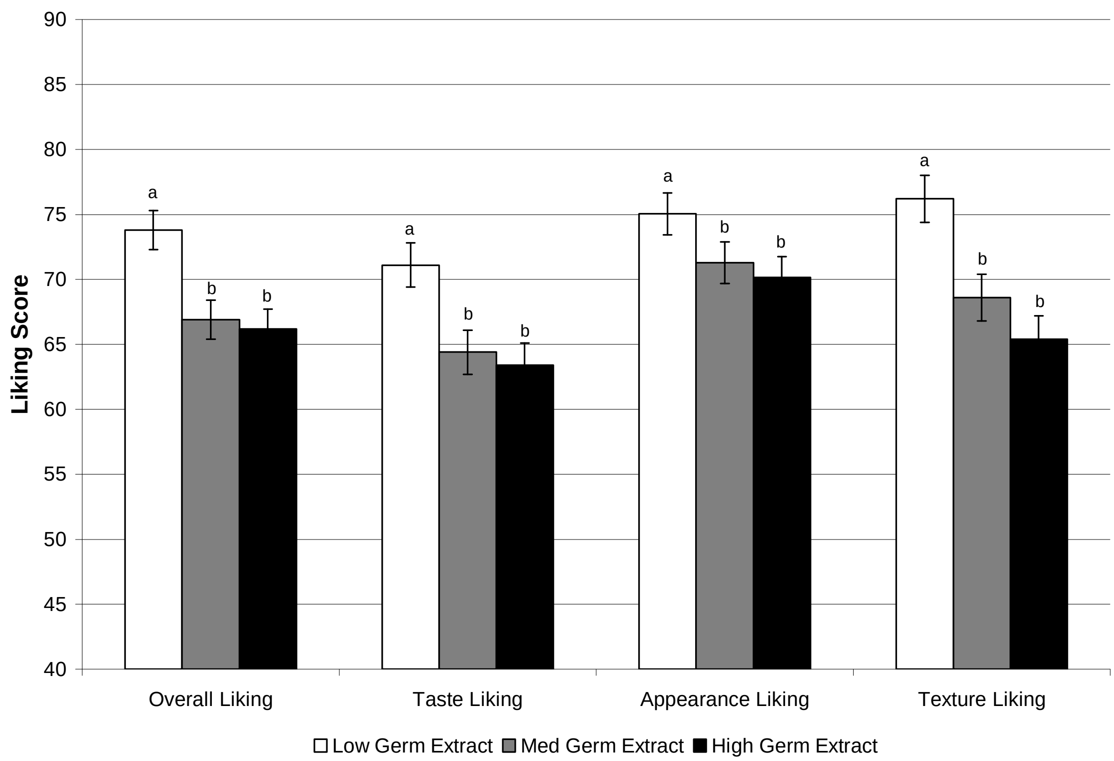


Effects of bitter germ extract addition on liking

Consumers liked the breads with no added bitter germ extract significantly better than the breads with bitter germ extract overall and for taste, texture, and appearance liking (all $t > 2.2$, all $p < 0.030$) (Figure 8).

Figure 8

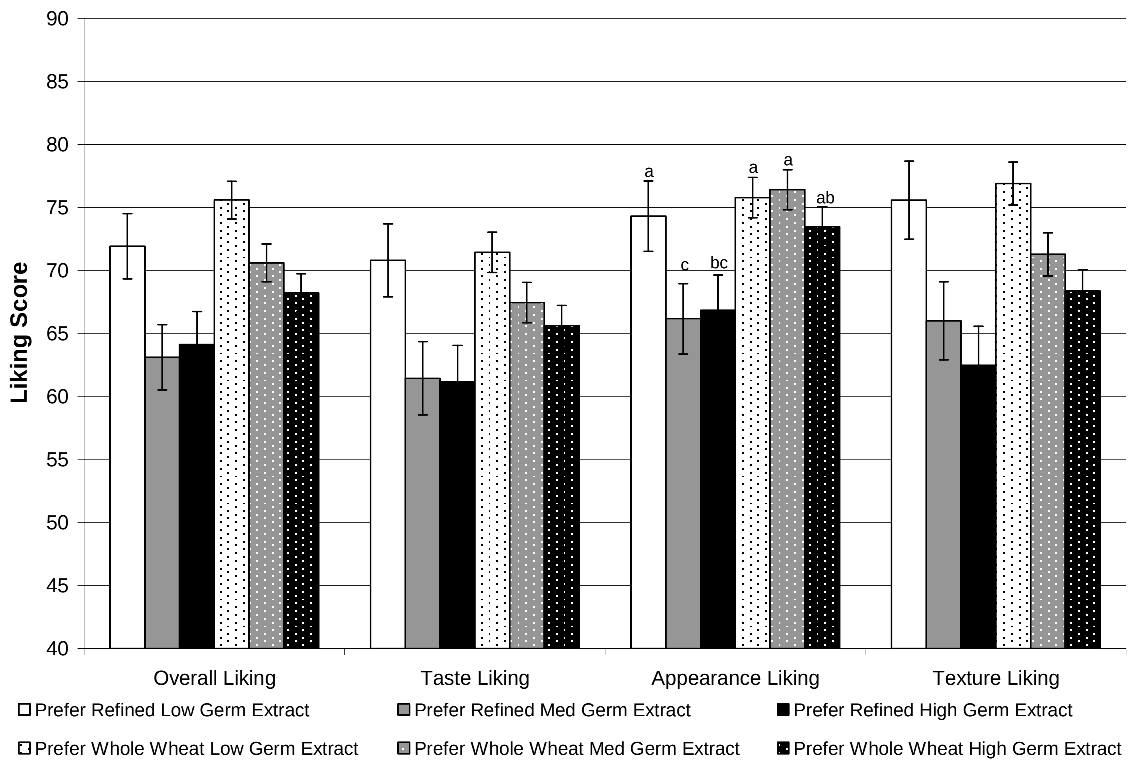
Average liking ratings for the three levels of added bitter germ extract. The left most set of bars represents overall liking scores, the next set of bars to the right represents taste liking scores, the set of bars second to the right represents appearance liking scores, and the right most set of bars represents texture liking scores. White bars represent samples with no added bitter germ extract, grey bars represent samples with the medium level of added bitter germ extract, and black bars represent samples with the highest level of added bitter germ extract. Seventy-eight subjects rated nine bread samples on 120 point LAM scales, where a rating of 60 corresponded to the descriptor 'neither like or dislike,' a rating of 67 corresponded to the descriptor 'like slightly', and a rating of 82 corresponded to the descriptor 'like moderately'. Bars within a liking measure grouping that share a letter designation do not significantly differ in liking.



Consumers whose bread type preference was refined liked the appearance of the bread with no added bitter germ extract better than the appearance of the breads with medium and high level bitter germ extract (both $t > 2.4$, both $p < 0.015$). Added bitter germ extract did not affect appearance liking scores for those consumers whose bread type preference was whole wheat (all $t < 1.8$, all $p > 0.081$) (Figure 9). While there were no significant interactions between bread type preference and added bitter germ extract for overall, taste, and texture liking, trends show that subjects whose bread type preference was whole wheat seem to be more accepting of breads with added bitter germ extract than are subjects whose bread type preference was refined.

Figure 9

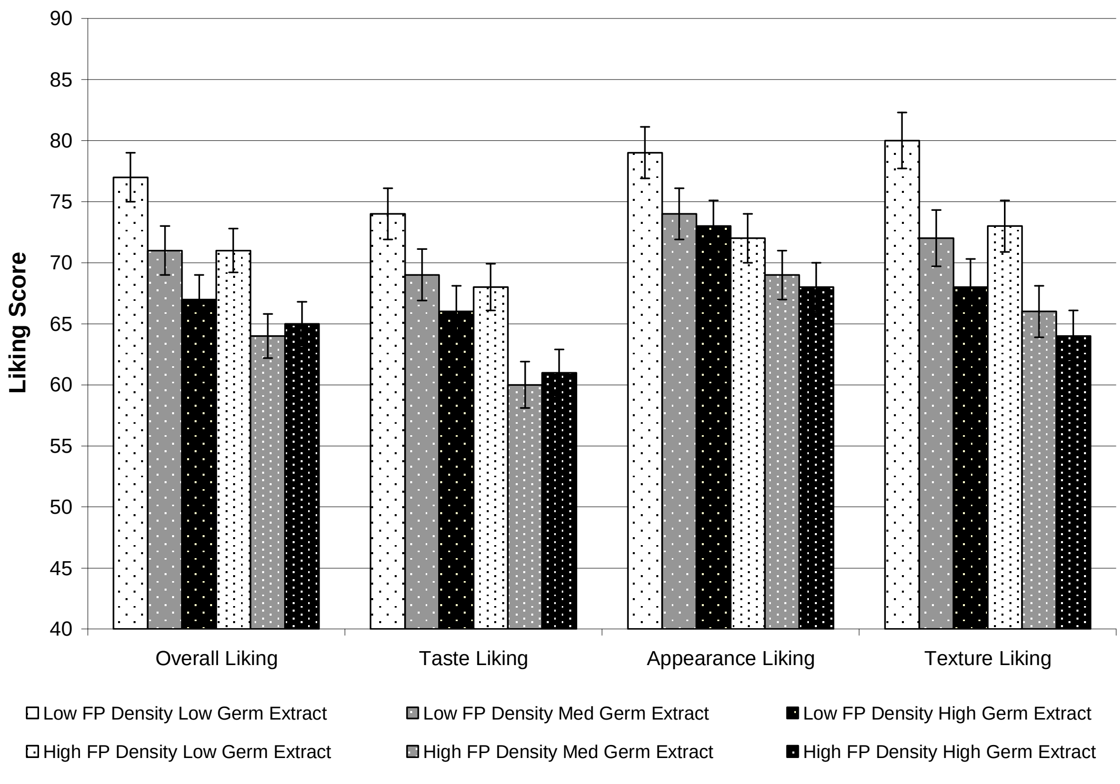
Average liking ratings for the three levels of added bitter germ extract for the two bread type preference groups. The left most set of bars represents overall liking scores, the next set of bars to the right represents taste liking scores, the set of bars second to the right represents appearance liking scores, and the right most set of bars represents texture liking scores. White bars represent samples with no added bitter germ extract, grey bars represent samples with the medium level of added bitter germ extract, and black bars represent samples with the highest level of added bitter germ extract; solid bars represent consumers whose bread type preference was refined wheat (21%) and dotted bars represent consumers who bread type preference was whole wheat (79%). Seventy-eight subjects rated nine bread samples on 120 point LAM scales, where a rating of 60 corresponded to the descriptor 'neither like or dislike,' a rating of 67 corresponded to the descriptor 'like slightly', and a rating of 82 corresponded to the descriptor 'like moderately'. Bars within a liking measure grouping that share a letter designation do not significantly differ in liking.



There were no significant interaction effects between added bitter germ extract and fungiform papillae density, although subjects with higher papillae densities tended to like all the breads less. (Figure 10)

Figure 10

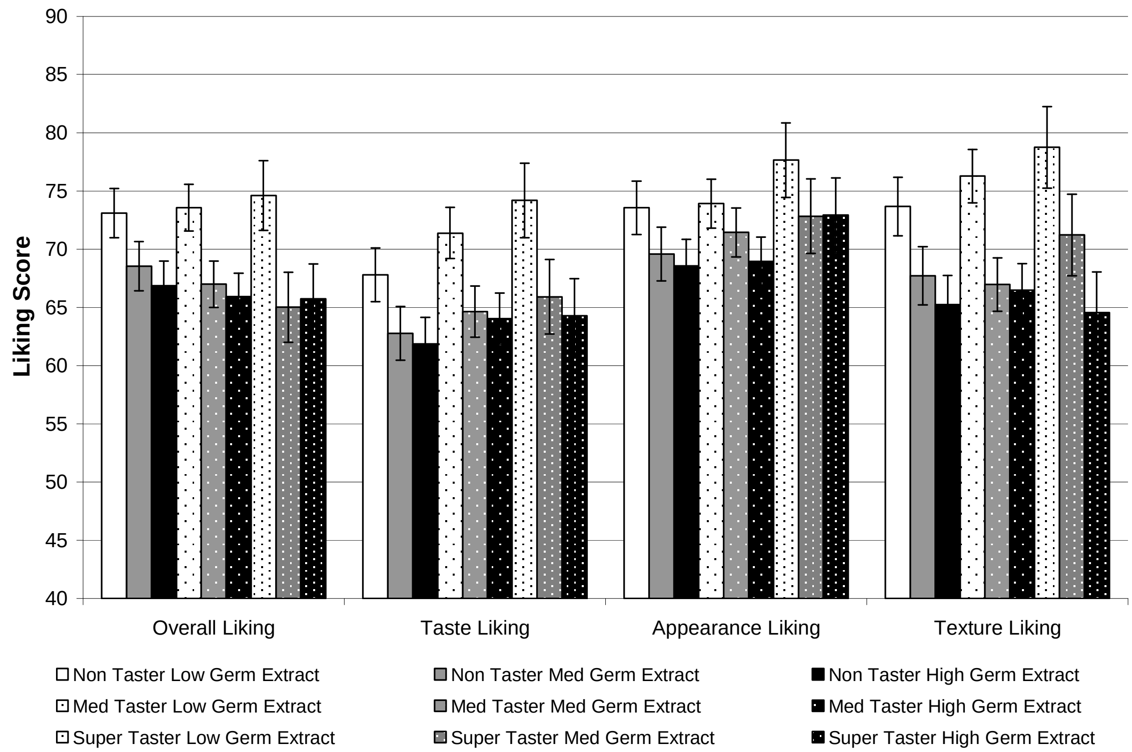
Average liking ratings for the three levels of added bitter germ extract for the two papillae density groups. The left most set of bars represents overall liking scores, the next set of bars to the right represents taste liking scores, the set of bars second to the right represents appearance liking scores, and the right most set of bars represent texture liking scores. White bars represent samples with no added bitter germ extract, grey bars represent samples with the medium level of added bitter germ extract, and black bars represent samples with the highest level of added bitter germ extract; sparsely dotted bars represent consumers with low papillae densities (54%) and densely dotted bars represent consumers with high papillae densities (46%). Seventy-eight subjects rated nine bread samples on 120 point LAM scales, where a rating of 60 corresponded to the descriptor 'neither like or dislike,' a rating of 67 corresponded to the descriptor 'like slightly', and a rating of 82 corresponded to the descriptor 'like moderately'.



There were no significant interaction effects between added bitter germ extract and taster status on liking. Trends were as we predicted, however; differences in overall, taste, and texture liking between breads with no added bitter germ extract and breads with added bitter germ extract were largest for supertasters and smallest for nontasters. (Figure 11)

Figure 11

Average liking ratings for the three levels of added bitter germ extract for the three taster status groups. The left most set of bars represents overall liking scores, the next set of bars to the right represents taste liking scores, the set of bars second to the right represents appearance liking scores, and the right most set of bars represents texture liking scores. White bars represent samples with no added bitter germ extract, grey bars represent samples with the medium level of added bitter germ extract, and black bars represent samples with the highest level of added bitter germ extract; solid bars represent nontasters (33%), sparsely dotted bars represent medium tasters (50%), and densely spotted bars represent super tasters (17%). Seventy-eight subjects rated nine bread samples on 120 point LAM scales, where a rating of 60 corresponded to the descriptor 'neither like or dislike,' a rating of 67 corresponded to the descriptor 'like slightly', and a rating of 82 corresponded to the descriptor 'like moderately'. Bars within a liking measure grouping that share a letter designation do not significantly differ in liking.

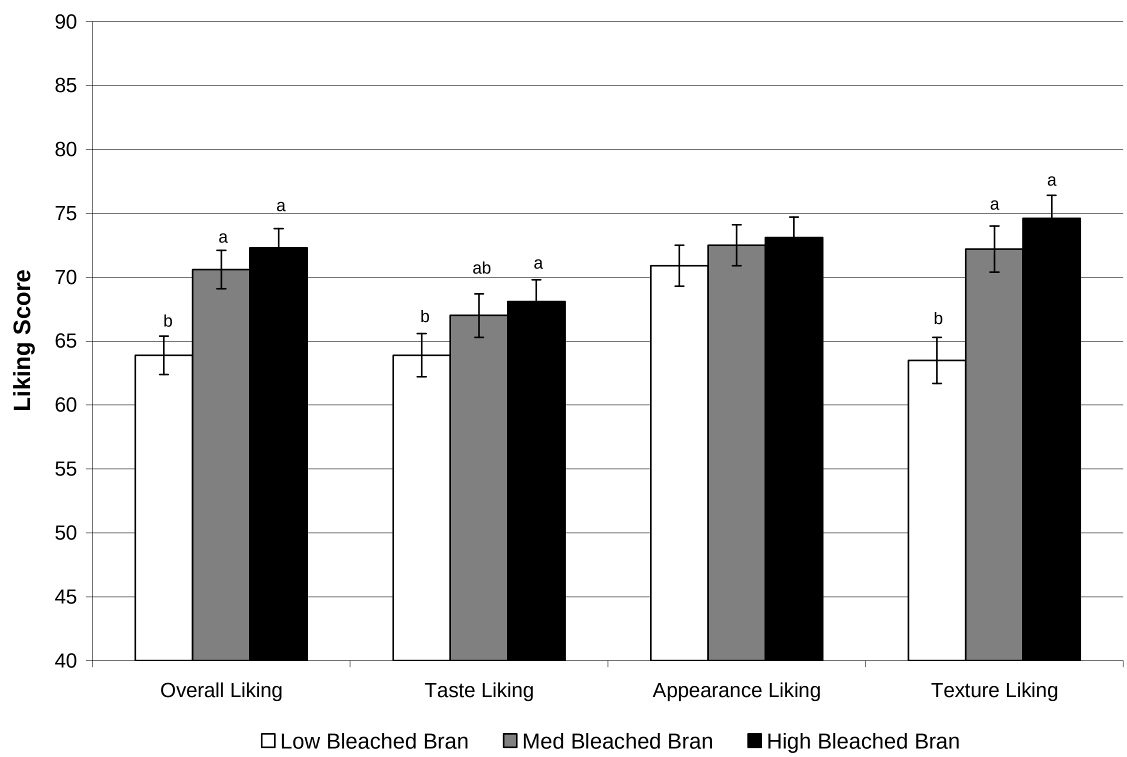


Effect of rough bleached bran addition on liking

Subjects rated breads with added rough bleached bran higher in overall and texture liking than breads with no added rough bleached bran (all $t > 3.7$, all $p < 0.0002$). Similar trends were found for taste liking, but the effect was not significant for appearance liking ($F=0.62$, $p=0.54$). (Figure 12)

Figure 12

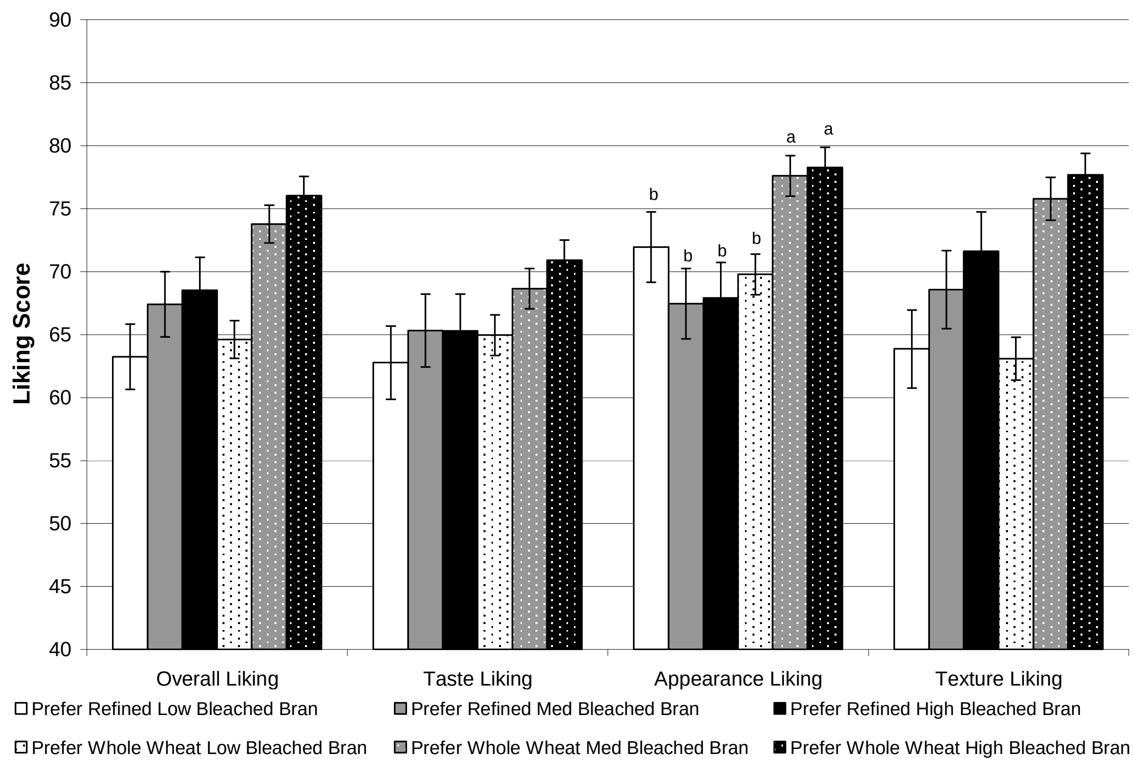
Average liking ratings for the three levels of added rough bleached bran. The left most set of bars represents overall liking scores, the next set of bars to the right represents taste liking scores, the set of bars second to the right represents appearance liking scores, and the right most set of bars represents texture liking scores. White bars represent samples with no added rough bleached bran, grey bars represent samples with the medium level of added rough bleached bran, and black bars represent samples with the highest level of added rough bleached bran. Seventy-eight subjects rated nine bread samples on 120 point LAM scales, where a rating of 60 corresponded to the descriptor 'neither like or dislike,' a rating of 67 corresponded to the descriptor 'like slightly', and a rating of 82 corresponded to the descriptor 'like moderately'. Bars within a liking measure grouping that share a letter designation do not significantly differ in liking.



Added rough bleached bran had a positive effect on appearance liking for those consumers whose bread type preference was whole wheat bread (all $t > 4.6$, all $p < 0.001$) and did not significantly affect appearance liking for those consumers whose bread type preference was refined wheat bread (all $t < 1.8$, all $p > 0.073$). There were no other significant interactions between bread type preference and added rough bleached bran, but subjects whose bread type preference was whole wheat tended to rate the breads with added rough bleached bran higher than did subjects who preferred refined breads. (Figure 13)

Figure 13

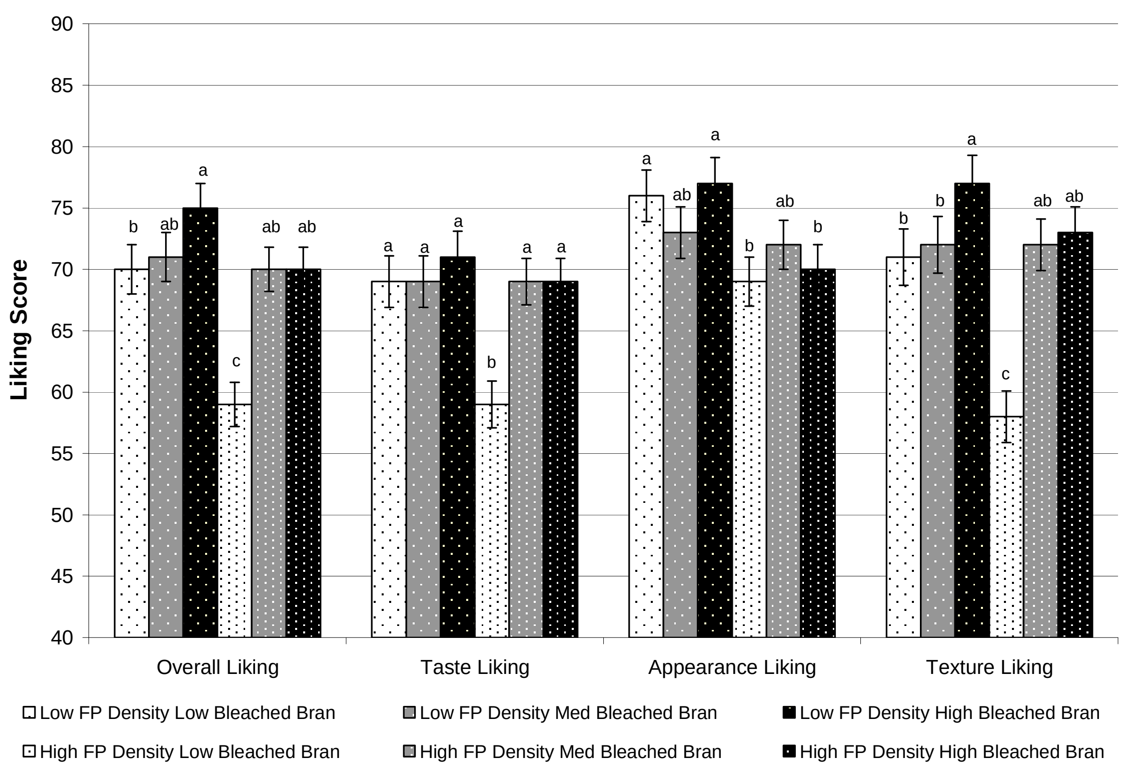
Average liking ratings for the three levels of added rough bleached bran for the two bread type preference groups. The left most set of bars represents overall liking scores, the next set of bars to the right represents taste liking scores, the set of bars second to the right represents appearance liking scores, and the right most set of bars represents texture liking scores. White bars represent samples with no added rough bleached bran, grey bars represent samples with the medium level of added rough bleached bran, and black bars represent samples with the highest level of added rough bleached bran; solid bars represent consumers whose bread type preference was refined wheat (21%) and dotted bars represent consumers who bread type preference was whole wheat (79%). Seventy-eight subjects rated nine bread samples on 120 point LAM scales, where a rating of 60 corresponded to the descriptor 'neither like or dislike,' a rating of 67 corresponded to the descriptor 'like slightly', and a rating of 82 corresponded to the descriptor 'like moderately'. Bars within a liking measure grouping that share a letter designation do not significantly differ in liking.



Addition of rough bleached bran at both high and medium levels increased overall, taste, and texture liking for subjects with high fungiform papillae density. The addition of rough bleached bran at the highest level increased overall liking and texture liking for consumers with low fungiform papillae densities (both $t > 2.4$, both $p < 0.018$). The trend was similar for taste liking. (Figure 14)

Figure 14

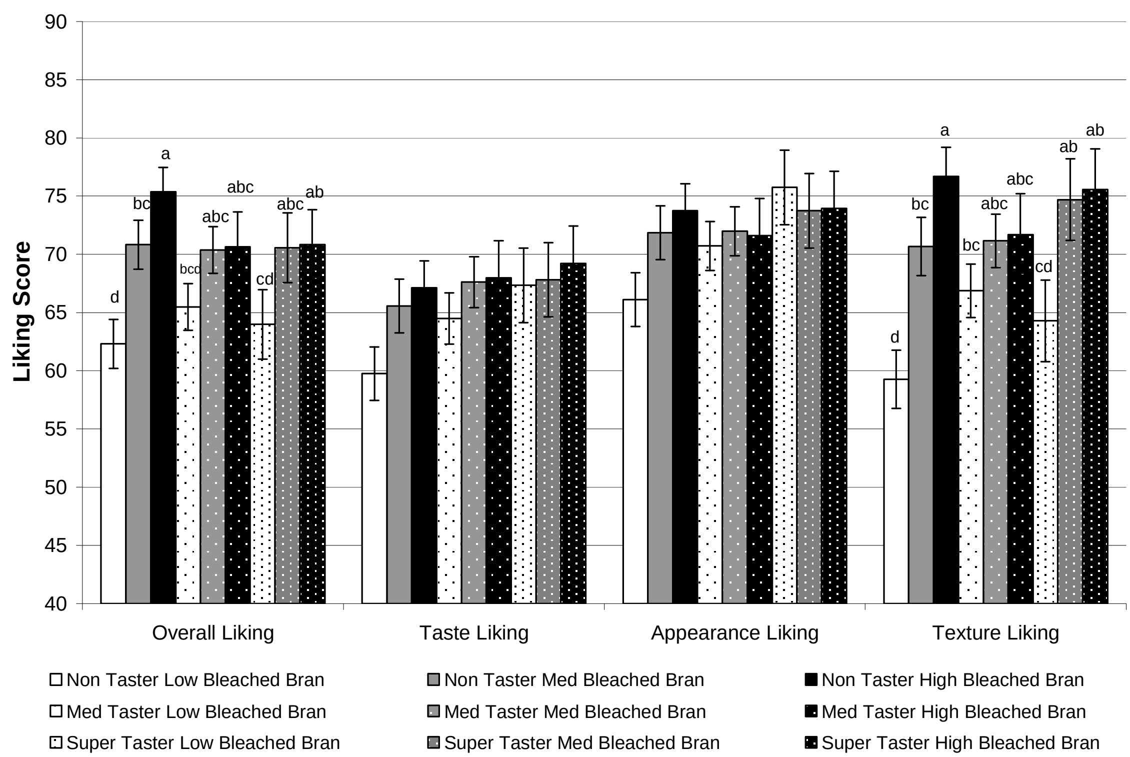
Average liking ratings for the three levels of added rough bleached bran for the two papillae density groups. The left most set of bars represents overall liking scores, the next set of bars to the right represents taste liking scores, the set of bars second to the right represents appearance liking scores, and the right most set of bars represents texture liking scores. White bars represent samples with no added rough bleached bran, grey bars represent samples with the medium level of added rough bleached bran, and black bars represent samples with the highest level of added rough bleached bran; sparsely dotted bars represent consumers with low papillae densities (54%) and densely dotted bars represent consumers with high papillae densities (46%). Seventy-eight subjects rated nine bread samples on 120 point LAM scales, where a rating of 60 corresponded to the descriptor 'neither like or dislike,' a rating of 67 corresponded to the descriptor 'like slightly', and a rating of 82 corresponded to the descriptor 'like moderately'. Bars within a liking measure grouping that share a letter designation do not significantly differ in liking.



Both nontasters and supertasters rated breads with added rough bleached bran significantly higher in overall and texture liking than bread without added rough bleached bran (all t > 1.9, all p < 0.054). The trend was similar but not significant for medium tasters (both t < 1.7, both p > 0.094). The effect of added rough bleached bran on overall and texture liking was greatest for nontasters. (Figure 15)

Figure 15

Average liking ratings for the three levels of added rough bleached bran for the three taster status groups. The left most set of bars represents overall liking scores, the next set of bars to the right represents taste liking scores, the set of bars second to the right represents appearance liking scores, and the right most set of bars represents texture liking scores. White bars represent samples with no added rough bleached bran, grey bars represent samples with the medium level of added rough bleached bran, and black bars represent samples with the highest level of added rough bleached bran; solid bars represent nontasters (33%), sparsely dotted bars represent medium tasters (50%), and densely spotted bars represent super tasters (17%). Seventy-eight subjects rated nine bread samples on 120 point LAM scales, where a rating of 60 corresponded to the descriptor 'neither like or dislike,' a rating of 67 corresponded to the descriptor 'like slightly', and a rating of 82 corresponded to the descriptor 'like moderately'. Bars within a liking measure grouping that share a letter designation do not significantly differ in liking.



Questionnaire

Taster status and fungiform papillae density did not affect liking ratings for any of the six cereal food items (all $F < 2.2$, all $p > 0.12$). Subjects whose bread type preference was refined rated their liking of popcorn ($F = 6.4$, $p = 0.014$) and corn chips ($F = 8.9$, $p = 0.004$) lower than did subjects whose bread type preference was whole wheat. Bread type preference was unrelated to liking for the other four cereal foods (all $F < 1.8$, all $p > 0.18$). (Table 12)

Table 12

Mean preference ratings for all cereal food items split by consumer subgroups. Consumers rated their liking for these items on 120 point LAM scales, where a rating of 60 corresponded to the descriptor 'neither like or dislike,' a rating of 67 corresponded to the descriptor 'like slightly', a rating of 82 corresponded to the descriptor 'like moderately', and a rating of 94 corresponds to 'like very much'.

Ratings within a row and column grouping that share a letter designation do not differ significantly at $p < 0.05$.

Cereal Food Item	All Consumers	Prefer Refined	Prefer Whole Wheat			Low Papillae Density	High Papillae Density			Non-taster	Medium Taster	Super Taster		
	Mean liking ratings	Mean liking ratings		F	p	Mean liking ratings		F	p	Mean liking ratings			F	p
Popcorn	86.7	**77.6 b**	**88.9 a**	**6.4**	**0.014**	86.4 a	86.9 a	0.02	0.89	82.0 a	87.7 a	92.8 a	2.2	0.12
Corn Tortilla Chips	85.0	**74.3 b**	**87.7 a**	**8.9**	**0.004**	86.5 a	83.6 a	0.62	0.43	82.3 a	86.2 a	86.5 a	0.52	0.59
Dry Cornflakes	71.1	66.4 a	73.0 a	1.8	0.18	72.0 a	71.3 a	0.03	0.87	67.8 a	72.5 a	77.0 a	1.3	0.28
White Rice	79.9	77.1 a	80.7 a	0.73	0.39	80.4 a	79.5 a	0.07	0.79	78.7 a	78.8 a	85.7 a	1.2	0.31
Cream of Wheat Cereal	69.1	73.2 a	68.0 a	0.61	0.43	70.3 a	68.0 a	0.19	0.66	67.2 a	69.6 a	71.4 a	0.16	0.86
Instant Oatmeal	73.5	68.1 a	74.9 a	1.7	0.20	77.0 a	70.4 a	2.3	0.13	73.1 a	70.8 a	82.5 a	1.9	0.16

Taster status was not related to the importance of taste, smell, texture, appearance, or nutritional value to the consumers when selecting foods (all $F < 2.1$, all $p > 0.13$). Subjects with higher papillae densities rated taste as more important than did subjects with lower papillae densities ($F = 5.2$, $p = 0.02$) . Papillae density did not affect the importance of nutrition, smell, texture, or appearance (all $F < 2.0$, all $p > 0.16$). Subjects whose bread type preference was whole wheat rated nutrition as more important than did subjects whose bread type preference was refined ($F = 4.0$, $p = 0.05$). Bread type preference did not affect the importance of taste, smell, texture, or appearance ($F < 0.70$, $p > 0.40$). (Table 13)

Table 13

Mean importance ratings for all factors affecting food choice split by consumer subgroups. Consumers rated the importance for these items on an 100 point unstructured line scales labeled with ‘Not at all Important’ on the left end and ‘Very Important’ on the right end. Ratings within a row and column group with the same letter do not differ significantly at $p < 0.05$.

Food Choice Factor	All Consumers	Prefer Refined	Prefer Whole Wheat			Low Papillae Density	High Papillae Density			Non-taster	Medium Taster	Super Taster		
	Mean importance ratings	Mean importance ratings		F	P	Mean importance ratings		F	P	Mean importance ratings			F	P
Taste	79.5	77.3 a	80.1 a	0.70	0.40	**76.2 a**	**82.6 a**	**5.3**	**0.02**	75.6 a	81.2 a	82.6 a	2.1	0.13
Smell	75.6	75.7 a	75.5 a	0.00	0.96	74.3 a	76.7 a	0.61	0.44	72.9 a	76.3 a	78.9 a	0.93	0.40
Nutritional Value	74.5	**67.8 b**	**76.3 a**	**4.0**	**0.05**	76.3 a	73.0 a	0.89	0.35	75.3 a	74.1 a	74.5 a	0.05	0.95
Appearance	68.8	68.2 a	69.0	0.04	0.85	71.6 a	76.4 a	2.0	0.16	68.6 a	68.3 a	71.1 a	0.16	0.86
Texture	66.3	65.9 a	56.4 a	0.01	0.92	65.7 a	66.9 a	0.09	0.76	64.1 a	68.7 a	63.5 a	0.77	0.47

None of the consumer classification factors, PROP taster status, fungiform papillae density, or bread type preference were related (Table 7). Nontasters had a median of 58 papillae (range 33-93), medium tasters 70 (37-121), and supertasters 76 (48-108).

Table 14

Counts of consumers that fell within the different classification groups. Exact Pearson's Chi-square tests were performed to determine if any of the classification groups were related.

Prop Taster Status	**Fungiform Papillae Density Group**	
	Low	**High**
Non-tasters	15	11
Medium Tasters	17	22
Super Tasters	5	8
	X^2= 1.7, p=0.46	
Prop Taster Status	**Bread Type Preference**	
	Refined	**Whole Wheat**
Non-tasters	8	18
Medium Tasters	5	34
Super Tasters	3	10
	X^2= 3.1, p=0.25	
Fungiform Papillae Density Group	**Bread Type Preference**	
	Refined	**Whole Wheat**
Low	7	30
High	9	32
	X^2= 0.11, p=0.79	

Discussion

Contrary to our hypothesis, the influence of bread bitterness on liking did not significantly depend on fungiform papillae density or PROP taster status, although supertasters tended to show bigger differences in liking between breads with no added bitter germ extract and bread with added bitter germ extract. Previous research in our laboratory showed medium tasters and supertasters like refined breads better than whole wheat breads, while nontasters liked refined and whole wheat breads equally well. We also found that perceived bitterness intensity from whole wheat bread increased with perceived PROP intensity. Those two studies included whole wheat breads, while this study used model breads. It is possible that the bitterness levels in our model breads were higher than what is typical for whole wheat. It is also possible that a higher level of bitterness would be discernable to consumers who might not perceive bitterness in conventional whole wheat breads. This may explain why we did not see significant interaction effects between taster status and bitterness level.

There is little information about the causes of bitterness in wheat breads. Previous speculation has focused on bran, more specifically phenolic acids in wheat bran, as the source of bread bitterness (Lehtinen, and Laakso, 2004). Jensen and others (personal communication, 2009) failed to find a relationship between free phenolic acid content and off flavor in bread but did find that an increase in lipid oxidation products accompanied an increase in bread off flavor over shelf life. We were unable to obtain bitter extracts from wheat bran in our laboratory, but were able to obtain bitter extracts from wheat germ. Although subjects were not specifically asked to rate bitterness intensity, eight subjects in our taste test commented that breads with added germ extract tasted bitter, while no subjects commented on bitterness in breads that did not contain germ extract, confirming our expectation that germ extract contributed bitter taste to bread. Subjects wore nose clips throughout the tasting, so any attributes contributing to taste liking would be restricted to basic tastes.

The addition of bitter germ extract resulted in lower appearance liking scores for only those subjects whose bread type preference was refined, which was unexpected since subjects were asked to make appearance liking ratings prior to tasting the products. All efforts were made to independently vary bread bitterness, color, and texture, but the addition of bitter germ extract may have resulted in slight color changes to the bread. It is also possible that despite the instructions, some subjects may have tasted the samples prior to rating their liking of the bread's appearance, which may have led to lower appearance liking ratings for the bitter tasting samples.

As expected, the addition of caramel color produced highly polarized reactions depending on the consumer's bread type preference. Added caramel color decreased liking for subjects whose bread type preference was refined bread and increased liking for subjects whose bread type preference was whole wheat bread. These results may present an opportunity for food manufacturers to reformulate products to appeal to those consumers whose current preference is refined breads. The availability of white wheat allows manufacturers to produce whole wheat breads with lighter color, which consumers may be more willing to accept. Lukow and others (2004) showed children preferred both the appearance and taste of whole white wheat bread over whole red wheat bread. Previous research in our laboratory, however, found no difference in liking between whole red wheat bread and whole white wheat bread.

We were quite surprised that the addition of rough bleached bran increased liking for all consumer groups when our previous research found lower texture liking for whole wheat breads compared to refined wheat breads. This finding may be a function of differences between our bread making process and typical procedures. In order to allow the caramel color to stain the rough bleached bran in breads that contained both additions, we soaked the bran in liquid overnight before baking. Presoaking bran allows for greater water absorption and results in improved loaf volume (Lai, Hoseney, and Davis, 1989) and may result in other improvements to bran-containing breads. Increased bread moisture is also associated with reduced firming rate over shelf life (He, and Hoseney, 1990), so the extra moisture in the bran-containing breads may have delayed bread firming. Manufacturers could overcome sensory problems, such as dryness, typically associated with whole wheat bread, by fully hydrating the bran via presoaking. We are not aware of any studies examining the effect of bran presoaking on liking. Future research into the nature of differences between refined bread and whole wheat bread texture and strategies to ameliorate these differences is warranted.

CHAPTER 5

CONCLUSIONS

A segment of the consumer population likes refined breads better than whole wheat breads, indicating that sensory properties are a barrier to consumption of whole wheat bread. A large proportion of subjects, however, like the commercially available samples of refined and whole wheat bread equally well, which may indicate that taste is not as great a barrier as has been previously assumed. For those consumers who dislike whole wheat bread, bitterness is likely to be a contributing factor. Dark color also contributes to bread dislike for subjects who prefer refined bread. While food manufacturers have already explored ways to overcome these sensory barriers, such as adding sugar to breads to counteract bitterness and using white wheat varieties to produce breads with lighter colors, some of these measures may not be the healthiest strategies to overcome these barriers. The Dietary Guidelines for Americans recommend that consumers limit their intake of added sugars, so this may not be the best strategy to ameliorate bitterness associated with whole wheat (U.S. Department of Health and Human Services, and U.S. Department of Agriculture, 2005). Future research into the specific causes of bitterness in whole wheat may lead to more desirable strategies, such as improved wheat breeding. We also did not find improvements in overall liking for whole wheat bread made with white wheat when compared to whole wheat bread made with red wheat. Although much lighter than red whole wheat bread, white whole wheat bread is still darker than refined wheat bread, so there may still be room to improve color. Darker color is associated with higher phenolic acid content, (Matus-Cadiz, et al, 2008) however, and high phenolic acid content is a purported mechanism for some of the benefits of whole grain foods (Slavin, 2004). A more appropriate strategy may be early interventions to shape consumer preferences in favor of darker colored breads, since large segments of our consumer population liked dark colored breads. Finally researchers studying whole wheat bread dislike may want to use PROP taster status as a recruitment criterion for any acceptance testing, since PROP supertasters perceived increased bread bitterness and roughness and tended to respond more negatively to both bitter and whole wheat breads compared to the general population. If breads were developed to satisfy these consumers, it is likely that they would also satisfy less discriminating consumers.

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APPENDIX I

Appendix I.I Sample Response Form for Study 1

Before you started this test, we looked at the bread label you brought with you today and assigned a letter designation to it. Please check the letter that was assigned to your bread label. (Check only one)

- ❑ A[1]
- ❑ B
- ❑ C

We asked you whether you would like butter, margarine, or nothing to eat with your bread samples. If you choose to use butter or margarine, please use approximately the same amount on all 9 samples.

Please check the spread that you will be using on your bread. (Check only one)

- ❑ Butter
- ❑ Margarine
- ❑ Nothing

Thanks for participating in this taste test on bread! The test will consist of two parts: Part I involves rating your liking of several bread samples. Part II involves rating the intensity of one non-bread sample. Below are the instructions for Part I of the taste test. You will receive instructions for Part II when you are finished with Part I. Please don't hesitate to ask if you have any questions!

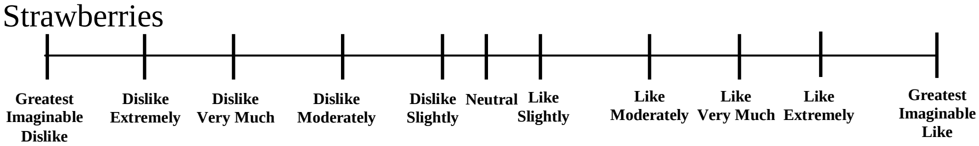
[1]*A was assigned to breads containing 100% whole grain flour, B was assigned to breads containing both whole grain and refined flours, C was assigned to breads containing 100% refined flours.*

Instructions for Part I:

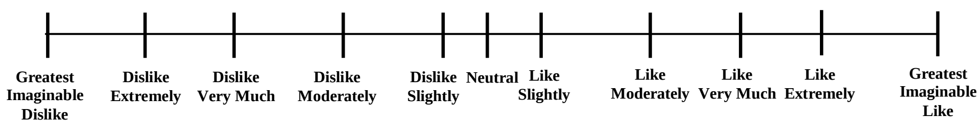
The you will be using for Part I is a line scale labeled with Greatest Disliking on the left end and Greatest Liking on the right end. These labels refer to the greatest disliking/liking you could feel in any situation, not only in reference to foods.

Please rate your liking of each of the following food items/situations by placing a vertical mark on the scale at a position that best describes your liking of that item. You can use any part of the scale that seems appropriate.

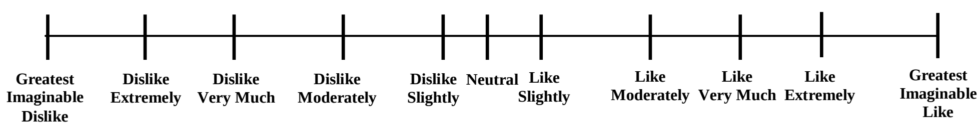
Strawberries



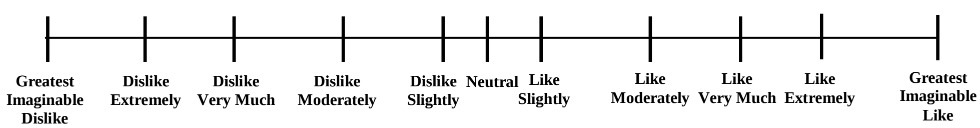
Mayonnaise



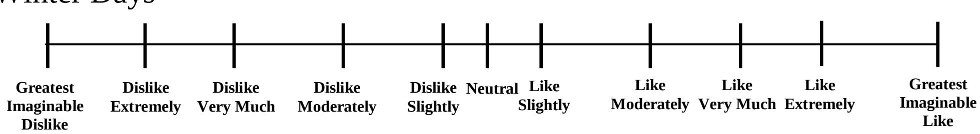
Kittens



Brussel Sprouts



Winter Days



Waiting in Line

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

Freshly Baked Cookies

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

Milk Chocolate

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

Grapefruit Juice

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

Getting a Traffic Ticket

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

Whipped Cream

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

Cooked mushrooms

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

Having a vacation day from work or school

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

You will receive nine samples coded with three digit numbers. Rate your response to the sample attributes by marking the position that best describes your liking of the attribute. Please make sure the sample code matches the code on the sheet you are marking.

Please look at Sample XXX and rate your liking of it based on its APPEARANCE only.

Sample XXX

Appearance Liking

Greatest Imaginable Dislike	**Dislike Extremely**	**Dislike Very Much**	**Dislike Moderately**	**Dislike Slightly**	**Neutral**	**Like Slightly**	**Like Moderately**	**Like Very Much**	**Like Extremely**	**Greatest Imaginable Like**

Now, you may spread butter or margarine on the bread if desired. Taste the sample and then rate it for the following attributes.

Overall Liking

Greatest Imaginable Dislike	**Dislike Extremely**	**Dislike Very Much**	**Dislike Moderately**	**Dislike Slightly**	**Neutral**	**Like Slightly**	**Like Moderately**	**Like Very Much**	**Like Extremely**	**Greatest Imaginable Like**

Texture Liking

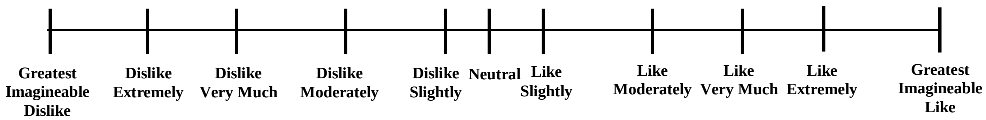
Greatest Imaginable Dislike	**Dislike Extremely**	**Dislike Very Much**	**Dislike Moderately**	**Dislike Slightly**	**Neutral**	**Like Slightly**	**Like Moderately**	**Like Very Much**	**Like Extremely**	**Greatest Imaginable Like**

Flavor Liking

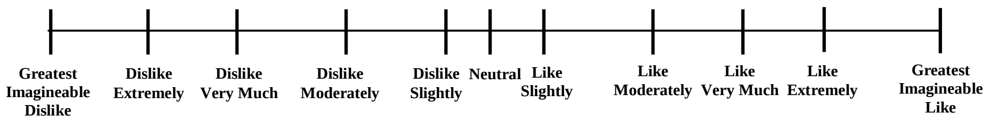
Greatest Imagineable Dislike	**Dislike Extremely**	**Dislike Very Much**	**Dislike Moderately**	**Dislike Slightly**	**Neutral**	**Like Slightly**	**Like Moderately**	**Like Very Much**	**Like Extremely**	**Greatest Imagineable Like**

Additional Comments

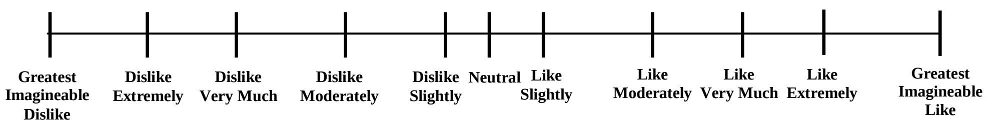
Please rate your liking of the best white bread (including home baked,specialty bakery, grocery store, etc…) you have ever tasted.



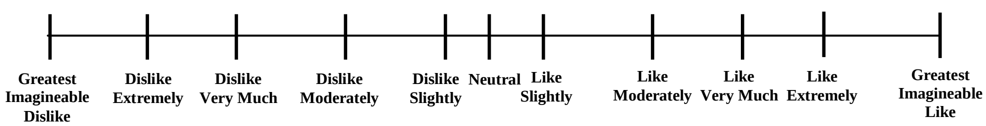
Please rate your liking of the best 100% whole wheat bread (including home baked, specialty bakery, grocery store, etc…) you have ever tasted.



Please rate your liking of the worst white bread (including home baked, specialty bakery, grocery store, etc…) you have ever tasted.



Please rate your liking of the worst 100% whole wheat bread (including home baked, specialty baker, grocery store, etc…) you have ever tasted.



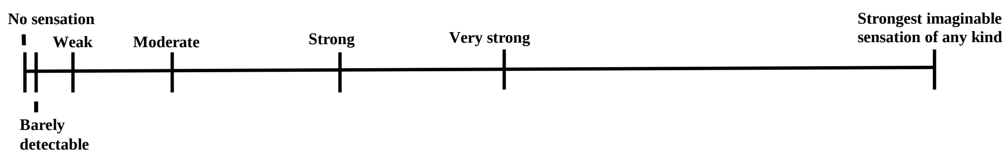
Instructions for Part II:

The scale you will be using for Part II is a line scale labeled with No Sensation on the left end and Strongest Sensation on the right end.

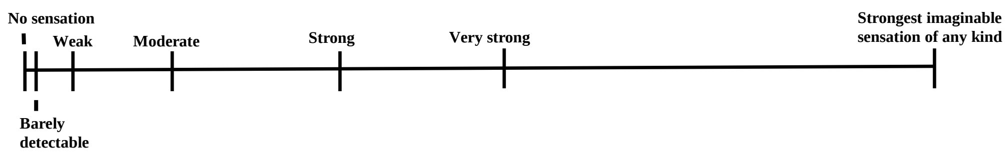
Think of the label, Strongest Sensation as the most intense sensation of any kind that you might experience with any of your senses.

Please rate the intensity of the following sensations (relative to any sensations you might experience with any of you senses). Rate the intensity by marking the scale at a position that best describes how intense you remember/ imagine those sensations to be. You can use any part of the line scale that seems appropriate.

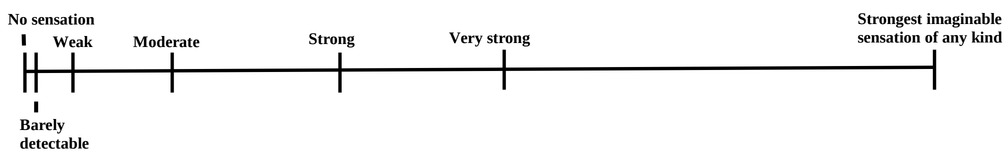
Brightness of a dimly-lit restaurant



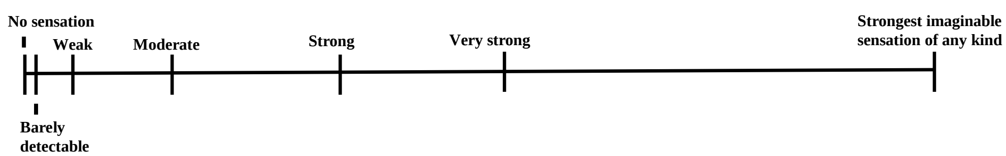
Brightness of the sun when looking directly at it



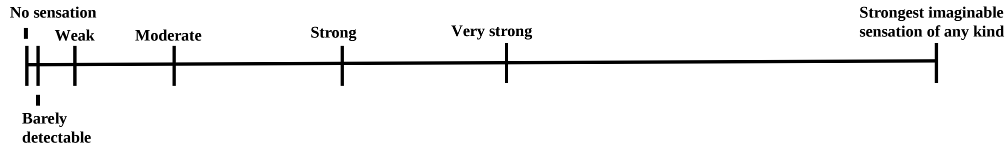
Loudness of a whisper



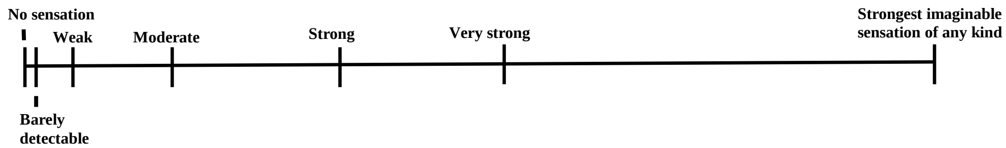
Loudness of a conversation



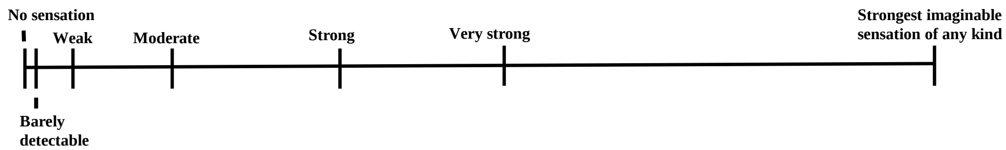
Smell of a rose



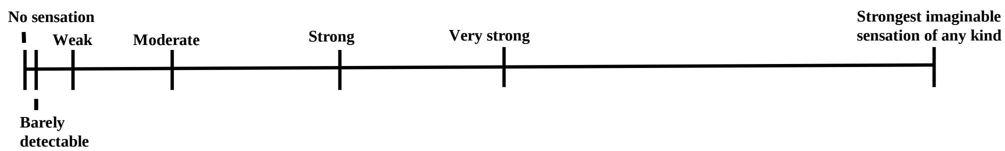
Sweetness of a Coke



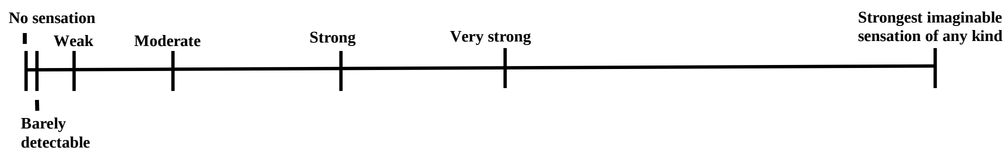
Bitterness of black coffee



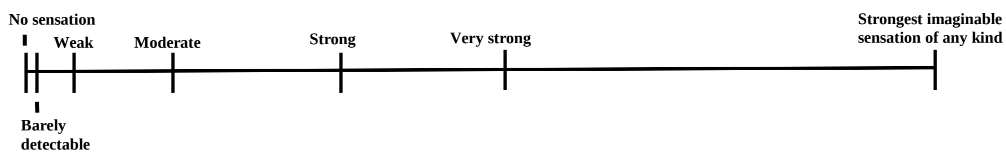
Saltiness of potato chips



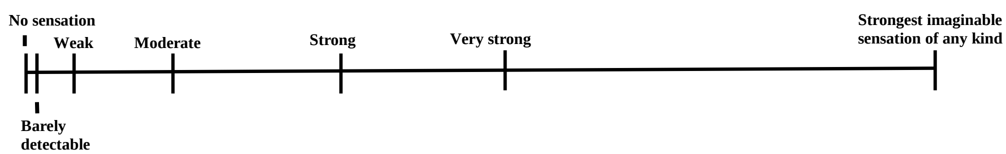
Loudness of a jet plane taking off 10 feet from you



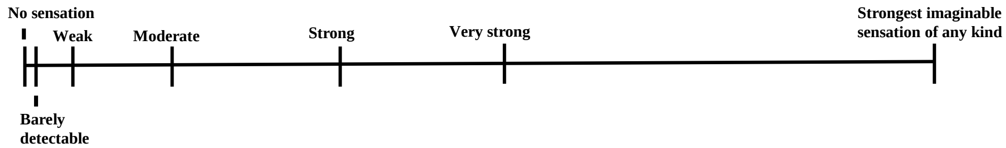
Strongest sweetness experienced



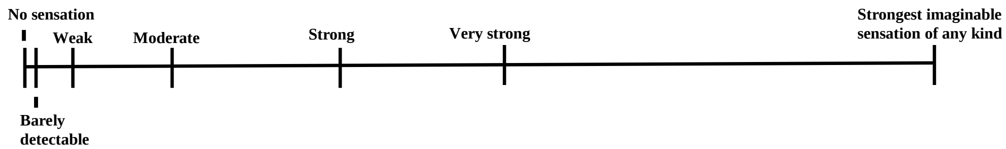
Sourness of a fresh lemon slice



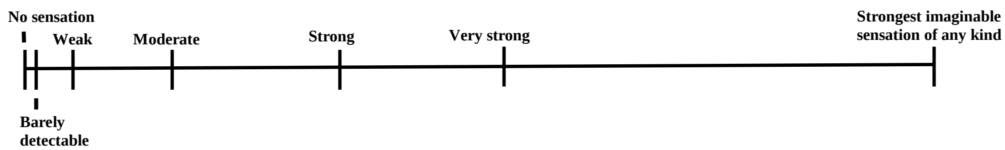
Oral burn from drinking a cold carbonated soda



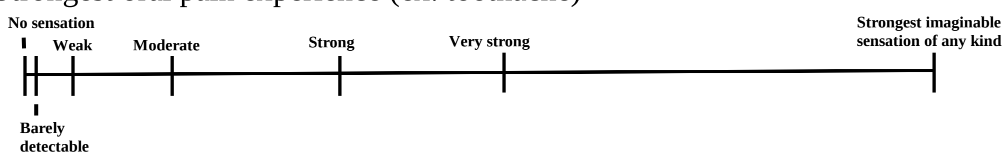
Brightness of this room



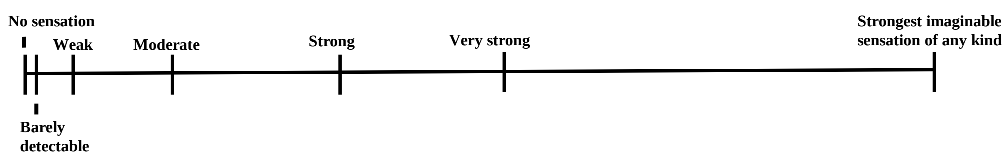
Strongest oral burn experienced (ex. eating a hot pepper, such as jalepeno)



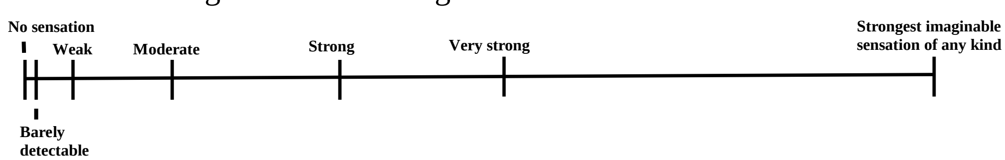
Strongest oral pain experience (ex. toothache)



Strongest pain of any kind experienced



Heat felt standing 5 feet from a large bonfire



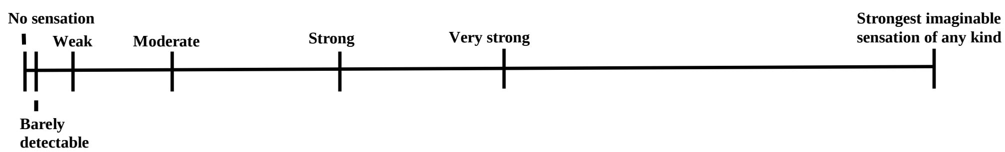
This is your last taste rating.

Put all of SAMPLE 001 into your mouth.

Swirl it around. DO NOT SWALLOW IT.

Rate the intensity of the sample by marking the scale position that best describes what you are experiencing. You can use any part of the line scale that seems appropriate.

Expectorate all of the sample into the cup provided to you.



Which bread do you prefer? (Check one)

- ❑ 100% Whole Wheat Bread
- ❑ White Bread

Why do you prefer this type of bread? (Check all that apply)

- ❑ Taste
- ❑ Smell
- ❑ Texture
- ❑ Nutrient Value
- ❑ Price
- ❑ Convenience
- ❑ Stays Fresh
- ❑ What you’re familiar with
- ❑ Other (Please Specify)_______________

Where do you obtain the bread you eat most often?

- ❑ Grocery Store
- ❑ Bakery
- ❑ Other Retailer
- ❑ Someone buys or provides it for me
- ❑ Other

Appendix I.II SAS Code for Study 1 Data Analysis

```
libname xxx 'g:\fscn\vickers_lab\bakke\my sas files\';
run;
/* Overall Liking and contrasts all consumers */
proc mixed data=xxx.all;
class bread;
model overall=bread;
random judge;
lsmeans bread / diff;
contrast 'whole vs. refined'
bread 5 -4 5 -4 5 -4 -4 5 -4;
contrast 'bakery ww vs. bakery refined'
bread 1 -1 0 0 0 0 0 0 0;
contrast 'commercial ww vs. commercial refined'
bread 0 0 0 0 0 0 -1 0 1;
contrast 'red refined vs. red ww'
bread 0 0 1 -1 0 0 0 0 0;
contrast 'white refined vs. white ww'
bread 0 0 0 0 1 -1 0 0 0;
contrast 'red refined vs. red mspv ww'
bread 0 0 1 0 0 0 0 -1 0;
contrast 'red vs. white'
bread 0 0 .5 .5 -.5 -.5 0 0 0;
contrast 'red ww vs. red mspv ww'
bread 0 0 0 1 0 0 0 -1 0;
contrast 'bakery and commercial refined vs. whole wheat'
bread .5 -.5 0 0 0 0 .5 0 -.5;
contrast 'lab refined vs. whole wheat'
bread 0 0 3 -2 3 -2 0 -2 0;
run;
/* Flavor Liking and contrasts all consumers */
proc mixed data=xxx.all;
class bread;
model flavor=bread;
random judge;
lsmeans bread /pdiff;
contrast 'whole vs. refined'
bread 5 -4 5 -4 5 -4 -4 5 -4;
contrast 'bakery ww vs. bakery refined'
bread 1 -1 0 0 0 0 0 0 0;
contrast 'commercial ww vs. commercial refined'
bread 0 0 0 0 0 0 -1 0 1;
```

```
contrast 'red refined vs. red ww'
bread 0 0 1 -1 0 0 0 0 0;
contrast 'white refined vs. white ww'
bread 0 0 0 0 1 -1 0 0 0;
contrast 'red refined vs. red mspv ww'
bread 0 0 1 0 0 0 0 -1 0;
contrast 'red vs. white'
bread 0 0 .5 .5 -.5 -.5 0 0 0;
contrast 'red ww vs. red mspv ww'
bread 0 0 0 1 0 0 0 -1 0;
run;
/* Texture Liking and contrasts all consumers */
proc mixed data=xxx.all;
class bread;
model texture=bread;
random judge;
lsmeans bread /diff;
contrast 'whole vs. refined'
bread 5 -4 5 -4 5 -4 -4 5 -4;
contrast 'bakery ww vs. bakery refined'
bread 1 -1 0 0 0 0 0 0 0;
contrast 'commercial ww vs. commercial refined'
bread 0 0 0 0 0 0 -1 0 1;
contrast 'red refined vs. red ww'
bread 0 0 1 -1 0 0 0 0 0;
contrast 'white refined vs. white ww'
bread 0 0 0 0 1 -1 0 0 0;
contrast 'red refined vs. red mspv ww'
bread 0 0 1 0 0 0 0 -1 0;
contrast 'red vs. white'
bread 0 0 .5 .5 -.5 -.5 0 0 0;
contrast 'red ww vs. red mspv ww'
bread 0 0 0 1 0 0 0 -1 0;
run;
/* Appearance Liking and contrasts all consumers */
proc mixed data=xxx.all;
class bread;
model appear=bread;
random judge;
lsmeans bread /diff;
contrast 'whole vs. refined'
bread 5 -4 5 -4 5 -4 -4 5 -4;
contrast 'bakery ww vs. bakery refined'
```

```
bread 1 -1 0 0 0 0 0 0 0;
contrast 'commercial ww vs. commercial refined'
bread 0 0 0 0 0 0 -1 0 1;
contrast 'red refined vs. red ww'
bread 0 0 1 -1 0 0 0 0 0;
contrast 'white refined vs. white ww'
bread 0 0 0 0 1 -1 0 0 0;
contrast 'red refined vs. red mspv ww'
bread 0 0 1 0 0 0 0 -1 0;
contrast 'red vs. white'
bread 0 0 .5 .5 -.5 -.5 0 0 0;
contrast 'red ww vs. red mspv ww'
bread 0 0 0 1 0 0 0 -1 0;
run;
/*End Liking and contrasts for all consumers*/
/*Liking by consumer groups- Serving order, spread type,
and the interactions of serving order and bread and spread type and bread were
originally included in the model, but were never significant, so they were
removed.*/
/*Overall liking by preference*/
proc mixed data=xxx.all;
class bread preference;
model overall=bread preference preferen*bread;
random judge(preference);
lsmeans preference*bread /pdiff;
run;
/*Overall liking by bread most purchased (label)*/
proc mixed data=xxx.all;
class bread label;
model overall=bread label label*bread;
random judge(label);
lsmeans label*bread /pdiff;
run;
/*Overall liking by taster status*/
proc mixed data=xxx.all;
class bread taster;
model overall=bread taster taster*bread;
random judge(taster);
lsmeans taster*bread;
run;
/*Flavor liking by preference*/
proc mixed data=xxx.all;
class bread preference;
```

```
model flavor=bread preference preference*bread;
random judge(preference);
lsmeans preference*bread /pdiff;
run;
/*Flavor liking by bread most purchased (label)*/
proc mixed data=xxx.all;
class bread label;
model flavor=bread label label*bread;
random judge(label);
lsmeans label*bread /pdiff;
run;
/*Flavor liking by taster status*/
proc mixed data=xxx.all;
class bread taster;
model flavor=bread taster taster*bread;
random judge(t);
lsmeans t*bread /pdiff;
run;
/*texture liking by preference*/
proc mixed data=xxx.all;
class bread preference;
model appear=bread preference preference*bread;
random judge(preference);
lsmeans preference*bread /pdiff;
run;
/*texture liking by bread most purchased (label)*/
proc mixed data=xxx.all;
class bread label;
model texture=bread label label*bread;
random judge(label);
lsmeans label*bread /pdiff;
run;
/*texture liking by taster status*/
proc mixed data=xxx.all;
class bread taster;
model texture=bread taster taster*bread;
random judge(taster);
lsmeans taster*bread /pdiff;
run;
/*Appearnce liking by preference*/
proc mixed data=xxx.all;
class bread preference;
model appear=bread preference preference*bread;
```

```
random judge(preference);
lsmeans preference*bread /pdiff;
run;
/*Appearance liking by bread most purchased (label)*/
proc mixed data=xxx.all;
class bread label;
model appear=bread label label*bread;
random judge(label);
lsmeans label*bread /pdiff;
run;
/*Appearance liking by taster status*/
proc mixed data=xxx.all;
class bread taster;
model appear=bread taster taster*bread;
random judge(taster);
lsmeans taster*bread /pdiff;
run;
/*Frequencies*/
/* Main Frequencies */
proc freq data=xxx.newprefer;
tables prerfertaste prefersmell prefertexture prefernutrition preferprice
preferconvenience preferfreshness prerffamiliarity / CHISQ;
run;
proc freq data=xxx.newprefer;
tables grocery bakery otheretail someelse obtainother;
run;
/* Frequencies between consumer classification groups */
proc freq data=xxx.newprefer;
tables label*preference / CHISQ;
exact pchi;
run;
proc freq data=xxx.newprefer;
tables taster*preference / CHISQ;
exact pchi;
run;
proc freq data=xxx.newprefer;
tables taster*label / CHISQ;
exact pchi;
run;
/* Frequencies by Preference */
proc freq data=xxx.newprefer;
tables prefertexture*preference / CHISQ;
exact pchi;
```

```
run;
proc freq data=xxx.newprefer;
tables prefertaste*preference / CHISQ;
exact pchi;
run;
proc freq data=xxx.newprefer;
tables prefersmell*preference / CHISQ;
exact pchi;
run;
proc freq data=xxx.newprefer;
tables prefernutrition*preference / CHISQ;
exact pchi;
run;
proc freq data=xxx.newprefer;
tables preferprice*preference / CHISQ;
exact pchi;
run;
proc freq data=xxx.newprefer;
tables preferconvenience*preference / CHISQ;
exact pchi;
run;
proc freq data=xxx.newprefer;
tables preferfreshness*preference / CHISQ;
exact pchi;
run;
proc freq data=xxx.newprefer;
tables preferfamiliariry*preference / CHISQ;
exact pchi;
run;
proc freq data=xxx.newprefer;
tables grocery*preference / CHISQ;
exact pchi;
run;
proc freq data=xxx.newprefer;
tables bakery*preference / CHISQ;
exact pchi;
run;
proc freq data=xxx.newprefer;
tables otherretail*preference / CHISQ;
exact pchi;
run;
proc freq data=xxx.newprefer;
tables someoneelse*preference / CHISQ;
```

```
exact pchi;
run;
```

APPENDIX II

Appendix II.I Sample Response Form for Study 2

NAME_____________________________

Please indicate your gender.

_________ Male ___________ Female

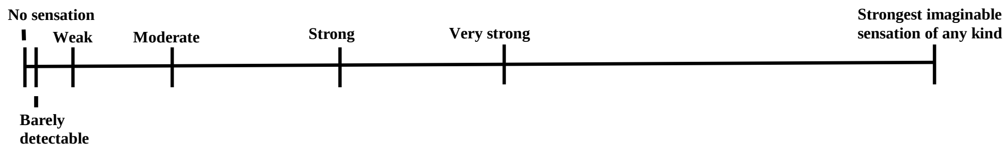
Please indicate your age.

____

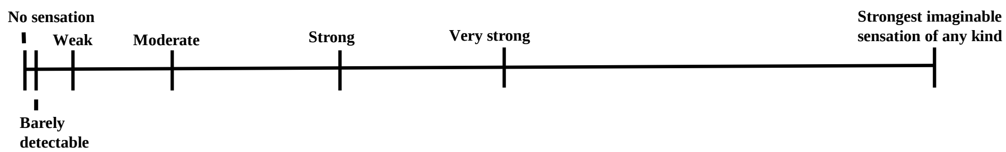
The scale you will be using is a line scale labeled with "No sensation" on the left end and "strongest imaginable sensation of any kind" on the right end. Think of the label, "Strongest imaginable sensation of any kind" as the most intense sensation of any kind that you might experience with <u>any of your senses.</u>

Please rate the intensity of the following sensations (relative to any sensations you might experience with any of your senses). Rate the intensity by placing a vertical mark on the scale at any position that best describes how you remember/ imagine those sensations to be. You can use any part of the line scale that seems appropriate.

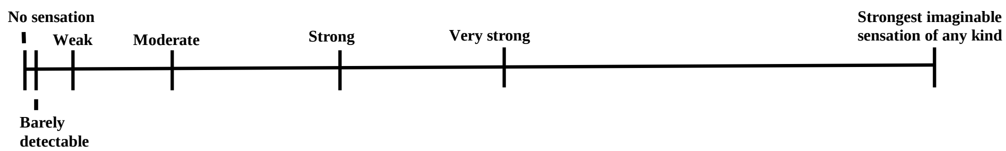
Brightness of a dimly-lit restaurant



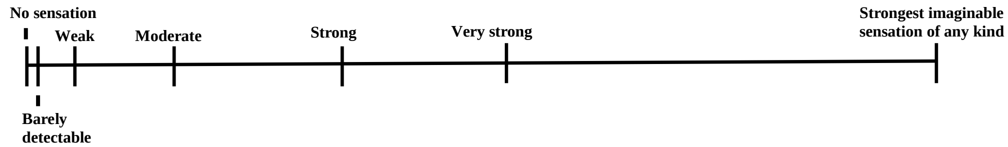
Brightness of the sun when looking directly at it



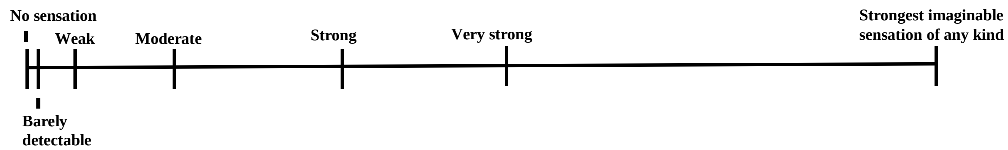
Loudness of a whisper



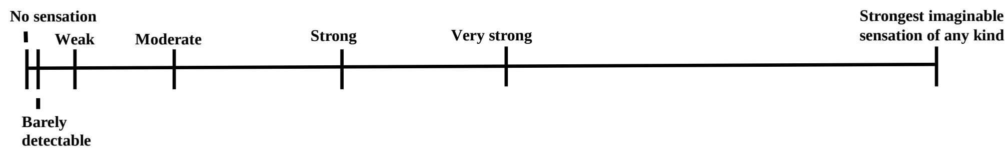
Loudness of a conversation



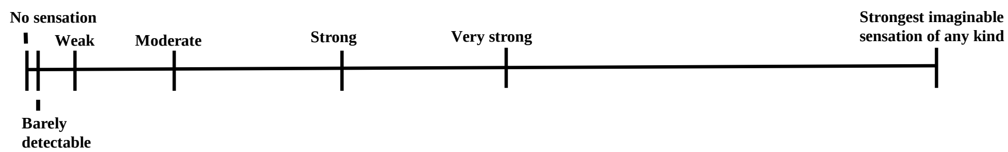
Smell of a rose



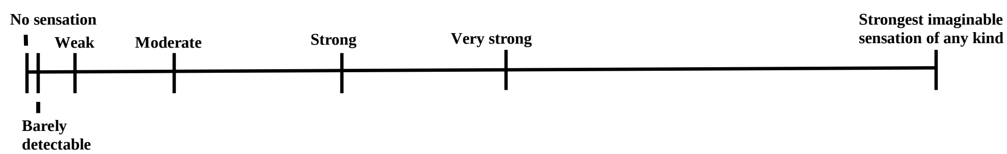
Sweetness of a Coke



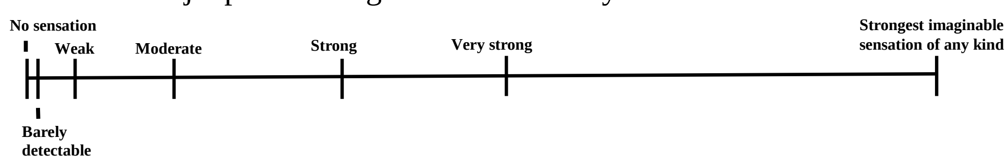
Bitterness of black coffee



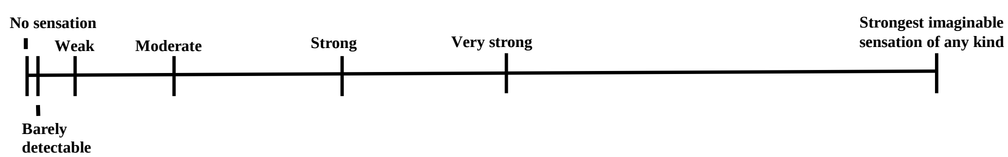
Saltiness of potato chips



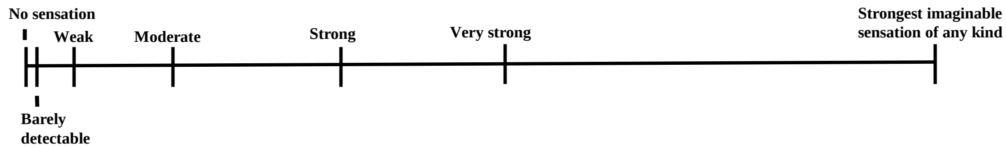
Loudness of a jet plane taking off 10 feet from you



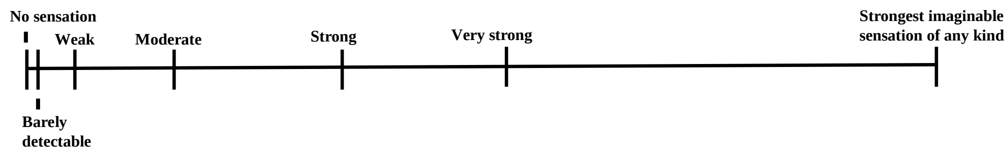
Strongest sweetness experienced



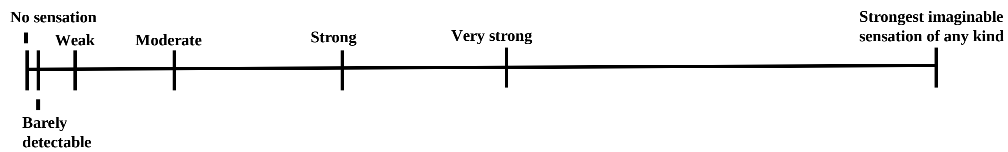
Sourness of a fresh lemon slice



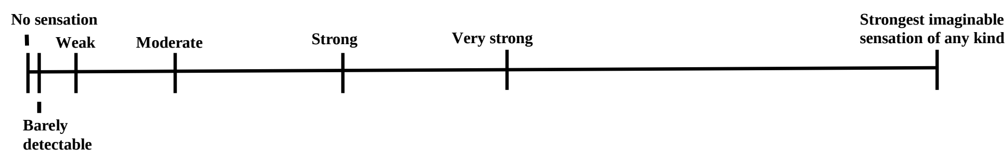
Oral burn from drinking a cold carbonated soda



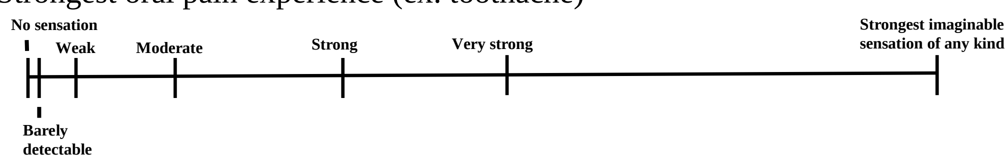
Brightness of this room



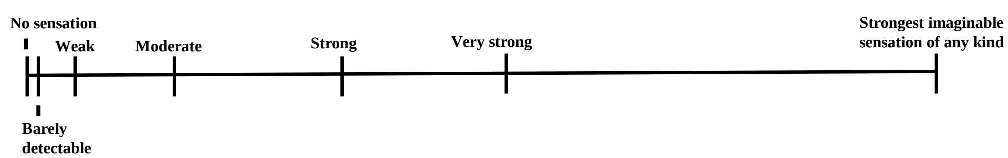
Strongest oral burn experienced (ex. eating a hot pepper, such as jalepeno)



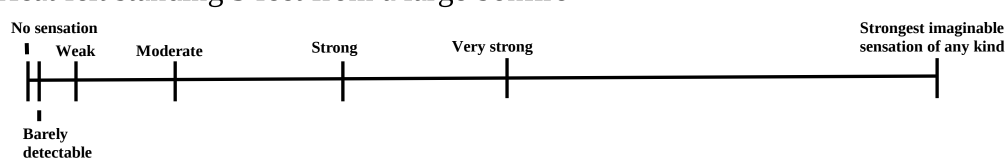
Strongest oral pain experience (ex. toothache)



Strongest pain of any kind experienced



Heat felt standing 5 feet from a large bonfire

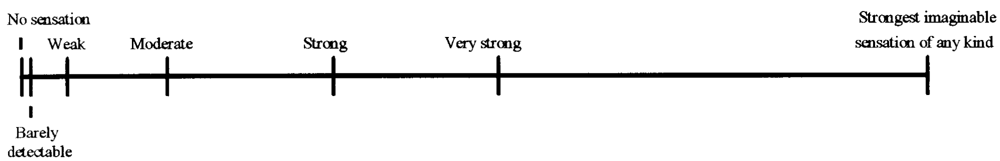


You will receive eight samples coded with three digit numbers. Rate your response to the sample attributes on the score sheets provided. Please make sure the score sheet code matches the sample code. Place a mark anywhere on the line corresponding to your response.

Sample XXX

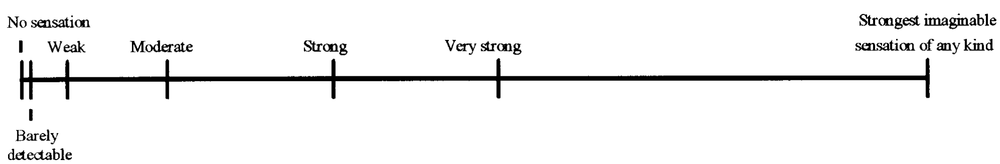
Take a large bite of the bread (avoiding the crust) and using your tongue touch the bread to the roof of your mouth. Immediately, rate how rough the sample feels.

Roughness

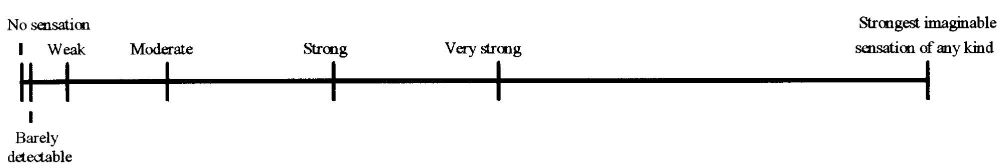


Continue to chew the sample, swallow, and rate its sweetness and bitterness.

Sweetness



Bitterness



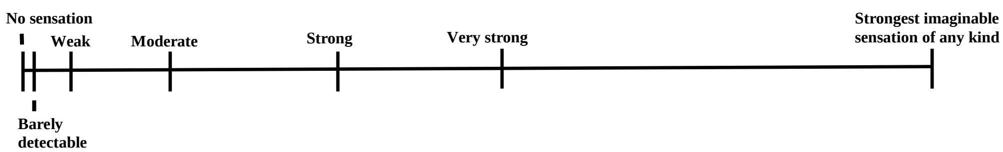
This is your last taste rating.

Put all of SAMPLE 001 into your mouth.

Swirl it around. DO NOT SWALLOW IT.

Rate the intensity of the sample by marking the scale position that best describes what you are experiencing. You can use any part of the line scale that seems appropriate.

Expectorate all of the sample into the cup provided to you.



Appendix II.II SAS Code for Study 2 Data Analysis

```
libname xxx 'e:my sas files';
run;
/* Changes in roughness, bitterness, and sweetness over time*/
proc mixed data=xxx.breadtextureall;
class day bread gender judge;
model lnrough = order age gender bread day day*bread / ddfm=satterth;
random judge;
lsmeans day*bread / pdiff;
run;
proc mixed data=xxx.breadtextureall;
class day bread gender judge;
model lnbitter = order age gender bread day day*bread / ddfm=satterth;
random judge;
lsmeans day*bread / pdiff;
run;
proc mixed data=xxx.breadtextureall;
class day bread gender judge;
model lnsweet = order age gender bread day day*bread;
random judge;
lsmeans day*bread / pdiff;
run;
/* End changes in roughness, bitterness, and sweetness over time*/
/* Roughness, sweetness, and bitterness vs. PROP and papillae*/
/*Formatting variables*/
data xxx.intensity;
set xxx.breadtextureall;
lnpapillae= log(papillae);
run;
data xxx.intensity;
set xxx.intensity;
if bread = 'whole' then b = 1;
else if bread = 'refined' then b=0;
run;
data xxx.intensity;
set xxx.intensity;
if gender = 'male' then g=1;
else if gender = 'female' then g=0;
run;
data xxx.intensity;
set xxx.intensity;
lnpapillaeb= b*lnpapillae;
```

```
run;
data xxx.intensity;
set xxx.intensity;
lnpapillaebd= b*lnpapillae*day;
run;
data xxx.intensity;
set xxx.intensity;
lnpropb= b*lnprop;
run;
data xxx.intensity;
set xxx.intensity;
lnpropbd= b*lnprop*day;
run;
data xxx.intensity;
set xxx.intensity;
lnpapillaed= day*lnpapillae;
run;
data xxx.intensity;
set xxx.intensity;
lnpropd= day*lnprop;
run;
/*End formatting variable*/

/*Taste position (called order in SIMS), lnpapillae*bread, and lnprop*bread
were initially included but were removed, because they were never significant
predictors*/

proc reg data=xxx.intensity;
model lnrough = age g b day lnpapillae lnprop;
run;

proc reg data=xxx.intensity;
model lnbitter = age g b day lnpapillae lnprop;
run;

proc reg data=xxx.intensity;
model lnsweet = age g b day lnpapillae lnprop;
run;
/*End Roughness, sweetness, and bitterness vs. PROP and papillae*/

/* Roughness discrimination vs papillae and PROP */
/* formatting variables*/
data xxx.discrimination;
```

```
set xxx.discrimination;
if bread = 'whole' then b = 1;
else if bread = 'refined' then b=0;
run;
data xxx.discrimination;
set xxx.discrimination;
if gender = 'male' then g=1;
else if gender = 'female' then g=0;
run;
data xxx.discrimination;
set xxx.discrimination;
propb= prop*b;
run;
data xxx.discrimination;
set xxx.discrimination;
papillaeb= papillae*b;
run;
/*End formatting variables*/
/* serving order, bread type, age, gender and interactions between bread and
papillae and bread and prop removed because they were not significant*/
proc reg data=xxx.discrimination;
model roughslope = papillae prop;
run;
/* End Roughness discrimination vs papillae and PROP */
```

APPENDIX III

Appendix III.I Sample Response Form for Study 3

Thank you for participating in this bread taste test. Today you will rate your liking of 9 bread samples while wearing a nose clip, rate the intensity of one liquid sample, and answer a few questions.

Please indicate your gender.

_________ Male ___________ Female

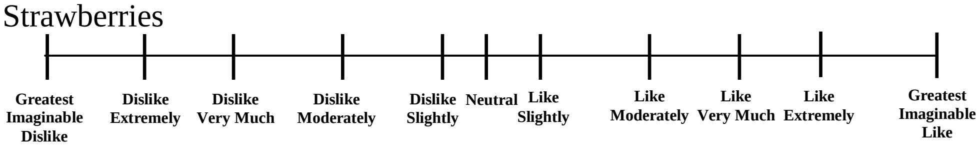
Please indicate your age.

____

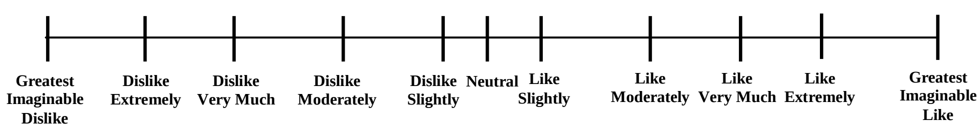
The scale you will be using is a line scale labeled with “Greatest imaginable disliking” on the left end and “Greatest imaginable liking of any kind” on the right end. <u>These labels refer to the strongest liking/ disliking you could feel in any situation not only in reference to foods.</u>

Please rate your liking/disliking of the following items by clicking on the scale at any position. You can use any part of the line scale that seems appropriate.

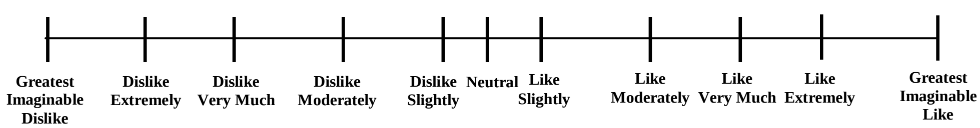
Strawberries



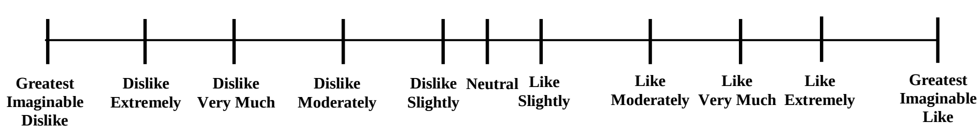
Mayonnaise



Kittens



Brussel Sprouts



Winter Days

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

Waiting in Line

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

Freshly Baked Cookies

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

Milk Chocolate

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

Grapefruit Juice

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

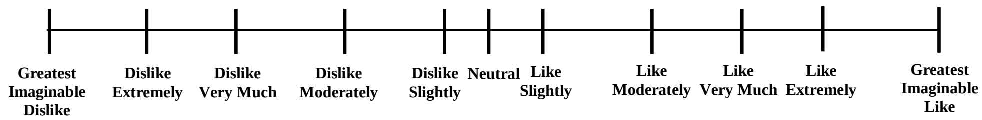
Getting a Traffic Ticket

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

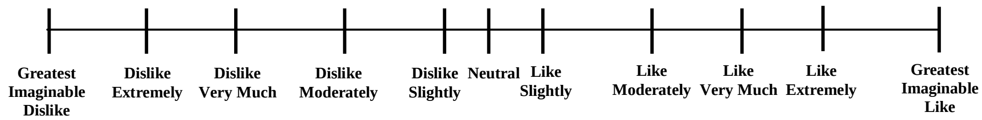
Whipped Cream

Greatest Imaginable Dislike	Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neutral	Like Slightly	Like Moderately	Like Very Much	Like Extremely	Greatest Imaginable Like

Cooked mushrooms



Having a vacation day from work or school



Please place the provided nose clip onto your nose.

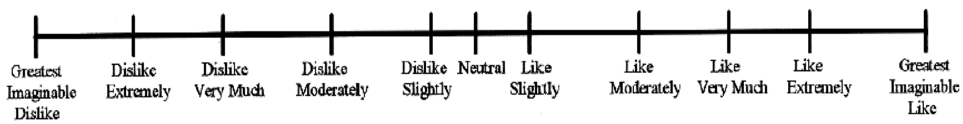
Take a moment to get used to wearing the clip and to breathing through your mouth. Take a sip of water to notice what happened when you swallow. Your ears may plug, and you may need to rebalance the pressure in your ears.

Please keep the nose clip on while tasting all bread samples. You may remove the nose clip in between samples.

Sample ###

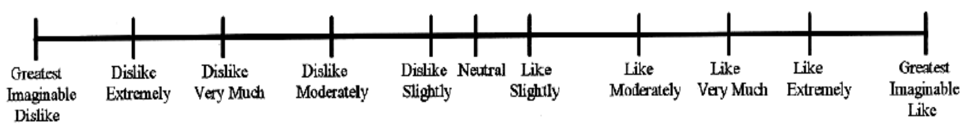
Please look at the sample and rate your liking based on its appearance only.

Appearance Liking

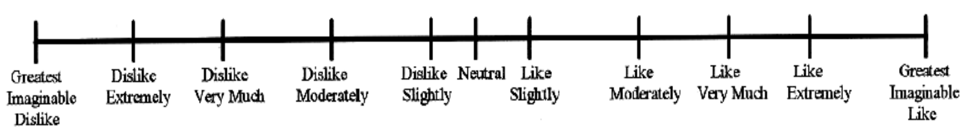


Now please take at least two bites of the sample, and then rate your liking of the bread for the following attributes.

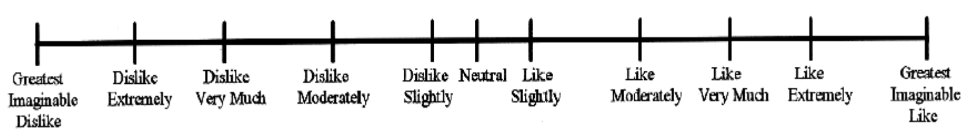
Overall Liking



Texture Liking

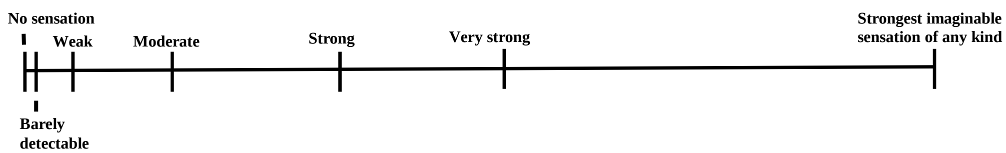


Taste Liking

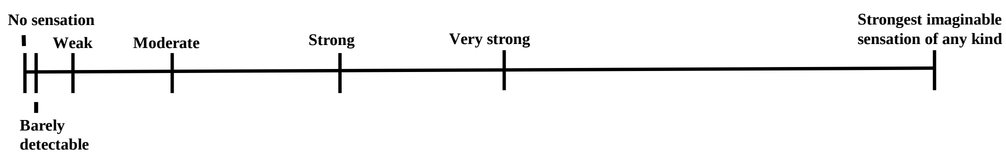


The scale you will be using to rate the last sample is a line scale labeled with “No sensation” on the left end and “strongest imaginable sensation of any kind” on the right end. Think of the label, “Strongest imaginable sensation of any kind” as the most intense sensation of any kind that you might experience with <u>any of your senses.</u>
Please rate the intensity of the following sensations (relative to any sensations you might experience with any of your senses). Rate the intensity by clicking on the scale at any position that best describes how you remember/ imagine those sensations to be. You can use any part of the line scale that seems appropriate.

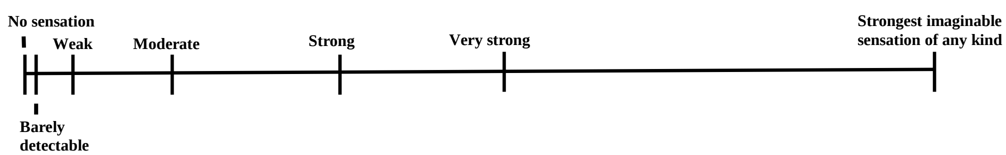
Brightness of a dimly-lit restaurant



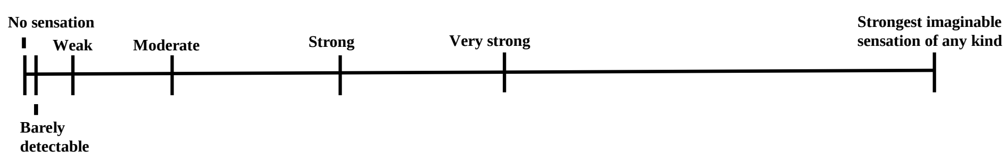
Brightness of the sun when looking directly at it



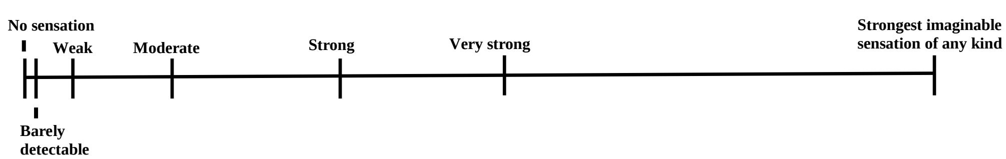
Loudness of a whisper



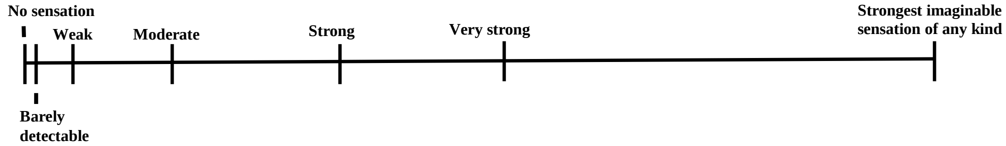
Loudness of a conversation



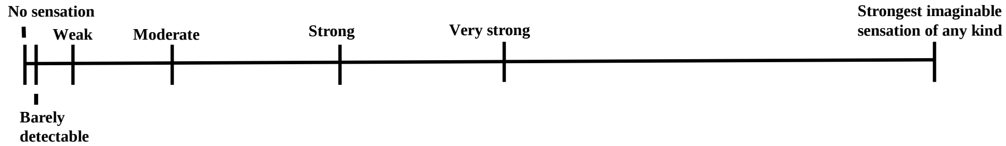
Smell of a rose



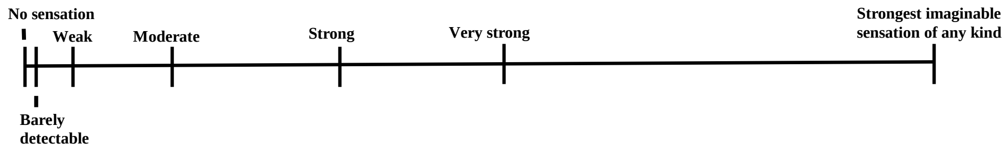
Sweetness of a Coke



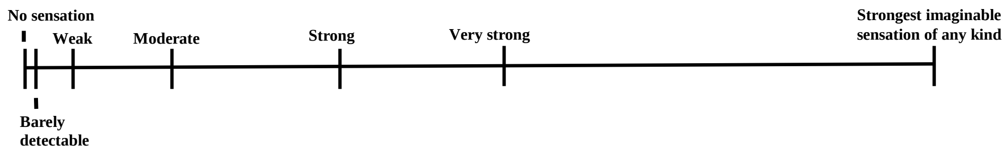
Bitterness of black coffee



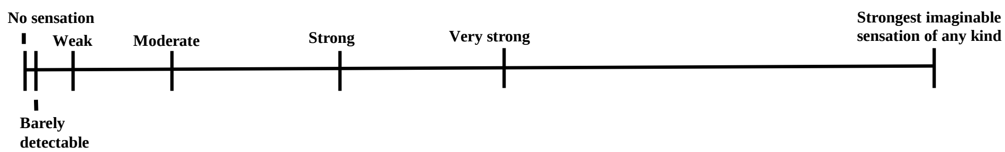
Saltiness of potato chips



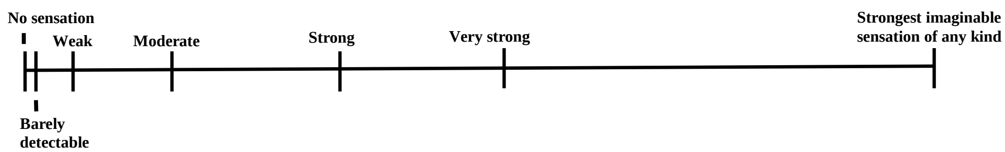
Loudness of a jet plane taking off 10 feet from you



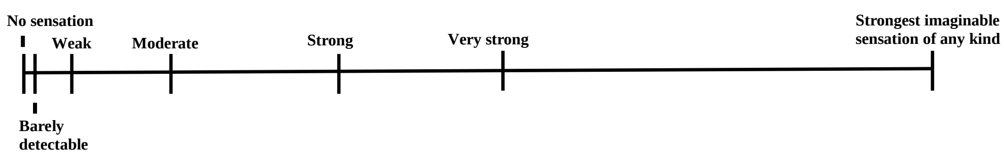
Strongest sweetness experienced



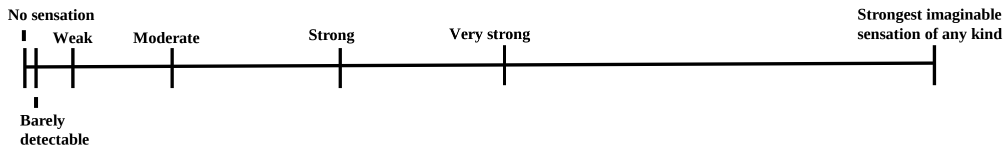
Sourness of a fresh lemon slice



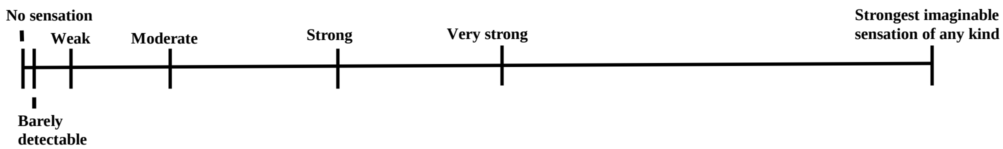
Oral burn from drinking a cold carbonated soda



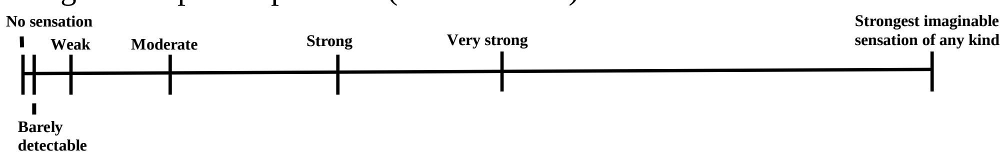
Brightness of this room



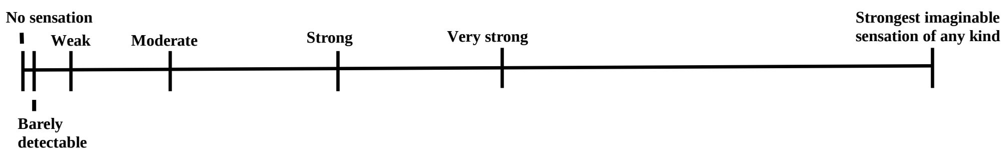
Strongest oral burn experienced (ex. eating a hot pepper, such as jalepeno)



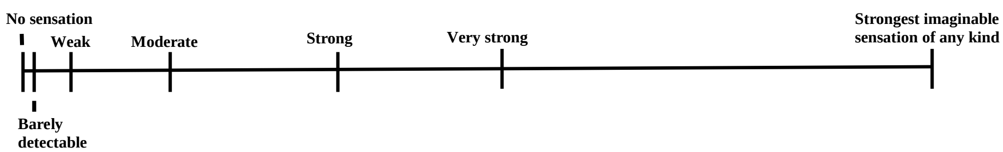
Strongest oral pain experience (ex. toothache)



Strongest pain of any kind experienced



Heat felt standing 5 feet from a large bonfire



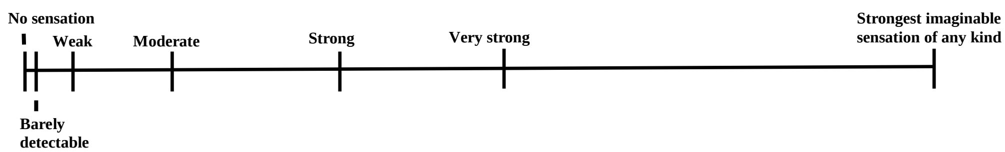
This is your last taste rating.

Put all of SAMPLE 001 into your mouth.

Swirl it around. DO NOT SWALLOW IT.

Rate the intensity of the sample by marking the scale position that best describes what you are experiencing. You can use any part of the line scale that seems appropriate.

Expectorate all of the sample into the cup provided to you.



Which of the following bread types do you like best?

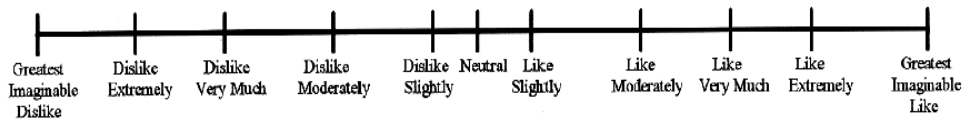
- ❑ 100% whole wheat bread
- ❑ 100% refined wheat bread (i.e. "white bread")

Based on ONLY the sensory qualities of the bread (i.e. taste, flavor, texture, smell, appearance, touch, etc…) DISREGARDING ALL OTHER FACTORS, which of the following bread types do you like best?

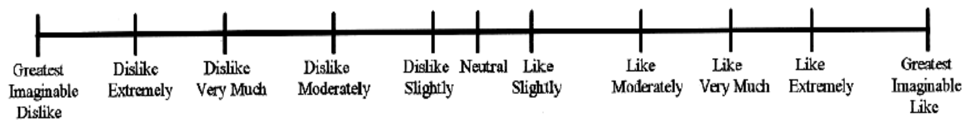
- ❑ 100% whole wheat bread
- ❑ 100% refined wheat bread (i.e. "white bread")

Rate how well you like the texture of the following foods

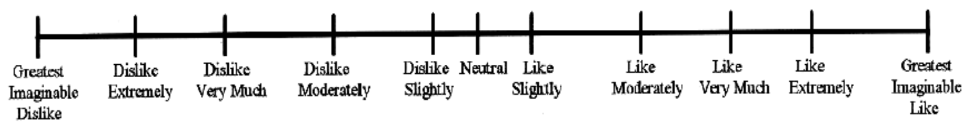
Cream of Wheat cereal



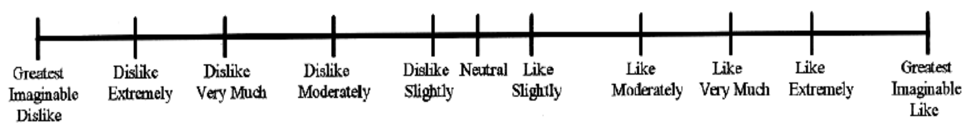
Popcorn



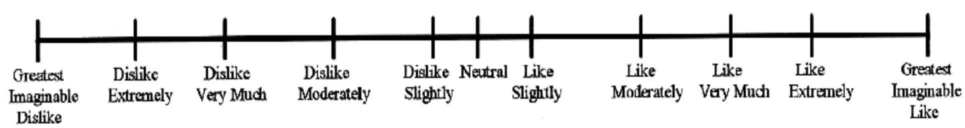
Dry cornflakes



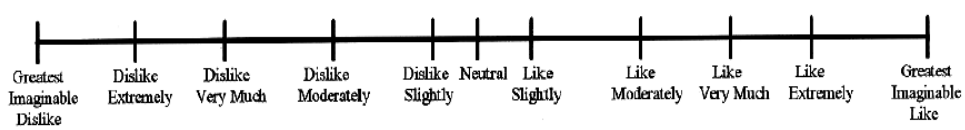
Instant oatmeal



Corn tortilla chips



Cooked white rice



When selecting foods for yourself, how important is the flavor of the food?

Not at all important | Very important

When selecting foods for yourself, how important is the smell of the food

Not at all important | Very important

When selecting foods for yourself, how important is the texture of the food?

Not at all important | Very important

When selecting foods for yourself, how important is the appearance of the food?

Not at all important | Very important

When selecting foods for yourself, how important is the nutritional value of the food?

Not at all important | Very important

Appendix III.II SAS Code for Study 3 Data Analysis

```
/* removed block age and gender never sig*/
/*Overall Liking vs bread factors and consumer characteristics*/
proc mixed data=xxx.thirdliking2;
class judge preference fpdensity taster bitterness color roughness;
model overall= preference taster fpdensity bitterness color roughness
bitterness*taster bitterness*fpdensity bitterness*preference
roughness*taster roughness*fpdensity roughness*preference
color*taster color*fpdensity color*preference / ddfm=satterth;
random judge;
lsmeans color preference bitterness roughness roughness*fpdensity
color*preference /pdiff;
run;
/*Texture Liking vs bread factors and consumer characteristics*/
proc mixed data=xxx.thirdliking2;
class judge preference fpdensity taster bitterness color roughness;
model texture= preference taster fpdensity bitterness color roughness
bitterness*taster bitterness*fpdensity bitterness*preference
roughness*taster roughness*fpdensity roughness*preference
color*taster color*fpdensity color*preference / ddfm=satterth;
random judge;
/*lsmeans color preference fp2den bitterness roughness roughness*taster
roughness*fp2den color*preference / pdiff;*/
run;
/*Taste Liking vs bread factors and consumer characteristics*/
proc mixed data=xxx.thirdliking2;
class judge preference fpdensity taster bitterness color roughness;
model taste= preference taster fpdensity bitterness color roughness
bitterness*taster bitterness*fpdensity bitterness*preference
roughness*taster roughness*fpdensity roughness*preference
color*taster color*fpdensity color*preference / ddfm=satterth;
random judge;
/*lsmeans preference bitterness roughness taster roughness*taster
roughness*fp2den color color*preference /pdiff;*/
run;
/*Appearance Liking vs bread factors and consumer characteristics*/
proc mixed data=xxx.thirdliking2;
class judge preference fpdensity taster bitterness color roughness;
model appear= preference taster fpdensity bitterness color roughness
bitterness*taster bitterness*fpdensity bitterness*preference
roughness*taster roughness*fpdensity roughness*preference
color*taster color *fpdensity color*preference / ddfm=satterth;
```

```
random judge;
lsmeans preference bitterness preference*bitterness roughness*preference
fpdensity  color
color*preference fpdensity*color roughness roughness*taster
roughness*fpdensity /pdiff;
run;
/*Cereal food liking vs taster and papillae*/
proc anova data=xxx.thirdquest;
class preference fpdensity taster;
model creamwheat= preference taster fpdensity;
means preference taster fpdensity;
run;
proc anova data=xxx.thirdquest;
class preference fpdensity taster;
model popcorn= preference taster fpdensity;
means preference taster fpdensity /T;
run;
proc anova data=xxx.thirdquest;
class preference fpdensity taster;
model cornflakes= preference taster fpdensity;
means preference taster fpdensity /T;
run;
proc anova data=xxx.thirdquest;
class preference fpdensity taster;
model oatmeal= preference taster fpdensity;
means preference taster fpdensity /T;
run;
proc anova data=xxx.thirdquest;
class preference fpdensity taster;
model cornchips= preference taster fpdensity;
means preference taster fpdensity / T;
run;
proc anova data=xxx.thirdquest;
class preference fpdensity taster;
model rice= preference taster fpdensity;
means preference taster fpdensity /T;
run;
/*Importance ratings vs taster and papillae*/
proc anova data=xxx.thirdquest;
class preference fpdensity taster;
model smellimp= preference taster fpdensity;
means preference taster fpdensity / T ;
run;
```

```
proc anova data=xxx.thirdquest;
class preference fpdensity taster;
model textureimp= preference taster fpdensity;
means preference taster fpdensity /T ;
run;
proc anova data=xxx.thirdquest;
class preference fpdensity taster;
model tasteimp= preference taster fpdensity;
means preference taster fpdensity / T;
run;
proc anova data=xxx.thirdquest;
class preference fpdensity taster;
model nutrimp= preference taster fpdensity;
means preference taster fpdensity / T;
run;
proc anova data=xxx.thirdquest;
class preference fpdensity taster;
model appearimp= preference taster fpdensity;
means preference taster fpdensity / T;
run;
/*Frequencies between consumer characteristics*/
proc freq data= xxx.thirdquest;
tables fpdensity*preference / CHISQ;
exact pchi;
run;
proc freq data= xxx.thirdquest;
tables fpdensity*taster / CHISQ;
exact pchi;
run;
proc freq data= xxx.thirdquest;
tables preference*taster / CHISQ;
exact pchi;
run;
proc freq data= xxx.thirdquest;
tables preference*taster*fpdensity / CHISQ;
exact pchi;
run;
```