Can you taste sustainability?:
Connecting product source and soil health to organoleptic performance

by

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B.A., Appalachian State University, 2020

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We acknowledge and respect the lək̓ʷəŋən peoples on whose traditional territory the university stands and the Songhees, Esquimalt, and W̱SÁNEĆ peoples whose historical relationships with the land continue to this day.

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Abstract

Taste and price tend to have a greater influence on food choices than extrinsic motivations such as nutrition and environmental performance. The connection between the taste of agricultural products and production methods has proven difficult in past research due to farming practices being treated as factors in such experiments without the use of specific farm operations or environmental conditions. Therefore, if consumers prefer the organoleptic properties of more ecologically friendly products, then consumer self-interest can be utilized to drive the market towards more eco-friendly food production methods.

To explore this, I asked the question: do farm type, physio-chemical attributes, and/or soil health parameters and fertilization methods affect the organoleptic properties of different agricultural products? The first chapter examined if different farm types with different operations and localities influence the organoleptic perception of four different products (cherry tomato, table tomatoes, lettuce, and garlic) using three different farm types (small, local, large, local, and conventional). The second chapter assessed if fertilization method and soil health indicators influenced the organoleptic properties of three products (kale, carrots, and string beans) of two different fertilizer treatments (synthetic and compost) from a restoration agriculture project.

The first chapter indicated that the more ecologically friendly farms had the more preferred products. The second experiment indicated that in an immature production system, the type of fertilizer used did not have a significant effect on the organoleptic properties of the products. Carrots were the only product where an effect was found, as the synthetic fertilized carrots were more preferred than the compost treatment. However, in neither case were the participants willing to pay a premium price for the more preferred products. Therefore, consumers can discriminate superior products but are not willing to pay a higher price for them. Self-interest (i.e. better-tasting products) has the potential to affect market share in favor of environment-responsive producers.

Table of Contents

Supervisory Committee..ii

Abstract...iii

Table of Contents..iv

List of Tables..vi

List of Figures..ix

Acronyms...x

Dedication...xi

1. Chapter 1: Introduction…..……………………………………………………………………1
   - 1.1. Introduction...2
   - 1.2. Food Choices……………..…………………………………………………………3
   - 1.3. Defining Product Quality…………..…………………………..……………………3
   - 1.4. Sensory Analysis………………...……………………………………...……………..3
   - 1.5. Willingness-to-Pay………………………………………..…………………………5
   - 1.6. Physio-Chemical Analyses………………………………..………………..………5
   - 1.7. Soil Health…………………………………………..…………..……………………6
   - 1.8. Hypotheses……………………………………..……………………………………8
   - 1.9. References………………………..…………………………..………………………8
2. Chapter 2: Connecting farm type to organoleptic performance……......................................12
   - 2.1. Introduction...13
   - 2.2. Methods...15
     - 2.2.1. Experimental Design...15
     - 2.2.2. Sensory Analysis..16
     - 2.2.3. Willingness-to-Pay..19
     - 2.2.4. Physio-chemical Analyses...19
     - 2.2.5. Statistical Analysis..21
   - 2.3. Results..22
     - 2.3.1. Participant Precision………..………………..………………………………22
     - 2.3.2. Sensory Analysis..23
     - 2.3.3. Willingness-to-Pay (WTP)..28
     - 2.3.4. Physio-chemical Analyses...29
   - 2.4. Discussion...31
     - 2.4.1. Things to Consider…………………………………………………………………34

2.5. Conclusion....35
2.6. References....35
3. Chapter 3: Connecting soil health and fertilization methods to organoleptic performance…39
   3.1. Introduction....40
   3.2. Methods....42
      3.2.1. Experimental Design....42
      3.2.2. Sensory Analysis....42
      3.2.3. Willingness-to-Pay....45
      3.2.4. Physio-chemical Analyses....46
      3.2.5. Soil Health....47
      3.2.6. Statistical Analysis....48
   3.3. Results....50
      3.3.1. Participant Precision....50
      3.3.2. Sensory Analysis....50
      3.3.3. Willingness-to-Pay (WTP)....54
      3.3.4. Physio-chemical Analyses....54
      3.3.5. Soil Health....55
   3.4. Discussion....56
      3.4.1. Things to Consider....60
   3.5. Conclusion....60
   3.6. References....60
4. Chapter 4: Concluding Remarks....64
   4.1. Summary....65
   4.2. Caveats....66
   4.3. Conclusion....67
5. Appendix....68

List of Tables

Table 2.1: Definitions of the three farm type categories and products acquired from each........16
Table 2.2: For physio-chemical analyses, variable tissue water content of each product type necessitated water addition to achieve a consistent concentration of liquid...................17
Table 2.3: Sensory panel statistics…………………………………………………………..........17
Table 2.4: Total number of human sensory evaluations of each source farm for each product.18
Table 2.5: Nine-point hedonic scale and modified nine-point presented to panelists…………..19
Table 2.6: Penetrometer testing of firmness for lettuce, garlic, and tomatoes………..………...20
Table 2.7: Participant precision using t-tests to evaluate the magnitude of baseline-duplicate deviation…...…………………………………………………………………………….23
Table 2.8: Sensory evaluation results for all products combined and participant precision controlled………..…………………………………………………………………….…24
Table 2.9: Sensory evaluation results for each product-farm source combination………………26
Table 2.10: Visualizing Fisher LSD groupings by colour for each product and all products combined………..……………………………………………………………………….27
Table 2.11: Product-source score rank, ANOVA result, mean score, and Fisher's LSD group for individual and combined products………..…………………………………………….30
Table 2.12: AIC, delta AIC (ΔAIC), and AIC weights (AICw) values for GLM of "overall preference" for each product's physio-chemical analyses……………………………..…31
Table 3.1: For physio-chemical analyses, variable tissue water content of each product type necessitated water addition to achieve a consistent liquid………………..……….……43
Table 3.2: Sensory panel statistics……………………………………………………….………...43
Table 3.3: Total number of human sensory evaluations of each product in the synthetic fertilizer (F) and compost (C) treatments and the duplicate of the conventional baseline……..44
Table 3.4: Nine-point Hedonic scale and modified nine-point presented to panelists…………...45
Table 3.5: Penetrometer testing of firmness for kale, carrots, and string beans………………...46
Table 3.6: Sensory evaluation results for all products combined and all products combined and participant precision controlled……………...……………..……………………………..50
Table 3.7: Each product-treatment combination ranked 1 (highest) - 4 (lowest), ANOVA results summary, mean score, and grouping by Fisher's LSD……………………………..…51
Table 3.8: Visualizing Fisher LSD Groupings by colour for each product and all products combined.……………………………………….………………………..…………52
Table 3.9: Each product-treatment combination absolute ranks, ANOVA results summary, mean score, and the grouping from Fisher's LSD………………………...……………..54

Table 3.10: AIC, delta AIC (ΔAIC), and AIC weights (AICw) values for GLM of "overall preference" for each product's physio-chemical analyses……………..…………..……….55

Table 3.11: AIC, delta AIC (ΔAIC), and AIC weights (AICw) values for GLM of "overall preference" for each product's soil health indicators……………………………………56

Table 5.1: Chapter 2 Sensory Evaluation summary statistics (sample size (n), min, max, mean, and SD) for each product-source combination for all sensory evaluation questions……69

Table 5.2: Chapter 2 physio-chemical summary statistics…..……………………………………70

Table 5.3: Values for titratable acidity formula for citric and malic acid…………..………………70

Table 5.4: Chapter 2 Sensory and WTP Shapiro-Wilks test (test statistic and p-value) for each product………………………………………………………………………………………71

Table 5.5: Chapter 2 Bartlett's Test (Bartlett's K-squared and p-value) for the sensory evaluation of each product………..……………………………………..……………………………71

Table 5.6: Chapter 2 One-way ANOVA (source) results summary……………….……………72

Table 5.7: Chapter 2 Two-way ANOVA (source + consumer) results summary……………….73

Table 5.8: Chapter 2 Sensory and WTP Kruskal Wallis test……………...……………………74

Table 5.9: Chapter 2 Fisher's LSD results using ANOVA (source only)……………....……...74

Table 5.10: Chapter 2 WTP One-way ANOVA and Fisher's LSD results for all products…...…75

Table 5.11: Chapter 2 WTP Two-way ANOVA (source + consumer) and Fisher's LSD results for all products……………………………………………………………………………..75

Table 5.12: Chapter 3 sensory evaluation summary statistics…………………………………76

Table 5.13: Chapter 3 physio-chemical summary statistics……………………………………77

Table 5.14: Participant precision using t-tests to evaluate the magnitude of baseline-duplicate deviation……………………………………………………………………………..77

Table 5.15: Chapter 3 Sensory and WTP Shapiro-Wilks test (test statistic and p-value) for each product………………………………………………………………………………………77

Table 5.16: Chapter 3 Bartlett's Test…………………………………………………………………78

Table 5.17: Chapter 3 Sensory and WTP Kruskal Wallis test……………..…………...…………78

Table 5.18: Chapter 3 One-way ANOVA (source) results summary……………………………79

Table 5.19: Fisher's LSD results using ANOVA (source only)……………………………………..80

Table 5.20: Chapter 3 WTP ANOVA and Fisher's LSD results for all products……....………80

List of Figures

Figure 2.1: Example sample presentation to participants…..19

Figure 2.2: MDS with k-mean clustering comparing all product-source combination's means of sensory data including all categories……..………..……………………………………..28

Figure 2.3: HCA clusters comparing all product-source combination's means of sensory data including all categories…………………..……………………………………………….29

Figure 3.1: Example of how the trays were presented to participants…...…………………..…….45

Figure 3.2: The treatment plot design (not too scale)…………………...………………………..48

Figure 3.3: MDS with two (left) and three (right) k-mean clusters…...…...……..…………...……53

Figure 3.4: HCA clusters comparing all product-treatment combination's means of sensory data including all categories……..……………………………………………………………53

Acronyms

ANOVA	Analysis of Variance
BC	British Columbia
C	Compost Fertilizer Experimental Group
$CaCl^2$	Calcium Chloride
CON	Conventional Farm Source Experimental Group
F	Synthetic Fertilizer Experimental Group
Fe	Iron
HCA	Hierarchical Clustering Analysis
K	Potassium
LL	Large, Local Farm Source Experimental Group
LSD	Least Significant Difference
Mg	Magnesium
Mn	Manganese
N	Nitrogen
NaOH	Sodium Hydroxide
P	Phosphorus
pH	Potential Hydrogen
S	Sulfur
SL	Small, Local Farm Source Experimental Group
TA	Titratable Acidity
TSS	Total Soluble Solids
WTP	Willingness-to-Pay

Dedication

I would like to first thank my supervisor, Dr. John Volpe for all of his support and guidance. John encouraged me to follow my passion, even if I was a bit timid at times. Secondly, I would like to thank my wonderful labmates, Brooke Hayes and Matthew Kyriakides, for sharing their data, knowledge, and kindness. Thanks to the Sea Buckthorn cohort, it was truly an honor to be around so many lovely and intelligent people.

Thank you to all the local farmers that contributed to this project and for doing such meaningful work toward a more sustainable food system. I would also like to thank Scott Van Haren for all the help during my lab work and your knack for finding participants. Thank you to all the participants who participated in my sensory evaluations, especially the ones I gave tear inducing raw garlic to.

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1. Chapter 1: Introduction

1.1 Introduction

It is widely thought that different agricultural methods (like organic or conventional) affect the taste and quality of the products produced in those systems. In a survey conducted in 2001, 43% of consumers believed that organic food had a better taste and stated that was the reason they purchased it (Heaton, 2001).

The connection between the taste of agricultural productions and production methods has proven difficult in past research due to farming practices (like organic and conventional) being treated as factors in such experiments without the use of specific farm operations or environmental conditions (Theuer, 2006). The ambiguity of results is expected because of the incorrect assumption that inter-farm variance across those assigned to the same factor is zero. It is assumed that all “organic” or “conventional” farms follow the same protocols, however, this is largely not true. Conventional farming is usually associated with a high-input agricultural system where synthetic fertilizers, pesticides, herbicides, and fungicides are used (Le Campion et al., 2020). Conventional farms usually have very few, if any, standards to meet. Organic farming is defined as a farming technique that does not use any synthetic inputs, like fertilizer or pesticides (Bialais, 2020). However, meeting a production standard such as “organic” simply means being above or below a narrow set of threshold measures and does not mandate specific practices or product quality (Trewavas, 2001; Freyer et al., 2019). This is complicated even further as different organic farm standard holders have different thresholds. Historically, research connecting farming practices to organoleptic properties of the products has lacked the necessary precision to yield generalizable results (Basker, 1992; Fillion and Arazi, 2002; Theuer, 2006). Therefore, applying detailed farm-specific soil quality and/or environmentally relevant farm practice data alongside the product quality will constitute a significant contribution to this field of research.

The separation of product quality and the taste of foods from agricultural research disregards the food system as a whole. Ensuring that consumers are not separated from sustainable agriculture solutions is essential and can be better utilized to drive the market towards more ecologically friendly agricultural methods (Virginia Tech, 2018; Strauss, 2020). There is a current gap of trust between producers and consumers in the food system which is growing among the younger generations (CFANS Insights, 2022). This is only fueled by the greenwashing of marketing, misinformation, and the lack of regulations on food production (Northen, 2011; Fox et al., 2021). Consumers influence market demand, however, with the current distrust between the food producers and consumers, the consumers are not able to be properly utilized to drive change towards more sustainable agricultural methods. If more sustainable agricultural methods are going to become more common practice, then a more holistic view of the food system will need to be used. One large part of this is ensuring that consumers are given reliable information to make informed decisions when purchasing food (Virginia Tech, 2018; Lewis et al., 2021).

1.2 Food Choices

Food choices are influenced by many different factors including taste, cost, cultural and past experiences, health, and convenience to name a few (Steptoe et al., 1995; Mela, 2001; Chadwick et al., 2013; Tan, 2016). Taste tends to have a greater influence on food choices than extrinsic motivations such as nutrition and environmental performance (Steptoe et al., 1995; Glanz et al., 1998; Mela, 2001; Tan, 2016). However, price is often a more important motivator for food choices when individuals have less disposable income (Steptoe et al., 1995). The cost of food is a stronger motivator for food choices among low-income individuals compared to high-income individuals and low-income individuals also tend to rate taste as a less important motivator (Steptoe et al., 1995).

1.3 Defining Product Quality

My research uses both a consumer-oriented and product-oriented perspective to determine product quality (Shewfelt, 1999) meaning product quality is defined by organoleptic properties and willingness-to-pay (WTP) as well as physio-chemical tests. This is to ensure that a well-rounded understanding of the quality of the products is established from both the perspective of the consumer and the product (Shewfelt, 1999). Determining the quality of a product is a complex matter (Gruda, 2005) which makes defining product quality in the context of my research essential to properly analyze and interpret the data (Shewfelt, 1999). Both the sensory evaluation and WTP are examining the products from a consumer-oriented perspective in that they are using the consumer's preferences to access product quality. The physio-chemical analyses are a product-oriented perspective as they give an objective measurement of different attributes of the products.

1.4 Sensory Analysis

Sensory evaluation is defined as a scientific method used to “evoke, measure, analyze and interpret reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch, and hearing” (Stone and Sidel, 2004, 13). This is a multifaceted definition with many different important pieces. Participants are evoked in a controlled environment using a standardized test to quantitatively measure their perception of the samples (Lawless and Heymann, 2010). Then, like in most scientific disciplines, the researcher analyzes and interprets those results. The definition also specifically names all five of the human senses, which is important for designing and interpreting results from a sensory evaluation. Taste is usually perceived as the predominant sense used in a sensory evaluation; however, it is essential to point out that taste and the other senses cannot be separated from one another (Stone and Sidel, 2004).

Organoleptic refers to the characteristics of a substance that relate to sensory organs, such as taste, smell, sight, hearing, or touch. For the purposes of this research, I am using taste as a synonym for organoleptic with the understanding that taste is influenced by all sensory organs. Taste may also be informed by material differences such as water, sugar, and/or nutrient density or extrinsic properties such as cooking methods and panelist subjectivity (Heaton, 2001).

Since the analytical instrument used in a sensory evaluation is a human, yielding reliable results can be difficult due to a high degree of variability in both preferences and perception of taste (Reed et al., 2006; Njoman et al., 2017). Not only do humans have differences in perception stemming from biological differences and life experiences, but participants can experience sensory fatigue if given too many samples (Njoman et al., 2017). Taste can also be influenced by a number of external variables including lighting and sound (Spence et al., 2014; Biswas et al., 2017; Kimberley van der Heijden et al., 2021). Therefore, these external cues must be controlled to reduce the amount of variance (Lawless and Heymann, 2010). In this research red lights will be used to mask the colour of the products. Light colour is known to affect participants’ organoleptic impressions of products (Yang et al., 2016) and red lights are often used in sensory evaluations to mask colour (Nyitrai et al., 2022).

In sensory evaluations, there are three main classes of tests: discrimination, descriptive, and affective (Lawless and Heymann, 2010). Both discrimination and descriptive tests are analytic tests, while affective tests are hedonic tests. Analytic tests specifically look at differences in the products. Discrimination determines if the products are perceivably different, while descriptive determines specific differences in sensory characteristics. One example of a discrimination test is a paired comparison test, where two samples are given to participants and are asked to choose which product was stronger or more intense for a specific characteristic (Lawless and Heymann, 2010).

Affective determines the liking or preference of a product and typically uses untrained panelists (Lawless and Heymann, 2010). Affective tests use a hedonic scale to rate products in terms of liking or preference, similar to a Likert scale. Since hedonic scales are typically done to access consumers' sensory perception and are untrained, a sample size of 75-150 is recommended to control for the high variability that can be seen from individual preferences (Lawless and Heymann, 2010). A 9-point hedonic scale has been the most widely used scale for testing consumer preferences of foods (Lim, 2011).

1.5 Willingness-to-Pay

Because the cost of food is as important as taste when it comes to food choices, willingness-to-pay (WTP) was also considered in my research. WTP is defined as the highest amount of money of person will pay for a specific product.

It is essential to use WTP in climate mitigation research to ensure that psychological and social barriers are reduced (Streimikiene and Mikalauskiene, 2021). Past research has found that people have an increased WTP when products are marketed as being of higher quality (Mccluskey and Loureiro, 2003; Carpio and Isengildina-Massa, 2009; Grebitus et al., 2013; Sörqvist et al., 2013; Bernard and Liu, 2017; Gassler et al., 2019). A perceived high-quality product is only seen as important if that perception of quality is high enough to increase WTP (Grunert, 2005). Therefore, in examining if more "green" agricultural methods produced a better-quality product, WTP is essential to get a broader picture of the organoleptic differences found between products from different sources. Without an increased WTP, those differences are essentially meaningless in a marketing framework.

1.6 Physio-Chemical Analyses

Physio-chemical analyses of food are often done along with sensory analyses to add more breadth to the analyses with more objective tests. Physio-chemical analyses are tests that examine the physical and chemical properties of products. My research focuses on four different physio-chemical analyses including firmness, total soluble solids (TSS), titratable acidity (TA), and pH.

Firmness is a measure of how hard or soft the product is. Firmness can be affected by variety and ripeness, but also by growing regions and conditions (OECD, 2018). Firmness is typically measured using a penetrometer which measures the amount of force it takes to reach a certain depth. The more force that is needed to penetrate the product, the firmer the product is.

Total Soluble Solids (TSS) measure the number of solids that are water soluble present in products which are most commonly sugars like glucose and fructose (Zhu et al., 2018; Iowa State University, 2020). TSS can be measured using a °Brix analysis with a refractometer. The refractometer uses the reflection of light passing through the sample to give the °Brix value.

Both titratable acidity and pH are measures of acidity. Titratable acidity (TA), or percent acidity, represents the total acid concentration of the product sample and is considered to be a better predictor of the sensory impact of acid than pH (Nielsen, 2017). Human taste registers both free and bonded hydrogen ions, both of which are assessed in TA. TA is found by titrating a sample using NaOH until an endpoint is reached using an acid-base indicator, like phenolphthalein. Potential hydrogen, or pH, is also a measure of acid content and measures active acidity (Nielsen, 2017). It is more representative of the strength of the acid present rather than how much acid is present, as only the free hydrogen ions are measured.

1.7 Soil Health

Soil health is the capacity of soil to “function within ecosystem and land-use boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health” (Doran and Parkin, 1994, 7). Soil health can be interpreted by chemical, biological, and physical composition (Bünemann et al., 2018) and these biotic and abiotic elements are thought to contribute to product quality (Gruda, 2005; Bourne et al., n.d.). Soil health is hypothesized to contribute to the quality and nutritional value of fruits and vegetables: the greater the quality of the soil, the greater the nutrient content of fruits and vegetables (Wang et al., 2008; Reganold et al., 2010). However, this is debated as some studies fail to find evidence in support of food quality and nutrition as being linked to soil health (e.g. Stracke et al., 2008; Mukherjee et al., 2020).

Soil health is easily affected by agricultural practices that alter relationships of water, organic matter, and nutrients all of which can affect the soil's erosion potential, compaction, and microbial communities (Gregorich et al., 1995). The health of the soil within agricultural operations also contributes more broadly to environmental degradation because as soil health declines it becomes less able to adsorb chemical inputs like fertilizer or pesticides which contribute to the pollution of groundwater (Gregorich et al., 1995). Synthetic fertilizer reduces soil health by diminishing carbon sequestration potential (Lal, 2020) as well as decreasing microbial communities and biodiversity (Shen et al., 2021). Synthetic fertilizers remain popular as they are inexpensive, and nutrients are often tailored to the crop and are readily available for the plants (Sabry, 2015). In contrast, organic compost fertilizer must be biologically processed in the soil prior to being bioavailable to crops (Scotti et al., 2015), often take more time and effort on the part of the farmer, and the exact nutrients available in the compost are unknown (Oregon State University, 2015).

Soil health is difficult to quantify, however, measuring soil health indicators, like bulk density, aggregate stability, and pH, can give some insight into the health of the soil (Doran and Parkin, 1994). Aggregation is the arrangement of the primary soil particles around soil organic matter. Aggregate stability's function in the soil is to promote the maintenance of soil structure and helps mitigate erosion and damages from flooding or landslides (Krzic et al., 2021). Aggregate stability is a good indicator of soil health and is often used as a proxy for soil structure, which is difficult to quantify (Rieke et al., 2022; Soil Health Institute, n.d.).

Bulk Density is the mass of dry soil per unit bulk volume and is one measure of soil compaction (Krzic et al., 2021). Soil compaction is when the soil losses porosity and increases in density. Therefore, the lower the bulk density of soil the less compaction is present. Reducing compaction is important for soil health because life within soil happens within the pores, or air pockets, located in the soil (Krzic et al., 2021). Compaction reduces these pores and decreases water and gas movement within the soil which limits both root and microbial growth (de la Rosa and Sobral, 2008; Krzic et al., 2021).

Soil pH is a measurement of the concentration of hydrogen ions within the soil and is used to describe the acidity or alkalinity of the soil (Krzic et al., 2021). pH is primarily influenced by the geological parent material of the soil. Extreme pH values can have negative effects on nutrient uptake and plant growth (USDA Natural Resources Conservation Service, 1998; Krzic et al., 2021).

1.8 Hypothesis

Chapter 2 explores the effect of farm production methods, locality, and physio-chemical attributes on the sensory properties of four common agricultural products. This chapter utilizes sensory evaluations, willingness-to-pay, and physio-chemical laboratory tests to define the quality of agricultural products of three different farm types with variable production methods and locality.

Chapter 2 will test the null hypothesis that consumer sensory perception is independent of and source farm and the hypothesis that consumer perception and physio-chemical tests of food are associated with the source farm in which the product grew. The following research question will be examined: does farm type predict the physio-chemical and/or human sensory performance of different agricultural products?

Chapter 3 explores the effect of soil health indicators, fertilization methods, and physio-chemical attributes on the sensory properties of three common agricultural products grown in synthetic and compost fertilizers. This chapter will utilize sensory evaluations, willingness-to-pay, and physio-chemical laboratory tests to define the quality of agricultural products from two treatment plots with different fertilization methods (synthetic and compost) and has the inclusion of three soil health indicators (bulk density, aggregate stability, and pH).

Chapter 3 will test the null hypothesis that consumer sensory perception and physio-chemical tests of foods are independent of the fertilization method used and soil health indicators and the hypothesis that consumer perception and physio-chemical tests of food are associated with the fertilization method and soil health in which the product grew. The following research question will be examined: do soil health parameters, physio-chemical attributes of products, and/or fertilization methods affect the organoleptic properties of different agricultural products?

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2. Chapter 2:

Connecting farm type to organoleptic performance

2.1 Introduction

A common assumption is that more ecologically friendly or sustainably grown food, such as that grown using organic methods, improves product quality and organoleptic perception (Theuer, 2006). How a person experiences food via the sensory organs, taste, smell, sight, sound, and touch, comprise the organoleptic perception of the food and these can inform product quality from a consumer orientation. The relationship between farm production methods and food organoleptic properties remains poorly defined with some arguing that favorable consumer opinion is more attributable to a placebo or halo effect than organoleptic properties (Theuer, 2006; Foodwise, 2011). Marketing may be responsible for creating a consumer impression that ‘organic’ is synonymous with ‘superior quality’, including organoleptically (Northen, 2011). However, organoleptic profile and consumer preference as functions of farm production practices have not been accurately articulated.

Most research has focused heavily on broad agricultural production methods (e.g., Theuer, 2006). Typically, farming practices (e.g., conventional, integrative, or organic) are treated as factors in such experiments without detailed farm-specific data. Ambiguous results are assured due to the assumption that inter-farm variance across those assigned to the same factor is zero. For instance, “organic” is an umbrella term under which falls a wide array of permitted practices. ‘Organic’ farms do not necessarily follow the same protocols or employ the same specific operations. Meeting a production standard such as “organic” simply means being above or below a narrow set of threshold measures and does not mandate specific practices or product quality/traits (Trewavas, 2001; Freyer et al., 2019). Different organic standards may vary significantly with regard to thresholds and practices while conventional farms have no such standards, further complicating the issue. Not surprisingly, research to date has lacked the necessary precision to yield generalizable results (Basker, 1992; Fillion and Arazi, 2002; Theuer, 2006).

Another common assumption is that organic and local products possess superior taste as a result of being fresher (reduced time to market) than their conventional counterparts (Bourn and Prescott, 2002; Blair, 2011; Foodwise, 2011). Consumers seeking locally produced food may do so for various reasons, though superior taste is a common motivator. However, products labeled “local” or “organic” are more influential on the perception of taste than the actual taste of the product (Bernard and Liu, 2017; Levitt et al., 2023).

There is a growing trust gap between food system producers and consumers, especially among younger consumers (CFANS Insights, 2022). This is fueled by greenwashing, misinformation, and the lack of regulations on food production (Northen, 2011; Fox et al., 2021). Consumers are what influence market demand, however, with the current distrust of the food producers and consumers, the consumers are not able to be properly utilized to drive change towards more sustainable agricultural methods.

Taste and price tend to have a greater influence on food choices than extrinsic motivations such as nutrition and environmental performance (Steptoe et al., 1995; Mela, 2001). Therefore, if consumers prefer the organoleptic properties of more ecologically friendly products, consumer self-interest can be utilized to drive the market towards more eco-friendly food production methods.

This study uses four popular agricultural products (cherry tomatoes, table tomatoes, lettuce, and garlic) from three different farm types: small, local (SL); large, local (LL); and conventional (CON) to assess if farm type is associated with the perceived quality of the products. Product quality is determined using a sensory evaluation, willingness-to-pay (WTP), and physio-chemical laboratory tests. Physio-chemical tests are used to give a more comprehensive understanding of chemical and physical differences in the products using objective laboratory tests and will be used complementary to the sensory evaluation. To avoid any biases from labeling, all products had a blind presentation. All products were grown in the Lower Mainland and Vancouver Island, British Columbia, except for CON garlic which originated from China and were obtained from mature existing farm operations which lead to product variety varying between the farm types and sources.

The use of SL, LL, and CON farm types allows for two different aspects of the production system to be investigated that could have effects on consumer sensory perception of the products. The first is locality, as the difference between LL and CON is the time between harvest and purchase with LL representing local farms and CON more distant farms. The second is small vs large farm operations, which can be used as a proxy for agricultural production methods. The small farms used in this research are considered to be more ecologically friendly agricultural operations and use organic farming practices. The SL farms were recruited from another research study where 24 different farm operation data points were gathered on the participating farms. This allowed for confirmation of a homogenous grouping of farms in the SL group. Therefore, although these farms will be identified as “small” and “organic”, these factors are not the only alignments of the SL sources. This note is extremely important and is what separates this study from past research. All of these farms have not only similar farm operations, but soil health data, financial information, and data informing on the motivations of the farmers themselves. Both LL and CON are more broadly categorized as having conventional production methods. The CON was included as a baseline sample for all other samples to be referenced from. This was done to allow the participants to have something to directly compare each sample to. Therefore, if time since harvest is a significant predictor of consumer preference, then a difference between LL and CON would be seen, but if that difference in consumer preference is seen between SL and LL then production practices supersede the effects of harvest and travel time.

2.2 Methods

2.2.1 Experimental Design

I tested the relationship between farm type (size and locality) and the perceived quality of products to answer the question: does farm type predict the physio-chemical and/or human sensory performance of different agricultural products?

Three popular products (garlic, lettuce, and tomatoes) were each collected from three different types of farms: small local (SL) producers emphasizing “green/organic” environmental practices, large local conventional (LL) producers, and major conventional (CON) producers (Table 2.1). These products were chosen based on the available products from all three farm levels (with the SL being the most restrictive). The products were intentionally chosen to include products that represent different biological parts of the plant (i.e. leaves, fruit, bulbs). Different biological plant parts have the potential to react differently to their environment and could correspondingly affect the flavor of the products differently. Products were assessed by measuring consumer-relevant physio-chemical characteristics in addition to direct human sensory analysis.

Table 2.1: Definitions of the three farm type categories and products acquired from each.

Source	n	Definition
Small, Local (SL)	4	< 10 acres < 70km from Victoria Operations: Organic practices (certified or non-certified)
Large, Local (LL)	2	> 40 acres <70km from Victoria Conventional non-organic farm operations. All products field grown.
Conventional (CON)	4	From large, chain grocery stores from four different farms >80km from Victoria Tomatoes grown in hydroponic greenhouses. Lettuce and garlic were field grown.

SL and LL products were purchased directly from farms while CON products were purchased from local grocery chain stores. Both the CON and LL were included to account for how long-distance transport may affect the organoleptic properties of products. Time between harvest and acquisition is unknown for all CON products but is presumed to be extensive relative to LL and SL products which were harvested no more than one day before acquisition with the exception of garlic which was harvested one week to one month before acquisition. The maximum period between product acquisition to sensory analysis was one day, with the exception of garlic which was eight to 15 days. All SL and LL products were described as “market-ready” by farm producers at acquisition. Tomatoes and garlic were transported in a cooler at ~22°C and lettuce was transported in a cooler on ice (~12°C). Upon laboratory arrival, all products remained at room temperature except lettuce which was refrigerated at 3°C until analyses.

2.2.2 Sensory Analysis

A human sensory panel assessed products for discernable differences attributable to the production practice source farms. Panelists compared each experimental product sample to a conventionally grown baseline product (CON) purchased from a local grocery store.

All products, including the CON baseline sample, were presented ‘blind’ with minimal processing (Table 2.2) in 60mL and 150mL clear plastic bowls for the experimental and baseline samples respectively. All samples were labeled with a three-digit alphanumeric code. The products were assessed by an untrained 102-member consumer panel (Tables 2.3 &

2.4). The recruitment for this panel and the experiment itself were completed on a university campus. Therefore, the majority of the participants were young students with an average age of 22 years (Table 2.3). The participants were also 75% biologically female (Table 2.3). Both indicate that the panel does not represent the population of the consumers in this area as a whole. However, it is thought that both age and sex can affect how a person tastes with younger individuals and biological females to be more sensitive to differences in taste (Bartoshuk et al., 1994; Mojet, 2003; Oliveira-Pinto et al., 2014; Schiffman, 1997).

Table 2.2: For physio-chemical analyses, variable tissue water content of each product type necessitated water addition to achieve a consistent concentration of liquid (Schvambach et al., 2020; Ruiz-Aceituno and Lázaro, 2021). For the sensory analysis, each product was presented to the participant with minimal processing.

	Physio-Chemical Liquid Sample Preparation		Sensory analysis Preparation and Presentation	
	Weight (g) of product	Volume (mL) of water added	Processing	Sample Presentation
Cherry Tomato	60g (20g from 3 separate tomatoes)	160mL	Cut in half	2 halves (~6g)
Table Tomato	60g (20g from 3 separate tomatoes)	160mL	Sliced into 5mm thick discs and then cut into quarters	2 pieces (~6g)
Lettuce	15g (5g from 3 separate heads of lettuce)	100mL	Split down the center vein and cut into 1cm strips	3 strips (~3g)
Garlic	30g (10g from 3 separate heads of garlic)	120mL	Minced. Added to canola oil. Steeped for 18 hours	3g (w/ both oil and minced pieces)

Table 2.3: Sensory panel statistics. Additional details can be found in Appendix, Table 5.1.

Variable	Value
Total individual participants	n = 102
Product-source evaluations per participant	Mean = 6.35 (+/- 3.57 sd) Minimum = 3 and Maximum = 23
Total number of evaluations	n = 629
Sex (%)	Male = 21 Female = 76 Prefer not to Answer = 4
Age (years)	Mean = 22 (+/- 7.002 sd) Minimum = 16 and Maximum = 57

Participants were seated in individual cubicles (70cm x 70cm horizontal area) fitted with visual dividers to eliminate exposure to other participants. Water and crackers were provided as palate cleansers and the participants were instructed to take both as needed between samples. Blackout curtains and ceiling-mounted whole-room red high-performance LED lights (Insight Lighting; Model: Structure Mini Direct; Output: 5 W/FT; RGB= 255,0,0) eliminated colour variation and other visual cues of product samples.

Table 2.4: Total number of human sensory evaluations of each source farm for each product.

Source/ Product	SL1	SL2	SL3	SL4	LL1	LL2	CON	**Total**
Cherry Tomato	0	24	36	0	0	61	61	**182**
Table Tomato	24	0	0	24	0	51	51	**150**
Lettuce	24	0	36	0	24	35	58	**177**
Garlic	24	0	24	24	24	0	24	**120**
Total	**72**	**24**	**96**	**48**	**48**	**147**	**194**	**629**

Each panelist was presented with a sample array comprised of three to five experimental treatment samples together with a baseline sample for one different product. Unknown to panelists, the CON product was the baseline sample in all cases. The samples together with water and crackers were placed in cubicles prior to participant arrival (Figure 2.1). Participants were instructed to assess each sample relative to the baseline sample using a modified nine-point hedonic scale (Table 2.5). Unbeknownst to the participants, each sample array contained a replicate of the CON baseline the LL and SL experimental samples (Figure 2.1). Inclusion of the duplicate sample permits evaluation of panel scoring precision.

Participants began by tasting the baseline sample and recording their overall preference. Participants then sampled each product, left to right, and scored each relative to the baseline for sweetness, acidity, bitterness, texture, flavor intensity, and/or overall preference using the modified hedonic scale relative to the baseline sample (Table 2.5). Sample order in the array, after the baseline sample, was randomized for each participant.

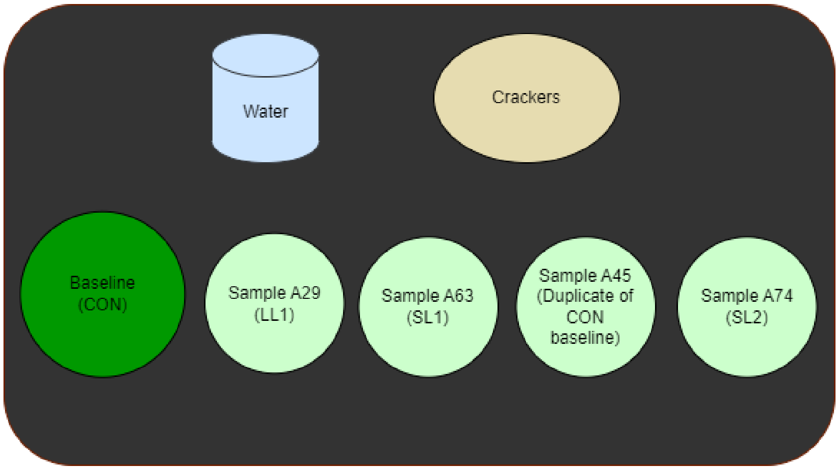


Figure 2.1: Example sample presentation to participants. Sample order was randomized but participants were instructed to begin with the "baseline sample" on the far left and move rightwards.

Table 2.5: Nine-point hedonic scale (left) and modified nine-point presented to panelists (right) (Lawless and Heymann, 2010). The modified hedonic scale allowed participants to rate the samples relative to the baseline.

Scale	Nine-point hedonic scale	Modified nine-point hedonic scale used here
9	Like extremely	Extremely More
8	Like a lot	A lot more
7	Like moderately	Moderately more
6	Like a little	A little more
5	Neither like nor dislike	Same as baseline
4	Dislike a little	A little less
3	Dislike moderately	Moderately less
2	Dislike a lot	A lot less
1	Dislike extremely	Extremely less

2.2.3 Willingness-to-Pay (WTP)

Participants were asked how much more/less they were willing to pay (WTP) for each sample (product-source combination) (Appendix; Table 5.1) relative to a reference price provided for the baseline sample (/lbs); $2.50 for cherry tomatoes, table tomatoes, and lettuce and $6.00 for garlic.

2.2.4 Physio-Chemical Analyses

Firmness: A penetrometer (Yuecoom; Model: GY-3; Capacity: 24kg/cm^2 d=0.2, 8mm head) generated values (kg/cm^2) from three produce samples (Table 2.6) haphazardly selected from each product-source. Mean values and standard deviation are reported in Appendix; Table 5.2*.*

Table 2.6: Penetrometer testing of firmness for lettuce, garlic, and tomatoes (table and cherry). Each product was using an 8mm head.

Product	Penetrometer Methods
Lettuce	One leaf was tested mid-way on the long axis of the leaf blade avoiding the vein while still attached to the full head of lettuce.
Garlic	In the middle of a peeled clove of garlic.
Table and Cherry Tomatoes	Skin was peeled and the fleshy part of the tomato was tested avoiding the seeds.

Chemical characteristics of each product-farm source combination were assessed by blending products into a liquid using a Vitamix E310 blender (Table 2.2). Each product was blended at medium speed for 10 seconds and strained through a 2mm mesh strainer. This process was repeated yielding two replicates for each product-farm source combination.

Total soluble solids (TSS): TSS is a measure of water-soluble solids present in products which are most commonly sugars such as glucose and fructose (Zhu et al., 2018; Iowa State University, 2020). Four drops of distilled water were placed on the plate 0-90% hand-held refractometer to confirm a ^{o}Brix reading of zero before being wiped dry and adding four drops of the liquid sample to be assessed. This was replicated three times for each sample. Mean values and standard deviation are reported in Appendix; Table 5.2.

Titratable acidity (TA): TA represents the total acid concentration of the product sample and is considered to be a better predictor of the sensory impact of acid than pH (Nielsen, 2017). Human taste registers both free and bonded hydrogen ions, both of which are assessed in TA whereas pH only accounts for free ions. The percent acidity of each sample was determined by titration of 0.1M NaOH into 25mL of liquid sample diluted to 250mL with boiled water cooled to room temperature. Five drops of phenolphthalein indicator were used and each sample was titrated to the first appearance of light pink colour. Each sample was replicated three times and mean values and standard deviation are reported in Appendix; Table 5.2.

TA was calculated using the following formula (Nielsen, 2017):

$$\% \text{ acidity} = \frac{N * V * M / \# \text{ of } H^{+} \text{ ions}}{S * 10}$$

where N is the normality of NaOH, V is the volume (mL) of NaOH, M is the molecular weight of the predominant acid (Appendix; Table 5.3), the number of H+ ions is the number of hydrogen ions in the acid (Appendix; Table 5.3), and S is the sample mass (g). Citric acid is predominant in tomatoes and garlic while malic acid predominates in lettuce (Joslyn, 1970; Petropoulos et al., 2018; Ruiz-Aceituno and Lázaro, 2021).

pH: Potential hydrogen, or pH, is also a measure of acid content and measures active acidity (Nielsen, 2017). It is more representative of the strength of the acid present rather than how much acid is present, as it only measures the free hydrogen ions in a sample. pH was measured using the Orion Star A111 pH meter recalibrated using 4.01, 7.00, and 10.01 buffers for every three samples. Each juice sample was replicated three times and mean values and standard deviations are reported in Appendix; Table 5.2.

2.2.5 Statistical Analysis

All statistics will be performed and visualized using the statistical program R (RStudio for Windows; Version: 2022.12.0) using the FactoMineR (Le et al., 2008), agricolae (De Mendiburu, 2009), qpcR (Spiess, 2018), and ggplot2 (Wickham, 2016) packages.

Participant Precision

Participants were instructed to assess each sample relative to the baseline sample provided. Participants were unaware that the baseline sample was repeated within the sample array. The blind duplication of the baseline allows an assessment of participant sensory precision. A high-performing participant would score the duplicate as “same as the baseline” (“5” on the modified hedonic scale). Participant precision declines as deviation in either direction from “5” increases. A one-way t-test was used to assess overall participant precision.

Age and sex can affect a person’s organoleptic perceptions (Bartoshuk et al., 1994; Mojet, 2003; Oliveira-Pinto et al., 2014; Schiffman, 1997). Generalized linear models (GLM) were used to evaluate if age, sex, or assessment date are significant determinants of the "overall preference" of each product-farm source combination and thus should be included in subsequent analyses.

Sensory Evaluation

Effect of Source Farm: To test if source farm significantly influenced participants' sensory perception, one-way ANOVA tests were employed. To discriminate which farm source generated statistically different responses, post-hoc Fisher's Least Significant Difference (LSD) tests were done for each product-farm source that had significant differences revealed by ANOVA.

Evaluating All Product-Source Farm Groupings: To evaluate farm source-related effects across all product-farm source combinations, a multidimensional scaling (MDS) model was used with k-means clustering. The clusters of the k-means were confirmed with a hierarchical cluster analysis (HCA) using the table function in the R base package (R Core Team, 2022). Unlike k-means, HCA employs a linkage method that does not rely solely on establishing a centroid. Further, the axes of k-means ordination are undefined making interpretation challenging. Congruence of results generated by both methods provides robust evidence of substantial product discrimination by panelists.

Willingness-to-pay (WTP)

Effect of Source Farm: To test if product source farm significantly influenced participants' WTP for each product, one-way ANOVA and Fisher's LSD tests were used to determine if participants differentially valued products produced from the different farm sources.

Correlation WTP and Preference: A correlation analysis was employed to test for a relationship linking overall preference of farm source products and WTP.

Physio-chemical Analyses

To evaluate which physio-chemical analyses are important factors in explaining "overall preference" of each product, generalized linear models (GLM) using the identity link were used. Best fit models were identified using the Akaike information criterion (AIC).

2.3 Results

2.3.1Participant Precision

Participant precision was assessed by including a duplicate of the baseline CON sample in each product sample array. Deviation of scores between the duplicates across all product categories were not significantly different from the baseline except in the cases of cherry tomato “overall preference” and “flavor intensity” (Table 2.7). Further analysis showed that one of the two cherry tomato sample arrays (containing a SL, LL, and CON sample each) was predominantly responsible for the divergence of the participants between the baseline and duplicate scores for cherry tomato “overall preference” and “flavor intensity”. Removal of this particular sample array resulted in the remaining cherry tomato duplicate samples no longer being significantly different from the baseline for “overall preference” (t(35) = 0.65, p = 0.52) and “flavor intensity” (t(35) = 1.26, p = 0.215).

Age (t = 0.882, p = 0.381), sex (t = 0.040, p = 0.969), and date (t = 1.33, p = 0.189) of evaluation were not significant predictors for “overall preference” for all products.

Table 2.7: Participant precision using t-tests to evaluate the magnitude of baseline-duplicate deviation. Significant values ($p \leq 0.05$) indicate the mean response of the duplicate is significantly different from the baseline mean response.

Product	Category	t-test Results	Product	Category	t-test Results
Cherry Tomato	Sweetness	t(60) = 0.78, p = 0.44	Table Tomato	Sweetness	t(51) = -1.32, p = 0.19
	Acid	t(60) = -1.03, p = 0.31		Acid	t(51) = 0.00, p = 1.00
	Flavor Intensity	t(60) = 2.44, p = 0.02*		Flavor Intensity	t(51) = 0.61, p = 0.54
	Overall Preference	t(60) = 2.15, p = 0.04*		Overall Preference	t(51) = -0.82, p = 0.42
	Texture	t(60) = 0.56, p = 0.58		Texture	t(51) = -0.20, p = 0.84
	WTP	t(60) = 2.05, p = 0.05*		WTP	t(51) = -1.58, p = 0.12
Lettuce	Bitterness	t(60) = -1.79, p = 0.08	Garlic	Acid	t(24) = -0.12, p = 0.91
	Flavor Intensity	t(60) = 0.43, p = 0.67		Flavor Intensity	t(24) = 0.78, p = 0.44
	Overall Preference	t(60) = 0.72, p = 0.47		Overall Preference	t(24) = 0.81, p = 0.42
	Texture	t(60) = -0.37, p = 0.71		Texture	t(24) = 0.80, p = 0.44
	WTP	t(60) = -0.45, p = 0.66		WTP	t(24) = 0.28, p = 0.78

2.3.2 Sensory Evaluation

Effect of Source Farm

A Shapiro-Wilks test found the majority of the sensory evaluations violate the normality assumption of the ANOVA test (Appendix; Table 5.4). However, the f-test is robust even with violations of assumptions with the exception of the homogeneity of variance assumption (Carifio and Perla, 2008). Bartlett's test of variance homogeneity found no products violated this assumption (Appendix; Table 5.5).

When all product categories were combined and tested for differences in sensory perception, "overall preference" and "flavor intensity" scores for SL-sourced products were significantly greater than for LL products, but not CON products (Table 2.8). When reassessed by individual products, SL cherry and table tomatoes had significantly greater scores for "overall preference" (Table 2.9) which could be the main contributor to the differences seen when all products were combined.

Table 2.8: Sensory evaluation results for all products combined and participant precision controlled: ANOVA results, absolute rank, mean score, and groups by Fisher's LSD. The participants were controlled using a duplicate of the baseline sample in the sample array and a one-way t-test was used to find deviation from baseline (Table 2.7). When the precision was controlled, one cherry tomato sample array was removed. When precision was not controlled (top panel) SL and CON were not significantly different for "overall preference". When precision was controlled for (bottom panel) SL and CON became significantly different.

Precision not Controlled	Overall Preference			Flavor Intensity			Texture		
ANOVA:	f(2) = 4.49, p = 0.012*			f(2) = 8.56, p = 2e-4*			f(2) = 1.72, p = 0.180		
Farm Type:	Rank	Mean	Group	Rank	Mean	Group	Rank	Mean	Group
SL	1	5.41	a	1	5.78	a	1	5.13	a
CON	2	5.15	ab	2	5.25	b	2	5.02	a
LL	3	4.90	b	3	5.20	b	3	4.89	a
Precision Controlled	Overall Preference			Flavor Intensity			Texture		
ANOVA:	f(2) = 4.45, p = 0.012*			f(2) = 8.75, p = 2e-4*			f(2) = 1.32, p = 0.268		
Farm Type:	Rank	Mean	Group	Rank	Mean	Group	Rank	Mean	Group
SL	1	5.43	a	1	5.81	a	1	5.11	a
CON	2	5.06	b	2	5.22	b	2	5.03	a
LL	3	4.90	b	3	5.18	b	3	4.89	a

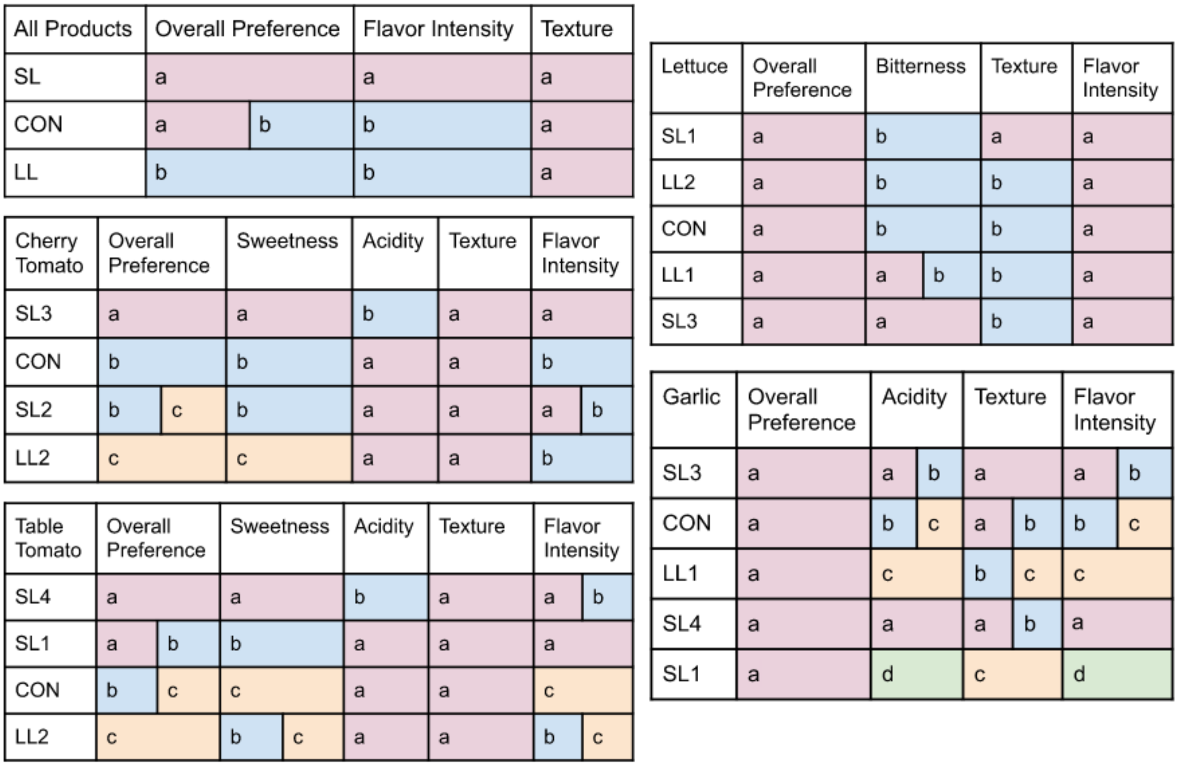
*significant p-value (p≤ 0.05)

The imprecision of participant scores associated with one cherry tomato sample array (which included one SL, LL, and CON sample each), sufficiently skewed results to diminish discrimination between all CON and SL products, suggesting similar levels of preference (Tables 2.8, 2.9, & 2.10). However, when participant precision is controlled by removing the single problematic cherry tomato array, all SL farm types differed significantly from CON (and LL) farm types (Table 2.8).

Table 2.9: Sensory evaluation results for each product-farm source combination: ANOVA results (statistical values indicated by p≤ 0.05), absolute rank, mean score, and groups by Fisher's LSD.

Cherry	Overall Preference			Sweetness			Acidity			Texture			Flavor Intensity		
ANOVA:	f(3) = 5.91, p = 7e-4*			f(3) = 21.96, p = 4e-15*			f(3) = 11.42, p = 7e-7*			f(3) = 0.728, p = 0.54			f(3) = 5.1, p = 0.002*		
Source:	Rank	Mean	Group	Rank	Mean	Group	Rank	Mean	Group	Rank	Mean	Group	Rank	Mean	Group
SL3	1	6.22	a	1	7.06	a	4	3.28	b	4	4.83	a	1	6.16	a
CON	2	5.41	b	3	5.19	b	3	4.79	a	3	5.08	a	3	5.49	b
SL2	3	5.20	bc	2	5.56	b	2	4.80	a	1	5.28	a	2	5.56	ab
LL2	4	4.80	c	4	4.14	c	1	5.11	a	2	5.10	a	4	4.95	b
Table	Overall Preference			Sweetness			Acidity			Texture			Flavor Intensity		
ANOVA:	f(3) = 6.22, p = 5e-4*			f(3) = 15.4, p = 8e-9*			f(3) = 8.56, p = 3e-5*			f(3) = 2.91, p = 0.24			f(3) = 1.85, p = 0.017*		
Source:	Rank	Mean	Group	Rank	Mean	Group	Rank	Mean	Group	Rank	Mean	Group	Rank	Mean	Group
SL4	1	6.26	a	1	7.14	a	4	3.44	b	2	5.11	ab	2	5.96	ab
SL1	2	5.52	ab	2	5.60	b	1	5.40	a	1	5.52	a	1	6.28	a
CON	3	4.79	bc	4	4.63	c	2	5.00	a	3	4.94	ab	4	5.15	c
LL2	4	4.59	c	3	4.96	bc	3	4.81	a	4	4.85	b	3	5.33	bc
Lettuce	Overall Preference			Bitterness			Texture			Flavor Intensity					
ANOVA:	f(4) = 2.35, p = 0.056			f(4) = 2.53, p = 0.04*			f(4) = 2.91, p = 0.02*			f(4) = 1.85, p = 0.11					
Source:	Rank	Mean	Group	Rank	Mean	Group	Rank	Mean	Group	Rank	Mean	Group			
SL1	1	5.88	a	4	4.68	b	1	5.92	a	1	5.96	a			
LL2	2	5.39	ab	3	4.69	b	5	4.81	b	3	5.61	ab			
CON	3	5.15	ab	5	4.62	b	2	4.93	b	5	5.08	b			
LL1	4	4.76	b	2	5.04	ab	4	4.88	b	4	5.4	ab			
SL3	5	4.59	b	1	5.78	a	3	4.91	b	2	5.76	a			
Garlic	Overall Preference			Acidity			Texture			Flavor Intensity					
ANOVA:	f(4) = 1.12, p = 0.35			f(4) = 15.08, p = 5e-10*			f(4) = 3.92, p = 5e-3*			f(4) = 9.10, p = 2e-6*					
Source:	Rank	Mean	Group	Rank	Mean	Group	Rank	Mean	Group	Rank	Mean	Group			
SL3	1	5.32	a	2	5.72	ab	1	5.4	a	2	6.16	ab			
CON	2	5.28	a	3	4.96	bc	2	5.2	ab	3	5.28	bc			
LL1	3T	5.20	a	4	4.76	c	4	4.64	bc	4	4.72	c			
SL4	3T	5.20	a	1	6.44	a	3	5.16	ab	1	6.28	a			
SL1	5	4.36	a	5	2.92	d	5	4.24	c	5	3.68	d			

Table 2.10: Visualizing Fisher LSD groupings by colour for each product and all products combined. This table is a distillation of the product discrimination from Table 9.



All Products	Overall Preference	Flavor Intensity	Texture
SL	a	a	a
CON	a b	b	a
LL	b	b	a

Cherry Tomato	Overall Preference	Sweetness	Acidity	Texture	Flavor Intensity
SL3	a	a	b	a	a
CON	b	b	a	a	b
SL2	b c	b	a	a	a b
LL2	c	c	a	a	b

Table Tomato	Overall Preference	Sweetness	Acidity	Texture	Flavor Intensity
SL4	a	a	b	a	a b
SL1	a b	b	a	a	a
CON	b c	c	a	a	c
LL2	c	b c	a	a	b c

Lettuce	Overall Preference	Bitterness	Texture	Flavor Intensity
SL1	a	b	a	a
LL2	a	b	b	a
CON	a	b	b	a
LL1	a	a b	b	a
SL3	a	a	b	a

Garlic	Overall Preference	Acidity	Texture	Flavor Intensity
SL3	a	a b	a	a b
CON	a	b c	a b	b c
LL1	a	c	b c	c
SL4	a	a	a b	a
SL1	a	d	c	d

Evaluating All Product-Farm Source Groupings

MDS with k-means clustering plots were created with three and four clusters corresponding to number of farm source categories (three) and number of products (four). The clustering was used to help identify if the predominant axis of discrimination is product identify or farm type. If panelists were predominantly responding to farm type, it would be expected that there would be clear clusters by farm type in the k=3 analysis. If, however product identity was the primary axis of determination then the k=4 analysis should clearly cluster by product. Neither scenario is clearly supported.

The k=3 analysis did not yield clear clustering by source. SL1 garlic is an outlier which resulted in a single large cluster comprised of the majority of the product-source combinations. Likewise, the k=4 analysis did not yield clear clustering by product, instead generating three separate SL clusters and one large CON and LL cluster that includes two SL products. SL product-sources are more variable in the preference and organoleptic attributes, while conventionally farmed sources (CON and LL) show only modest differentiation from each other. The k=4 analysis clearly suggests the most pronounced axis of discrimination is production practice, not product type or market proximity to farm.

The results of the k=4 analysis was confirmed by HCA (Figure 2.4), which uses a hierarchical clustering algorithm to predict clusters rather than the unsupervised learning algorithm used by k-means clustering. The HCA shows clear discrimination by farm practice, rather than by product identify or market proximity. The consensus between the HCA analysis and the four-cluster k-means analysis supports the hypothesis that the organoleptic properties of the products are affected by source, with the SL sources on average being more preferred than either CON and LL sources.

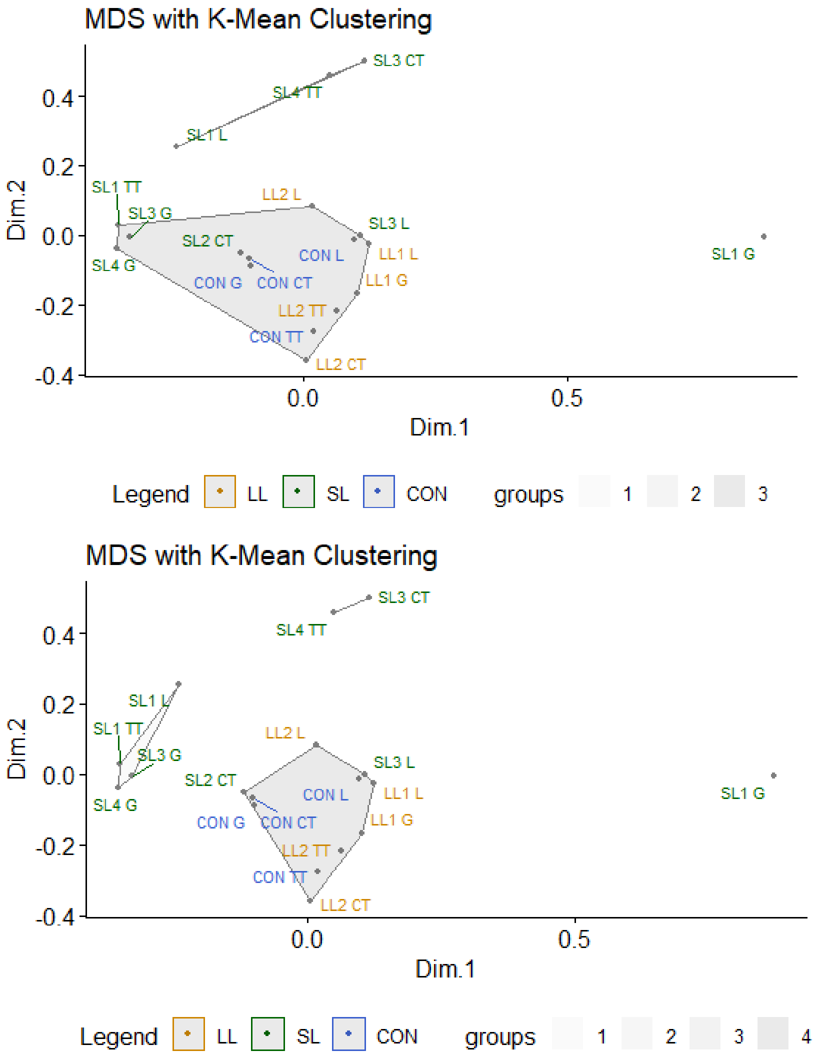


Figure 2.2: MDS with k-mean clustering comparing all product-source combination's means of sensory data including all categories (sweetness, texture, etc.). Product codes are cherry tomatoes (CT), table tomatoes (TT), lettuce (L), and garlic (G) and sources are small, local (SL), large, local (LL), and conventional baseline (CON).

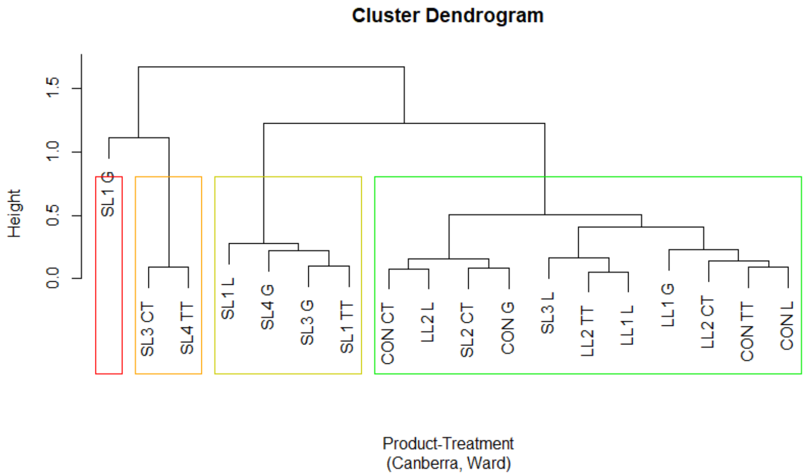


Figure 2.3: HCA clusters comparing all product-source combination's means of sensory data including all categories (sweetness, texture, etc.). Product codes are cherry tomatoes (CT), table tomatoes (TT), lettuce (L), and garlic (G) and sources are small, local (SL), large, local (LL), and conventional baseline (CON).

2.3.3 Willingness-to-pay (WTP)

Effect of Source

A Shapiro Wilk normality test indicated that all products' WTP values violate the assumption of normality (Appendix; Table 5.4). All product-farm source combinations had scoring outliers that could have skewed the results. Therefore, both an ANOVA and Kruskal-Wallis test were performed. The Kruskal-Wallis results were consistent with the ANOVA analysis and did not alter the interpretation of results (Appendix; Table 5.8).

When all products were combined, WTP did not differ as a function of farm source (Table 2.11), meaning the different production practices did not influence participant's willingness-to-pay for products. The only exception was participants were willing to pay $0.67 and $0.76 more for SL4 table tomatoes than table tomatoes from CON and LL sources, respectively (Table 2.11). Fisher's LSD groupings confirm participants were consistently willing to pay more for SL4's table tomatoes.

Participants were willing to pay $0.67 and $0.76 more for the SL4's table tomatoes than CON and LL's respectively (Table 2.11). Fisher's LSD groupings confirm participants were consistently willing to pay more for SL4's table tomatoes.

Correlation WTP and Preference

For all products combined, WTP and "overall preference" were not correlated (r(643) = 0.52, p < 2e-16). Therefore, in general, although participants did identify organoleptic differences and expressed clear preferences among products, they were unwilling as a group to pay a premium for preferred products.

Table 2.11: Product-source score rank, ANOVA result, mean score, and Fisher's LSD group for individual and combined products. 'All products' WTP was calculated by subtracting the baseline's reference price from each participant's WTP score, as the reference price for each product was not the same.

		WTP					WTP					WTP		
Cherry Tomato	ANOVA:	f(3) = 1.79, p = 0.152			Table Tomato	ANOVA:	f(3) = 5.31, p = 0.002*			All Products	ANOVA:	f(3) = 5.31, p = 0.002*		
	Source:	Rank	Mean	Group		Source:	Rank	Mean	Group		Farm Type:	Rank	Mean	Group
	SL3	1	2.82	a		SL4	1	3.01	a		CON	1	-0.08	a
	CON	2	2.77	a		SL1	2	2.59	ab		LL	2	-0.23	a
	SL2	3	2.62	a		CON	3	2.33	b		SL	3	-0.30	a
	LL2	4	2.46	a		LL2	4	2.24	b					
Lettuce	ANOVA:	f(4) = 0.77, p = 0.55			Garlic	ANOVA:	f(4) = 1.05, p = 0.38							
	Source:	Rank	Mean	Group		Source:	Rank	Mean	Group					
	SL1	2	2.63	a		SL3	2	4.89	a					
	LL2	1	2.60	a		CON	1	5.09	a					
	CON	3	2.46	a		LL1	3	4.88	a					
	LL1	4	2.36	a		SL4	4	4.82	a					
	SL3	5	2.35	a		SL1	5	4.21	a					

*significant p-value ($p \leq 0.05$)

2.3.4 Physio-Chemical Analyses

For all four products, multiple best-fit models ($\Delta AIC < 2$) and modest AICw values made the declaration of a single best-fit model difficult (Table 2.12). All tomatoes' best-fit models include pH and for cherry tomatoes, TSS. The best-fit models for lettuce included firmness and TSS and a mixture of all four variables for garlic. Taken together, the four physio-chemical analyses do little to explain the variation in "overall preference" for any of the products.

Table 2.12: AIC, delta AIC (ΔAIC), and AIC weights (AICw) values for GLM of “overall preference” for each product’s physio-chemical analyses (titratable acidity (TA), total soluble solids (TSS), firmness (Firm), and pH).

Cherry Tomato				Table Tomato				Lettuce				Garlic			
Model Variables	AIC	ΔAIC	AICw	Model Variables	AIC	ΔAIC	AICw	Model Variables	AIC	ΔAIC	AICw	Model Variables	AIC	ΔAIC	AICw
Firm + TSS + pH	4209.84	0.000	0.341	pH	3801.23	0.000	0.308	Firm + TSS	4429.07	0.000	0.426	TSS + TA	3083.98	0.000	0.149
TSS + pH	4210.04	0.197	0.309	TSS + pH	3801.97	0.744	0.212	Firm + TSS + pH	4430.56	1.492	0.202	Firm + TA	3084.11	0.134	0.139
Firm + TSS + TA + pH	4210.95	1.114	0.196	TA + pH	3803.21	1.975	0.115	Firm + TSS + TA	4430.94	1.869	0.167	TSS + pH	3084.25	0.268	0.130
TSS + TA + pH	4211.44	1.603	0.153	Firm + pH	3803.21	1.981	0.114	Firm + TSS + TA + pH	4432.52	3.444	0.076	TSS	3084.56	0.580	0.111
pH	4223.99	14.15	0.000	Firm + TSS + pH	3803.70	2.473	0.089	Firm	4434.61	5.542	0.027	Firm + TSS + TA	3085.38	1.396	0.074
Firm + pH	4225.41	15.57	0.000	TSS + TA + pH	3803.79	2.562	0.085	TSS	4434.64	5.566	0.026	Firm + TSS + pH	3085.46	1.477	0.071
TA + pH	4225.49	15.65	0.000	Firm + TA + pH	3805.20	3.967	0.042	TSS + pH	4434.98	5.909	0.022	TSS + TA + pH	3085.51	1.525	0.069
Firm + TA + pH	4226.79	16.95	0.000	Firm + TSS + TA + pH	3805.62	4.390	0.034	Firm + pH	4436.30	7.224	0.011	Firm + TA + pH	3085.89	1.911	0.057
Firm + TSS	4228.74	18.90	0.000	TSS	3826.69	25.46	0.000	Firm + TA	4436.33	7.259	0.011	Firm + TSS	3086.49	2.508	0.042
Firm + TSS + TA	4230.49	20.66	0.000	TSS + TA	3828.32	27.09	0.000	TSS + TA	4436.42	7.346	0.011	Firm + TSS + TA + pH	3086.55	2.567	0.041
TSS	4243.16	33.32	0.000	Firm + TSS	3828.68	27.45	0.000	TSS + TA + pH	4436.94	7.868	0.008	Firm	3086.90	2.925	0.034
TSS + TA	4245.12	35.28	0.000	Null	3829.24	28.01	0.000	Firm + TA + pH	4438.11	9.043	0.005	Firm + pH	3086.93	2.954	0.034
Firm	4246.79	36.95	0.000	TA	3829.92	28.68	0.000	Null	4438.90	9.827	0.003	TA	3087.97	3.993	0.020
Firm + TA	4248.69	38.85	0.000	Firm + TSS + TA	3830.30	29.07	0.000	pH	4439.68	10.61	0.002	TA + pH	3088.26	4.284	0.017
Null	4256.06	46.22	0.000	Firm	3830.60	29.37	0.000	TA	4440.52	11.42	0.001	Null	3090.36	6.377	0.006
TA	4257.99	48.15	0.000	Firm + TA	3831.75	30.52	0.000	TA + pH	4441.53	12.45	0.001	pH	3092.16	8.176	0.002

2.4 Discussion

A commonly-held assumption is that the more ecologically friendly or sustainably grown a food product is, such as organic, the higher the quality and better the taste (Theuer, 2006). However, this relationship remains equivocal with some authors suggesting that consumer preference for “green” products is attributable to a placebo or halo effect (Theuer, 2006; Foodwise, 2011). Further, time since harvest (and therefore ripeness) may be confounding factors. Organic and/or local produce may offer superior organoleptic experience simply because such products are often harvested and available to consumers at peak freshness relative to conventionally farmed counterparts (Bourn and Prescott, 2002; Blair, 2011; Foodwise, 2011).

Overall, SL products were more preferred by panelists than either LL and CON products which were often found to be indistinguishable in preference from each other. Therefore, farm production method is a more significant predictor of consumer preference than locality. The harvest time for the SL and LL sources was the same for all products, therefore, ‘freshness’ was controlled for between these two farm types. The difference in preference between the SL and LL products suggests that these differences are not merely because of the freshness of the products. Contrary to popular belief (Bourn and Prescott, 2002; Foodwise, 2011; Annunziata and Vecchio, 2016), this means that organic products do not taste better just based on freshness or harvest time. This could suggest that organically grown food has the potential to have a higher quality even after transport. The addition of a distant small, organic farm would be an interesting addition to this research to see if freshness and harvest time affects the product quality and taste. All in all, more ecologically friendly agricultural production methods seem to contribute to product organoleptic properties more than transportation distance. Therefore, if taste is the most important variable for consumers when choosing food and small organic farms’ products had a more preferred taste, then consumer self-interest could be utilized towards more sustainable food production.

Food price is as important a factor for consumer choice as taste is (Steptoe et al., 1995; Glanz et al., 1998; Mela, 2001). Participants in this research were not willing to pay a premium for preferred products; the “overall preference” for each product was not correlated with WTP. Therefore, even though consumers often preferred small organic farm products, this did not translate to participants willing to pay more. Table tomatoes were the only product where “overall preference” and WTP showed similar trends. Despite a similar “overall preference” pattern observed in cherry tomatoes, consumers were unwilling to pay more than the benchmark price for tomatoes. This finding has serious potential implications regarding the feasibility of strategies dependent on leveraging consumer self-interest to incentivize changes in farm practices. In short, if adoption of climate-friendly practices does not translate to a market advantage via superior consumer taste experience, the only alternative is an appeal to altruism, a strategy with limited scope for success (Hardin 1977).

Participants were not provided options or suggestions regarding how much more or less they might be willing to pay for each product, but rather could provide any value, no matter how modest, relative to the baseline reference price. The participant’s WTP was $0.21 less than the baseline reference price for all the products combined. This could be for many reasons. First, a majority of the participants were university students, a population likely to not possess substantial disposable income. It could also be that taste alone is not enough to convince a person that that product is of higher quality and in turn is worth more money. WTP is affected by many factors, one of which is the labeling, such as “eco-friendly”, which has been widely studied and is known to promote increased WTP (Sörqvist et al., 2013; Gassler et al., 2019). WTP can also increase when the product is perceived to be of higher quality (Mccluskey and Loureiro, 2003). Production locality and proximity to market can also affect WTP, especially if local products are thought to be of higher quality (Carpio and Isengildina-Massa, 2009; Grebitus et al., 2013; Bernard and Liu, 2017). Taking all of the above into consideration, the blind presentation of the products could have decreased a participant's WTP given WTP is informed by these elements of information. In the case of cherry tomatoes, where the perception of taste was different between farm types but not the WTP, strategic labeling may convince a consumer to pay a premium for more preferred products (Teuber et al., 2016). Future studies examining the interaction of consumer information and organoleptic profile would significantly advance the “real-world” understanding of WTP dynamics. Environmental sustainability remains a relevant factor for consumers when choosing food products (Steptoe et al., 1995; Annunziata and Vecchio, 2016). Labeling in conjunction with increased consumer experience may be enough to drive the market toward more sustainable agricultural methods. The combination of self-interest (i.e. better-tasting products) and altruism (Czudec, 2022) has the potential to affect market share in favor of environment-responsive producers. A major caveat is consumer income; the importance of price above all else in driving consumer decisions is inversely related to consumer income (Steptoe et al., 1995).

Some variation in participant preference was seen across farm types. Not all LL or CON products were the least preferred and not all SL products were most preferred. However, in general, the products from SL were preferred more than LL and CON suggesting that more investigation is needed into mechanisms linking production practices and organoleptic properties and how these may change as a function of product. This is especially important for farmers interested in the market differentiation of their products. While more eco-friendly agricultural methods have the potential to produce better quality products in terms of taste, this might not hold true for every product. (Svec et al., 1976; Theuer, 2006).

The SL cherry and table tomatoes were more preferred and had a higher flavor intensity than the LL and CON products, a trend not found in garlic and lettuce. However, for both lettuce and garlic, “overall preference” was not a good indicator of consumer discrimination. For garlic, differences focused on “acidity” and “flavor intensity”, suggesting that participants were able to discriminate differences between the sources, but those differences did not equate to differences in “overall preference”. Garlic has a strong flavor and is pungent (Pardo et al., 2007) and even though the garlic was diluted in oil for the sensory evaluation, the strong flavor and pungency could have been unpleasant or overpowering and thus negating a preference for one over another. Therefore, differences seen in “acidity” and “flavor intensity” could have been a result of random chance stemming from participants being too overwhelmed to accurately score potential differences (Zhao et al., 2007). Were this so, we would expect a similar trend for “overall preference” scores. However, participant precision of “overall preference” with regard to the duplicate sample in each sample array was equally precise as with the other products. Therefore, it is unlikely participants were too overwhelmed to notice the differences but just did not positively take to one raw garlic over another.

Lettuce scores suggested the opposite challenge to garlic. Lettuce has very delicate flavor profile and the participants may have not been able to discriminate the differences easily, resulting in the participants not having a preference for one over the other. However, previous research has found that lettuce and other leafy greens usually have organoleptic differences responsive to agricultural production methods when using a trained panel (Theuer, 2006; Fontana et al., 2018). The trained panel results contrast to studies where no differences in preference were found in lettuce-production methods using untrained consumer panels (Zhao et al., 2007). Therefore, the lack of significant differences between the lettuce in this study could be attributable to an untrained panel being unable to discriminate between modest organoleptic differences in lettuce.

Utilizing an untrained consumer panel for sensory evaluation can be challenging because of the high degree of potential variability in both individual preferences and taste perception or physiology (Reed et al., 2006; Njoman et al., 2017). Preferences and perceptions of taste can be affected by many things like genetic and biological differences (Jaime-Lara et al., 2023), life experiences, and diet (Nuvoli et al., 2023), indeed both genetic and environmental factors contribute to how a person tastes (Reed et al., 2006) which makes working with untrained consumers challenging. One popular way to work around these individual differences in taste perception is by using a trained panel (Lawless and Heymann, 2010). However, when the goal is to characterize the response of the average consumer, training does little to answer the question. The goal of this research was to find if consumers can be used to drive the market towards more sustainable agricultural methods. All the preferences and individual differences are important because that is what the average consumer has. Using a trained panel is useful if the only goal is finding if differences exist, but those differences are only important if the general public can identify them. Therefore, utilizing an untrained consumer panel is how questions about a broad population can be answered.

The precision of the participants in this study lends merit to the utility of untrained panels. The modified hedonic scale used in this experiment was converted to have some aspects of an analytic sensory evaluation. There are two main types of analyses in a sensory evaluation: hedonic and analytic tests (Lawless and Heymann, 2010). Though the participants were not aware, the comparison to the baseline and modification made to the hedonic scale also function as a paired comparison test. Many believe untrained consumer panels to not be effective to give reliable and consistent results for analytic tests, like the paired comparison (Ares and Varela, 2017). The combination of the hedonic scale and the paired comparison test allowed for the participants to be evaluated for precision and to evaluate perceivable organoleptic differences as well as differences in preference in one test. Consumers can be expected to have a general consensus on organoleptic differences in products using a modified hedonic scale.

2.4.1 Things to Consider

Each source’s products were not of the same variety. Even some sources within each farm type for cherry tomatoes had multiple different varieties. Varieties have the potential to be influential in taste differences whether that be from organic varieties being more novel or the CON samples being more familiar to the participants. Therefore, it could be argued that differences in variety are skewing the results. However, the modest signal toward source rather than products indicates that it was less about the individual samples and more about samples from the sources as a whole.

Another limitation is that the exact farm operations and “sustainability” were not completely known for the LL and CON samples. Some information about farm operations and sustainability goals could be found on the farms’ web pages, but the exact sustainability of each CON and LL farm can only be inferred. Future research should aim to control for both variety and farm operations.

2.5 Conclusion

Small organic farms had the more preferred products, but consumers were not willing to pay a premium price for those products. This suggests that a modest improvement of taste cannot alone drive the food market towards more sustainable agricultural methods by utilizing consumer self-interest. However, the more ecologically friendly production methods did seem to improve the quality of the products in regard to taste more than the conventional growing methods, as opposed to the locality of the farms. Therefore, production methods may have a larger effect on the organoleptic properties of products than locality and freshness.

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Chapter 3:

Connecting soil health and fertilization methods to organoleptic performance

3.1 Introduction

Determining if organoleptic perceptions are influenced by farming techniques has proven equivocal (Succop and Newman, 2004; McCollum et al., 2005; Wszelaki et al., 2005; Theuer, 2006) due in large part to experimental designs being ill-conceived to provide conclusive results. Many research studies focus solely on “conventional” vs “organic” farming rather than focusing on specific farm practices and properties likely to affect product traits, such as soil health (Theuer, 2006).

Soil health is defined as the capacity of soil to function within ecosystems and land-use boundaries to sustain biological productivity, environmental quality, and plant and animal (including human) health (Doran et al. 1996). While the metrics typically used to measure soil health are dynamic (Doran and Parkin, 1994), there is a lack of understanding regarding the degree to which soil health and soil fertilization methods affect a food’s organoleptic characteristics. Soil health is thought to affect product quality broadly speaking (Spanner and Napolitano, 2015); however, the role of the fertilization method is not represented in the literature.

Soil health is easily affected by agricultural practices that alter relationships of water, organic matter, and nutrients all of which can affect the soil’s erosion potential, compaction, and microbial communities (Gregorich et al., 1995). The health of the soil within agricultural operations also contributes more broadly to environmental degradation because as soil health declines it becomes less able to adsorb chemical inputs like fertilizer or pesticides which contribute to the pollution of groundwater (Gregorich et al., 1995). Soil health is difficult to quantify, however, measuring soil health indicators, like bulk density, aggregate stability, and pH, can give some insight into the health of the soil (Doran and Parkin, 1994).

Synthetic fertilizer reduces soil health by diminishing carbon sequestration potential (Lal, 2020) as well as decreasing microbial communities and biodiversity (Shen et al., 2021). Synthetic fertilizers remain popular as they are inexpensive, and nutrients are often tailored to the crop and are readily available for the plants (Sabry, 2015). In contrast, organic compost fertilizer must be biologically processed in the soil prior to being bioavailable to crops (Scotti et al., 2015), often take more time and effort on the part of the farmer, and the exact nutrients available in the compost are unknown (Oregon State University, n.d.).

Degraded soils have a higher potential to sequester carbon than what could be captured in vegetation or other relatively healthy soils (Trumbore et al., 1996). Therefore, finding ways to increase carbon sequestration in degraded soils, like in agriculture, could be an essential way to help dampen the effects of climate change. However, separating product quality and the taste of foods from agriculture and its effects on the climate disregards the food system as a whole. Consumers are an essential part of the food system, so ensuring that consumers are not separated from sustainable agriculture solutions is essential and consumers could be better utilized to drive the market towards more ecologically friendly agricultural methods (Virginia Tech, 2018; Strauss, 2020).

By focusing on broadly defined production systems rather than specific soil health metrics, past research has largely ignored the potential soil-organoleptic link of agricultural products (Theuer, 2006). Organoleptic refers to the characteristics of a substance that relate to sensory organs, such as taste, smell, sight, hearing, or touch. It is thought that both tillage and synthetic fertilizer can affect the health of the soil and therefore would affect the product quality of the crops grown in those soils (Montgomery and Biklé, 2021). For instance, ‘organic’ production typically utilizes tillage, and conventional producers rely on synthetic fertilizers- both of which have the potential to affect product quality.

Taste and price tend to have a greater influence on food choices than extrinsic motivations such as nutrition and environmental performance (Steptoe et al., 1995; Mela, 2001). Therefore, if more ecologically friendly agricultural products are positively associated with the organoleptic properties of the products, then consumer self-interest can be utilized to drive the market towards more eco-friendly food production methods.

This study uses three common agricultural products (kale, carrots, and string beans) grown in experimental plots treated with either organic compost treatment or synthetic fertilizer treatment to assess if treatment or soil health metrics are associated with the perceived product quality. These products were intentionally chosen to include products that represent different biological parts of the plant (i.e. leaves, fruit, roots). Different biological plant parts have the potential to react differently to their environment and could correspondingly affect the flavor of the products differently. Product quality will be determined using a sensory evaluation, willingness-to-pay (WTP), and physio-chemical laboratory tests. The products were obtained from an ongoing restoration agricultural research project during its first growing season in North Saanich, British Columbia. The plots were created on heavily degraded, ex-industrial land.

3.2 Methods

3.2.1 Experimental Design

I tested the relationship between soil health and the perceived quality of products to answer the question: Do soil health parameters, physio-chemical attributes of products, and/or fertilization methods affect the organoleptic properties of different agricultural products?

Kale, carrots, and string beans were planted in twenty experimental treatment plots; eight plots were treated with synthetic fertilizer (F) and 12 plots were treated with organic compost (C). Each treatment plot was 7.5m by 1m with 1.5m spacing between plots. Each of the three products were randomly assigned to 2.5m long sections of each plot. All plots were managed identically except for the fertilizer treatment. Time from harvest to physio-chemical and sensory evaluation for kale was one day, eight days for carrots, and ten days for string beans. All products were refrigerated at 3°C until analysis.

3.2.2 Sensory Analysis

A human sensory panel assessed products for discernable differences attributable to the fertilizer treatments. Panelists compared each experimental product sample to a conventionally grown (CON) baseline product purchased from a local grocery store. CON products were not used in the analyses but instead served as a reference point for the participants to rate the experimental samples.

All products were presented ‘blind, including the store-bought CON sample, with minimal processing (Table 3.1) in 60mL and 150mL clear plastic bowls for the experimental and baseline samples respectively. The samples were labeled with a three-digit alphanumeric code.

The products were assessed by an untrained 70-member consumer panel (Tables 3.2 & 3.3). The recruitment for this panel and the experiment itself were completed on a university campus. Therefore, the majority of the participants were young students with an average age of 24 years (Table 3.2). The participants were also 71% biologically female (Table 3.2). Both indicate that the panel does not represent the population of the consumers in this area as a whole. However, it is thought that both age and sex can affect how a person tastes with younger individuals and biological females to be more sensitive to differences in taste (Bartoshuk et al., 1994; Mojet, 2003; Oliveira-Pinto et al., 2014; Schiffman, 1997).

Table 3.1: For physio-chemical analyses, variable tissue water content of each product type necessitated water addition to achieve a consistent liquid (Schvambach et al., 2020; Ruiz-Aceituno and Lázaro, 2021). For the sensory analysis, each product was presented to the participant with minimal processing.

	Physio-Chemical Liquid Sample Preparation		Sensory analysis Preparation and Presentation	
	Weight (g) of test produces	Volume (mL) of water added	Processing	Sample Presentation
Kale	15g (5g from 3 separate leaves)	100mL	Main stem cut out and then cut into 1 cm strips	2 strips (~3g)
Carrot	60g (20g from three separate carrots)	125mL	Peeled, cut into 4mm thick discs and then cut in half.	2 pieces (~6g)
String Bean	30g (10g from 3 separate beans)	120mL	The ends of the beans were cut off and then the rest was quartered	2 pieces (~3g)

Table 3.2: Sensory panel statistics. Additional details can be found in Appendix, Table 17.

Variable	Value
Total individual participants	n = 70
Product arrays per participant	Mean = 1.1(+/- 0.46 sd) Minimum = 1 and Maximum = 3
Total number of evaluations	n = 450
Sex (%)	Male = 26 Female = 71 Prefer not to Answer = 3
Age (years)	Mean = 24 (+/- 8.79 sd) Minimum = 16 and Maximum = 57

Participants were seated in individual cubicles (70cm x 70cm horizontal area) fitted with visual dividers to eliminate exposure to other participants. Water and crackers were provided as palate cleansers and the participants were instructed to take both as needed between samples. Blackout curtains and ceiling-mounted whole-room red high-performance LED lights (Insight Lighting; Model: Structure Mini Direct; Output: 5 W/FT; RGB= 255,0,0) eliminated colour variation and other visual cues of product samples.

Table 3.3: Total number of human sensory evaluations of each product in the synthetic fertilizer (F) and compost (C) treatments and the duplicate of the conventional baseline (CON).

Treatment/ Product	F	C	CON	**Total**
Kale	48	72	24	**144**
Carrots	48	72	24	**144**
String Beans	54	81	27	**162**
Total	**150**	**150**	**75**	**450**

Each panelist was presented with a sample array made up of seven samples: six experimental treatment samples and the CON baseline sample. Unknown to panelists, the CON product was the baseline sample in all cases. The samples together with water and crackers were placed in cubicles prior to participant arrival (Figure 3.1). Participants were instructed to assess each sample relative to a baseline sample on a modified nine-point hedonic scale (Table 3.4). Unbeknownst to the participants, each sample array contained a replicate of the CON baseline amongst two F and three C experimental samples (Figure 3.1). Inclusion of the duplicate sample permits evaluation of panel scoring precision.

Participants began by tasting the baseline sample and rating their overall preference. Participants then sampled each product, left to right, and scored each relative to the baseline sample for bitterness, texture, flavor intensity, and overall preference using a modified hedonic scale (Table 3.4). The order of products in the sample array, after the baseline sample, was randomized for each participant.

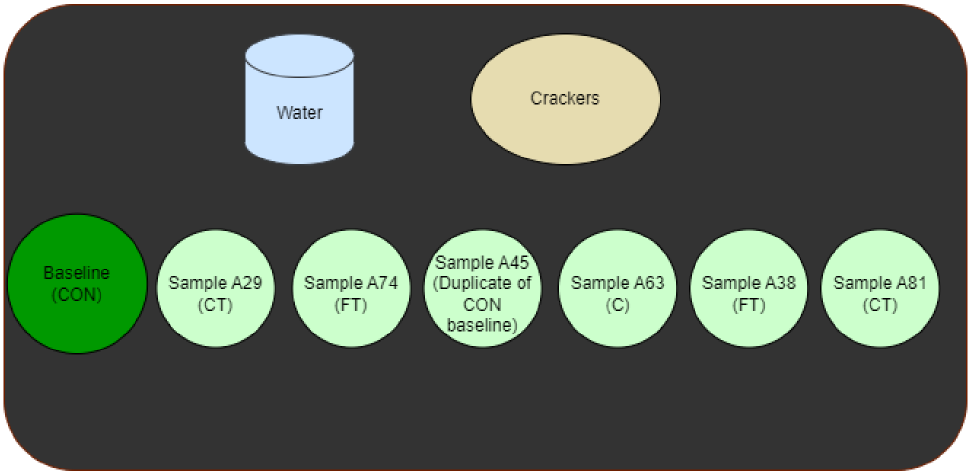


Figure 3.1: Example of how the trays were presented to participants. Sample order was randomized but participants were instructed to begin with the “baseline sample” on the far left and move rightwards.

Table 3.4: Nine-point Hedonic scale and modified nine-point presented to panelists (Lawless and Heymann, 2010). The modified hedonic scale allowed participants to rate the samples relative to the baseline.

Scale	Nine-point hedonic scale	Modified nine-point hedonic scale used here
9	Like extremely	Extremely More
8	Like a lot	A lot more
7	Like moderately	Moderately more
6	Like a little	A little more
5	Neither like nor dislike	Same as baseline
4	Dislike a little	A little less
3	Dislike moderately	Moderately less
2	Dislike a lot	A lot less
1	Dislike extremely	Extremely less

3.2.3 Willingness-to-Pay (WTP)

Participants were also asked how much more/less they would be willing to pay for each product-treatment combination (Appendix; Table 5.12) relative to a reference price for the baseline sample (/lb); $3.00 for kale, $2.50 for carrots, and $5.00 for string beans.

3.2.4 Physio-chemical analyses

Firmness: A penetrometer (Yuecoom; Model: GY-3; Capacity: 24kg/cm^2 d=0.2, 8mm head) generated values (kg/cm^2) from three produce samples (Table 3.5) haphazardly selected from each product-treatment. Mean values and standard deviation are reported in Appendix; Table 5.13.

Table 3.5: Penetrometer testing of firmness for kale, carrots, and string beans. Each product was tested using an 8mm head.

Product	Penetrometer Methods
Kale	One leaf was tested at the midpoint of the leaf blade ~1 cm laterally to the vein.
Carrot	The skin was peeled using a vegetable peeler and measured as the force necessary to penetrate 2mm into the carrot about 2cm from the top of the carrot
String Bean	The outer layer of skin was peeled using a vegetable peeler and then the bean was tested midway down the bean pod.

Chemical characteristics of each product-fertilizer combination were assessed by blending products into a liquid using a Vitamix E310 (Table 3.1). Each product was blended at medium speed for 10 seconds and strained through a 2mm mesh strainer. This process was repeated for each plot, yielding eight fertilizer and twelve compost replicates for each product.

Total soluble solids (TSS): TSS is a measure of water-soluble solids present in products which are most commonly sugars such as glucose and fructose (Zhu et al., 2018; Iowa State University, 2020). Four drops of distilled water were placed on the plate 0-90% hand-held refractometer to confirm a °Brix reading of zero before being wiped dry and adding four drops of the liquid sample to be assessed. This was replicated three times for each sample. Mean values and standard deviation are reported in Appendix; Table 5.13.

Titratable acidity (TA): TA represents the total acid concentration of the product sample and is considered to be a better predictor of the sensory impact of acid than pH (Nielsen, 2017). Humans taste registers both free and bonded hydrogen ions, both of which are assessed in TA whereas pH only accounts for free ions. The percent acidity of each sample was determined by titration of 0.1M NaOH into 25mL of liquid sample diluted to 250mL with boiled water cooled to room temperature. Five drops of phenolphthalein indicator were used and each sample was titrated to the first appearance of light pink colour. Each sample was replicated three times and mean values and standard deviations are reported in Appendix; Table 5.13. TA was calculated using the following formula (Nielsen, 2017):

$$\% \text{ acidity} = \frac{N * V * M / \# \text{ of } H^{+} \text{ ions}}{S * 10}$$

where N is the normality of NaOH, V is the volume (mL) of NaOH, M is the molecular weight of the predominant acid (Appendix; Table 5.4), the number of H+ ions is the number of hydrogen ions in the acid (Appendix; Table 5.4), and S is the sample mass (g). Kale has a majority of citric acid and string beans and carrots have a majority of malic acid (Joslyn, 1970).

pH: Potential hydrogen, or pH, is also a measure of acid content and measures active acidity (Nielsen, 2017). It is more representative of the strength of the acid present rather than how much acid is present, as it only measures the free hydrogen ions in a sample. pH was measured using the Orion Star A111 pH meter recalibrated using 4.01, 7.00, and 10.01 buffers for every three samples. Each juice sample was replicated three times and mean values and standard deviation are reported in Appendix; Table 5.15.

3.2.5 Soil Health

Three soil health indicators (soil bulk density, aggregate stability, and pH) were collected for each product-treatment combination after harvest. Soil samples were taken from every product-treatment section (three per plot x 20 plots = 60 total soil samples) using a point-sampling technique (Soil Health Institute, 2023a). Eight plots received synthetic fertilizer (F) and 12 received organic compost (C). The compost was added to the necessary treatments three days before seeding. An 8-24-16 synthetic fertilizer with added micronutrients (3Mg, 6.5S, 0.5Fe, and 0.01Mn) was added to necessary treatments the day of planting the seeds. Samples were taken from the middle of each crop section at a depth of 15cm, where treatment effects are expected to be most pronounced (Soil Health Institute, 2023a). The samples were collected using the methods outlined in the Standard Operating Procedure - Soil Health Sampling for wet aggregate stability, pH, and bulk density (Soil Health Institute, 2023a). Soil wet aggregate stability was calculated using image quantification (Soil Health Institute, 2023b). Soil bulk density was calculated using the field-composited soil core bulk density and stone volume procedure (Schindelbeck & Kurtz, 2022). pH was quantified using the in water or $CaCl^2$ method (Kalra & Maynard, 1991).

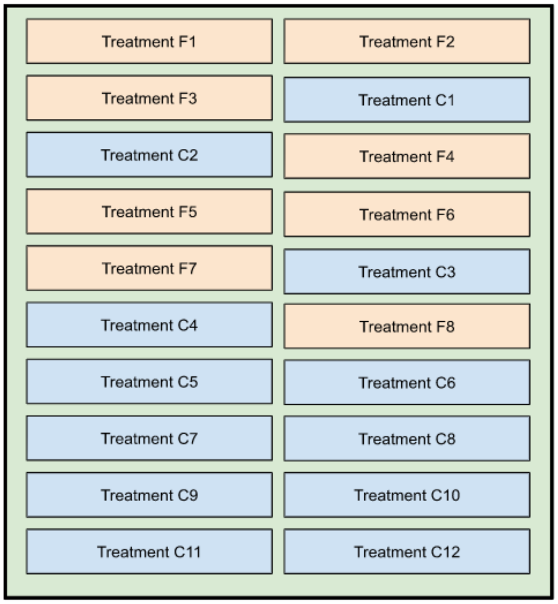


Figure 3.2: The treatment plot design (not to scale). Eight synthetic fertilizer (F) treatment plots and 12 compost (C) treatment plots in total. Each plot was planted with all three products in randomized order for each plot.

3.2.6 Statistical Analysis

All statistics were performed and visualized using the statistical program R (RStudio for Windows; Version: 2022.12.0) using the FactoMineR (Le et al., 2008), agricolae (De Mendiburu, 2009), qpcR (Spiess, 2018), and ggplot2 (Wickham, 2016) packages.

Participant Precision

Participants were instructed to assess each sample relative to the baseline sample provided. Participants were unaware that the baseline sample was repeated within the sample array. The blind duplication of the baseline allows an assessment of participant sensory precision. A high-performing participant would score the duplicate as “same as the baseline” (“5” on the modified hedonic scale). Participant precision declines as deviation in either direction from “5” increases. A one-way t-test was used to gauge overall participant precision.

Age and sex can affect a person’s organoleptic perceptions (Bartoshuk et al., 1994; Mojet, 2003; Oliveira-Pinto et al., 2014; Schiffman, 1997). Generalized linear models (GLM) were used to evaluate if age or sex are significant determinants of the “overall preference” of each product-treatment combination and thus to be included in subsequent analyses.

Sensory Evaluation

Effect of Treatment: To test if product treatment significantly influenced participants' sensory perception, one-way ANOVA tests were employed. To discriminate which treatments generated statistically different responses, post-hoc Fisher's Least Significant Difference (LSD) tests were done for each product-treatment showing significant differences revealed by the ANOVA test.

Evaluating All Product-Treatment Groupings: To evaluate treatment-related effects across all product-treatment combinations, a multidimensional scaling (MDS) model was used with k-means clustering. The clusters of the k-means were confirmed with a hierarchical cluster analysis (HCA) using the table function in the R base package (R Core Team, 2022). Unlike k-means, HCA employs a linkage method that does not rely solely on establishing a centroid. Further, the axes of k-means ordination are undefined making interpretation challenging. Congruence of results generated by both methods provides robust evidence of substantial product discrimination by panelists.

Willingness-to-pay (WTP)

Effect of Treatment: To test if product treatment significantly influenced participants' WTP for each product, one-way ANOVA and Fisher's LSD tests were used to determine if participants differentially valued products produced under the two different fertilizer treatments.

Physio-Chemical Analyses

To evaluate if any physio-chemical properties were important factors in explaining the "overall preference" of each product, generalized linear models (GLM) using the identity link were used. Best fit models were identified using the Akaike information criterion (AIC).

Soil Health

As with the physio-chemical analyses, to evaluate if soil health indicators are important factors in explaining the "overall preference" of each product, GLMs with the identity link were used. Best fit models were identified using the Akaike information criterion (AIC).

3.3 Results

3.3.1 Participant Precision

Participant precision was assessed by including a duplicate of the baseline CON sample in each product sample array (Appendix; Table 5.14). Deviation of scores between the duplicates across all product categories were not significantly different from the baseline except in the case of WTP for string beans (t(28) = 4.05, p = 4e-4*).

Age (t = 0.841, p = 0.41) and sex (t = 0.012, p = 0.991) of participants were not significant predictors of “overall preference” for all products.

3.3.2 Sensory Evaluation

Effect of Treatment

A Shapiro-Wilks test found the majority of sensory evaluation score distributions violated the normality assumption of an ANOVA (Appendix; Table 5.17). However, the f-test is robust to violations of assumptions with the exception of the homogeneity of variance assumption (Carifio and Perla, 2008). Barlett’s test of variance homogeneity found no products violated this assumption (Appendix; Table 5.18).

When all three products were combined and tested for overall differences in sensory perception, there were no significant differences between the treatments for “overall preference”, “flavor intensity”, “texture”, or “bitterness” (Table 3.6). When reassessed by individual products, the only significant finding was carrots treated with synthetic fertilizer had significantly greater scores for “overall preference” and “flavor intensity” (Table 3.7).

Table 3.6: Sensory evaluation results for all products combined and all products combined and participant precision controlled: ANOVA results, absolute rank, mean score, and grouping by Fisher’s LSD.

All Products	Overall Preference		Flavor Intensity		Texture		Bitterness	
ANOVA:	f(1) = 2.11, p = 0.147		f(1) = 0.79, p = 0.374		f(1) = 0.180, p = 0.672		f(1) =0.132, p = 0.716	
Treatment:	Mean	Group	Mean	Group	Mean	Group	Mean	Group
F	5.10	a	5.30	a	4.90	a	4.87	a
C	4.82	a	5.14	a	4.84	a	4.80	a

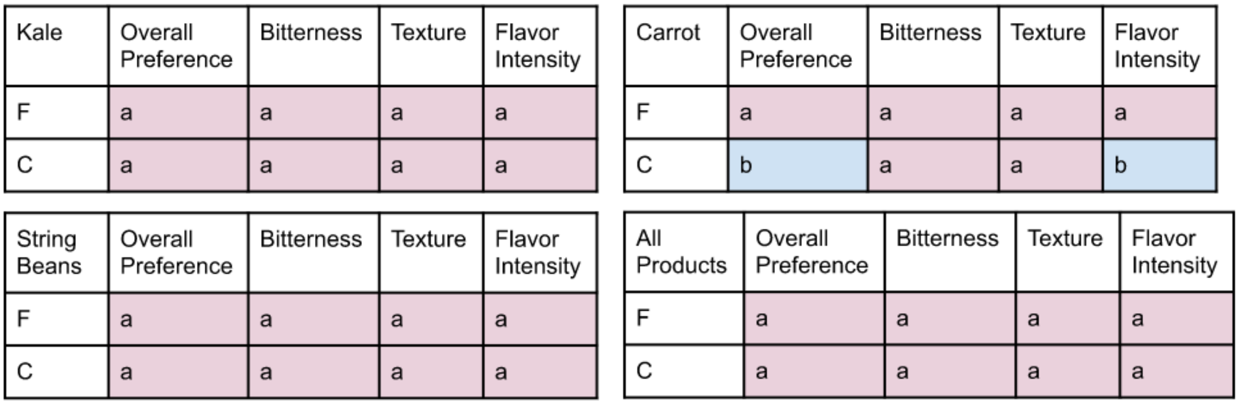
*significant p-value (p≤ 0.05)

Table 3.7: Each product-treatment combination ranked 1 (highest) - 4 (lowest), ANOVA results summary, mean score, and grouping by Fisher's LSD.

		Overall Preference		Bitterness		Texture		Flavor Intensity	
Kale	ANOVA:	f(1) = 0.03, p = 0.869		f(1) = 1.01, p = 0.317		f(1) = 0.45, p = 0.506		f(1) = 0.002, p = 0.967	
	Treatment:	Mean	Group	Mean	Group	Mean	Group	Mean	Group
	F	5.02	a	5.04	a	4.52	a	5.33	a
	C	4.97	a	4.68	a	4.33	a	5.32	a
Carrot	ANOVA:	f(1) = 4.20, p = 0.043*		f(1) = 0.07, p = 0.796		f(1) = 0.17, p = 0.683		f(1) = 8.18, p = 0.005*	
	Treatment:	Mean	Group	Mean	Group	Mean	Group	Mean	Group
	F	5.23	a	5.17	a	5.02	a	5.69	a
	C	4.65	b	5.25	a	4.93	a	4.82	b
String Beans	ANOVA:	f(1) = 0.12, p = 0.656		f(1) = 0.04, p = 0.851		f(1) = 0.07, p = 0.798		f(1) = 1.51, p = 0.222	
	Treatment:	Mean	Group	Mean	Group	Mean	Group	Mean	Group
	F	5.06	a	4.46	a	5.13	a	4.93	a
	C	4.91	a	4.52	a	5.20	a	5.27	a

*significant p-value (p≤ 0.05)

Table 3.8: Visualizing Fisher LSD Groupings by colour for each product and all products combined. This table is a distillation of the product discrimination from Table 8.



Kale	Overall Preference	Bitterness	Texture	Flavor Intensity
F	a	a	a	a
C	a	a	a	a

Carrot	Overall Preference	Bitterness	Texture	Flavor Intensity
F	a	a	a	a
C	b	a	a	b

String Beans	Overall Preference	Bitterness	Texture	Flavor Intensity
F	a	a	a	a
C	a	a	a	a

All Products	Overall Preference	Bitterness	Texture	Flavor Intensity
F	a	a	a	a
C	a	a	a	a

Evaluating All Product-Treatment Groupings

MDS with k-means clustering plots were created with two and three clusters corresponding to the number of treatments (two) and the number of products (three). The clustering was used to help identify if the predominant axis of discrimination is product identify or fertilizer treatment. If panelists were predominantly responding to treatment, it would be expected that there would be clear clusters by farm type in the k=2 analysis. If, however, product identity was the primary axis of determination then the k=3 analysis should clearly cluster by product.

The k=2 analysis did not yield readily interpretable results, whereas the k=3 analysis clearly demonstrates that product type is the dominant aspect of differentiation by panelists (Figure 3.3). Carrots are the only product with any appreciable variation in scores across treatments, explaining why the carrot treatments were separated in the k=2 analysis. However, when the arbitrary restriction of two clusters is eased to three, all products clustered together suggesting product scores were based more on product identity than intra-product differences attributable to treatment.

The results of the k=3 analysis was confirmed by HCA (Figure 3.4). which uses a hierarchical clustering algorithm to predict clusters rather than the unsupervised learning algorithm used by k-means clustering. The HCA shows clear discrimination by product type, rather than fertilizer treatment. The consensus between the HCA analysis and the k=3 analysis supports the null hypothesis that the organoleptic properties of the products are not affected by fertilizer treatment.

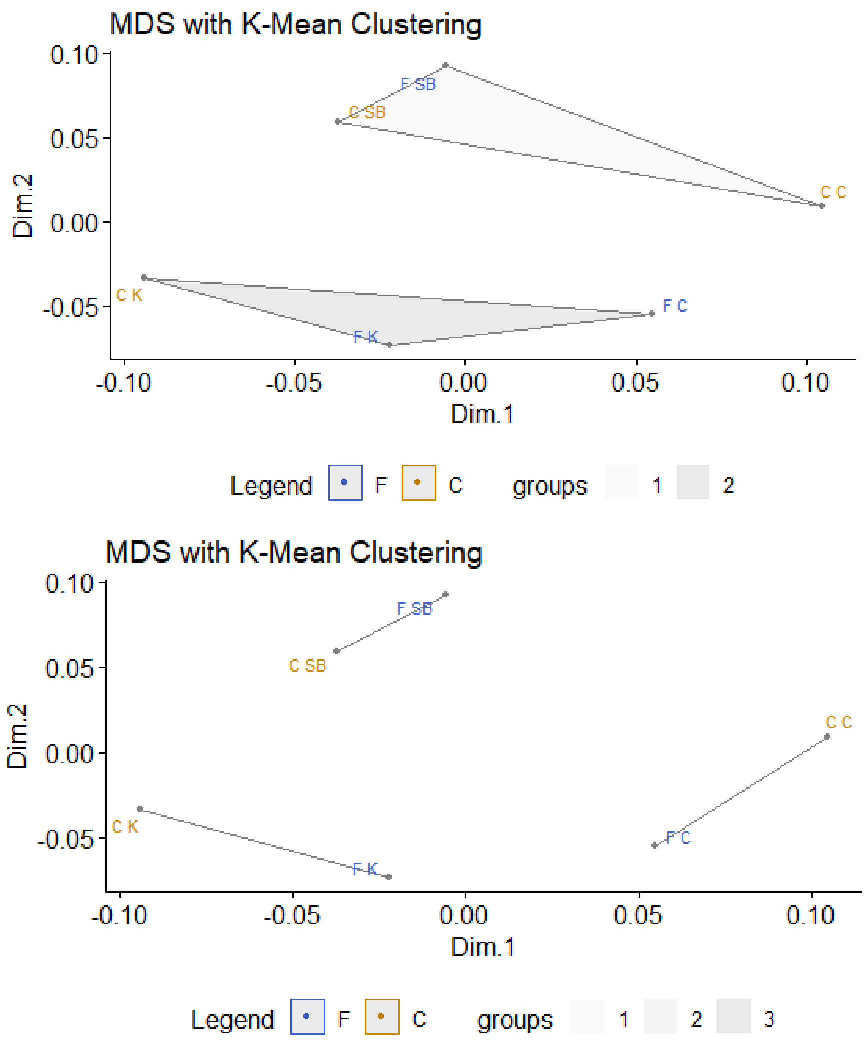


Figure 3.3: MDS with two (left) and three (right) k-mean clusters. Data are participant scores for all sensory categories (bitterness, texture, etc.). Abbreviations of products are kale (K), carrots (C), and string beans (SB) and treatments are synthetic fertilizer (F) and compost (C).

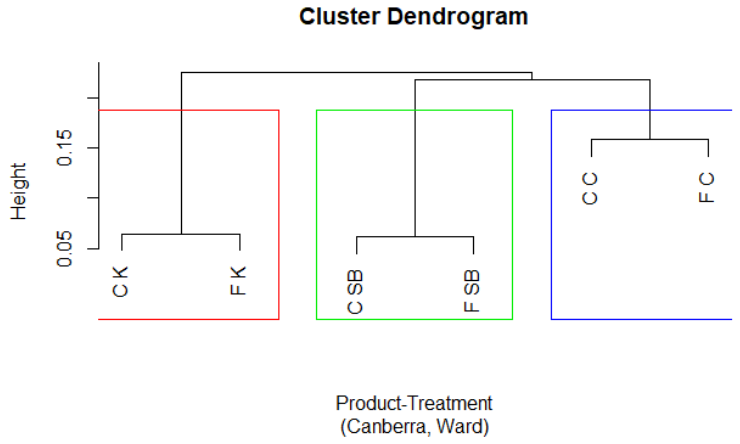


Figure 3.4: HCA clusters comparing all product-treatment combination's means of sensory data including all categories (bitterness, texture, etc.). Abbreviations of products are kale (K), carrots (C), and string beans (SB) and treatments are synthetic fertilizer (F) and compost (C).

3.3.3 WTP

Effect of Treatment

A Shapiro Wilk normality test indicated that all products' WTP values violate the assumption of normality (Appendix; Table 5.15). All product-treatment combinations had score outliers that could have skewed the results. Therefore, both an ANOVA and Krustal-Wallis were performed. The Kruskal- Wallis results were consistent with the ANOVA analysis and did not alter the interpretation of results (Appendix; Table 5.17).

When all products were combined, no differences in WTP were found between the different treatments (Table 3.9), meaning the type of fertilizer used did not consistently influence participant's willingness-to-pay for products.

Table 3.9: Each product-treatment combination absolute ranks, ANOVA results summary, mean score, and the grouping from Fisher's LSD.

		WTP				WTP	
Kale	ANOVA:	f(1) = 0.009, p = 0.926		String Beans	ANOVA:	f(1) = 0, p = 0.999	
	Treatment:	Mean	Group		Treatment:	Mean	Group
	F	2.87	a		F	4.17	a
	C	2.85	a		C	4.17	a
Carrots	ANOVA:	f(1) = 2.56, p = 0.113		All Products	ANOVA:	f(1) = 0.12, p = 0.728	
	Treatment:	Mean	Group		Treatment:	Mean	Group
	F	2.46	a		F	-0.36	a
	C	2.32	a		C	-0.41	a

*significant p-value ($p \leq 0.05$)

3.3.4 Physio-Chemical Analyses

For all three products, multiple best fit models (AIC scores within two units) and modest AICw values made the declaration of a single best-fit model difficult (Table 3.10). For string beans, all the best-fit models included TA and carrot's best-fit models included TSS and firmness. Kale's best-fit models included the null as well as each individual analysis. This shows that these four physio-chemical analyses are not explaining the variation in "overall preference" for any of the products.

Table 3.10: AIC, delta AIC (ΔAIC), and AIC weights (AICw) values for GLM of “overall preference” for each product’s physio-chemical analyses (titratable acidity (TA), total soluble solids (TSS), firmness (Firm), and pH).

Kale				Carrots				String Beans			
Model Variables	AIC	ΔAIC	AICw	Model Variables	AIC	ΔAIC	AICw	Model Variables	AIC	ΔAIC	AICw
Null	2689.98	0.000	0.199	TSS + Firm	2646.14	0.000	0.313	TA	3240.20	0.000	0.265
TA	2690.26	0.274	0.173	TA + TSS + Firm	2647.54	1.399	0.156	TA + pH	3240.39	0.184	0.242
pH	2691.69	1.712	0.085	TSS + pH + Firm	2648.09	1.957	0.118	TA + Firm	3241.82	1.621	0.118
Firm	2691.93	1.947	0.075	TSS	2648.23	2.093	0.110	TA + TSS	3242.15	1.947	0.100
TSS	2691.96	1.975	0.074	Firm	2649.36	3.221	0.063	TA + pH + Firm	3242.26	2.062	0.095
TA + pH	2692.07	2.093	0.070	TA + TSS + pH + Firm	2649.54	3.398	0.057	TA + TSS + pH	3242.37	2.171	0.090
TA + Firm	2692.15	2.173	0.067	TA + TSS	2649.85	3.709	0.049	TA + TSS + Firm	3243.75	3.545	0.045
TA + TSS	2692.25	2.265	0.064	TSS + pH	2650.19	4.054	0.041	TA + TSS + pH + Firm	3244.24	4.040	0.035
TSS + pH	2693.67	3.684	0.032	pH + Firm	2651.30	5.162	0.024	pH	3248.95	8.753	0.003
pH + Firm	2693.68	3.699	0.031	TA + Firm	2651.32	5.180	0.023	TSS + pH	3249.57	9.367	0.002
TA + pH + Firm	2693.83	3.844	0.029	TA + TSS + pH	2651.71	5.575	0.019	pH + Firm	3250.78	10.58	0.001
TSS + Firm	2693.90	3.915	0.028	Null	2653.11	6.976	0.010	TSS + pH + Firm	3251.31	11.11	0.001
TA + TSS + pH	2694.07	4.089	0.026	TA + pH + Firm	2653.28	7.139	0.009	TSS	3251.69	11.49	0.001
TA + TSS + Firm	2694.14	4.158	0.025	pH	2655.06	8.919	0.004	Null	3252.08	11.88	0.001
TSS + pH + Firm	2695.65	5.667	0.012	TA	2655.11	8.972	0.004	TSS + Firm	3252.79	12.59	0.000
TA + TSS + pH + Firm	2695.82	5.834	0.011	TA + pH	2657.06	10.92	0.001	Firm	3253.29	13.09	0.000

3.3.5 Soil Health

For all three products, multiple best fit models (ΔAIC < 2) and modest AICw values made the declaration of a single best-fit model difficult. For carrots, all best-fit models included bulk density. For both string beans and kale, the best-fit models included the null as well as each individual analysis separately. Taken cumulatively these data suggest the three soil health indicators do not explain the differences in “overall preference” for any of the products.

Table 3.11: AIC, delta AIC (ΔAIC), and AIC weights (AICw) values for GLM of “overall preference” for each product’s soil health indicators (aggregate stability (AS), bulk density (BD), and pH).

Kale				Carrots				String Beans			
Model Variables	AIC	ΔAIC	AICw	Model Variables	AIC	ΔAIC	AICw	Model Variables	AIC	ΔAIC	AICw
Null	1794.65	0.000	0.251	BD + pH	1763.02	0.000	0.369	Null	2169.39	0.000	0.279
AS	1794.79	0.133	0.235	BD	1763.17	0.148	0.342	pH	2170.01	0.621	0.205
pH	1795.69	1.032	0.150	AS + BD + pH	1765.02	1.999	0.136	BD	2170.78	1.396	0.139
BD	1796.63	1.971	0.094	AS + BD	1765.17	2.147	0.126	AS	2171.25	1.865	0.110
AS + pH	1796.64	1.986	0.093	Null	1770.08	7.052	0.011	BD + pH	2171.46	2.074	0.099
AS + BD	1796.77	2.118	0.087	pH	1770.51	7.488	0.009	AS + pH	2171.96	2.577	0.077
BD + pH	1797.67	3.011	0.056	AS	1771.95	8.928	0.004	AS + BD	2172.67	3.288	0.054
AS + BD + pH	1798.59	3.936	0.035	AS + pH	1772.39	9.361	0.003	AS + BD + pH	2173.40	4.016	0.037

3.4 Discussion

Synthetic fertilizer is known to reduce soil health by diminishing carbon sequestration potential (Lal, 2020) as well as decreasing microbial communities and biodiversity (Shen et al., 2021). Soil health is dynamic but it is essential for the production of food and the sustainability of environmental quality (Doran and Parkin, 1994). Degraded and agricultural soils have a higher potential to sequester carbon than what could be captured in vegetation or other “healthier” soils (Trumbore et al., 1996). Therefore, finding ways to increase carbon sequestration in degraded soils, like in agriculture, could be an essential way to help dampen the effects of climate change. However, separating product quality and the taste of foods from agriculture and its effects on the climate disregards the food system as a whole. Ensuring that consumers are not separated from sustainable agriculture solutions is essential and can allow consumers to be better utilized to drive the market towards more ecologically friendly agricultural methods.

When all the products were combined, no difference was found in the organoleptic characteristics of the products produced under the synthetic and compost fertilizer treatments. Therefore, no overall system-wide effects are attributable to fertilizer treatments. Product identity had a larger signal than the treatments, so there were more meaningful differences between the different products (kale, carrots, and string beans) than the different treatments (synthetic fertilizer and compost). This could be a result of the short amount of time the treatment plots had been established. The time needed for the restoration of highly degraded land is highly variable as soil recovery is complex. Soil erodibility of abandoned farmland took 28 years to become stable (Wang et al., 2013), significant changes in microbial abundance and diversity took seven years in degraded grasslands (Yao et al., 2018), and soil organic carbon increases 1.5% per decade in mine restoration areas (Kim et al, 2018). The plots used here were established as part an agricultural restoration research project. The soil was very degraded and variable at the beginning of the project and harvest was only three months after the first intervention. Therefore, the soil underlying this project was only three months into a years-long restoration effort. Given the time frame, the soil may not have had enough time to establish differences based on the treatment. However, the carrot-synthetic fertilizer treatment was more preferred and had greater perceived flavor intensity than the compost fertilizer treatment.

The carrots from the synthetic fertilizer treatment were more preferred by panelists than carrots from compost treatments. Synthetic fertilizer nutrients are immediately available for the plant to use, while organic compost requires time for bioprocessing before the nutrients are available (Sabry, 2015; Scotti et al., 2015). In the short time period between the establishment of the plots and harvest, it could be inferred that the synthetic fertilizer plots could show greater response relative to compost treated plots. However, the negative long-term effect of synthetic fertilizer on soil microorganisms could allow the compost treatments to outperform the synthetic treatments in future years. Further, the flavor of carrots is affected by temperature, soil type, and nitrogen levels in the soil (Kjellenberg, 2007; Muchlinski et al., 2020), thus the flavor of carrots is sensitive to environmental conditions. The short time turnaround of synthetic fertilizer could have been just enough to put less environmental stress on the carrot plants to produce more preferred organoleptic compounds.

Synthetic fertilizers are known to have detrimental effects on soil health and overall environmental health. However, the carrot fertilizer treatment having a more preferred taste did show that short-term synthetic fertilizer use can improve the organoleptic properties of carrots. When working with highly degraded land for agricultural space, synthetic fertilizer could be used alongside compost in the short term to jump-start the agricultural system with both a short and long-term fertilization method. The combination of both synthetic and compost fertilizers has been studied before and found that less synthetic fertilizer was needed and crop yields were increased (Mondal et al., 2015; Muktamar et al., 2016; Liu et al., 2021).

Carrots being a root crop and the soil being very degraded may also contribute to the story. Bulk density was identified as an important soil health indicator for the carrots' "overall preference" as the fertilizer treatment was less compacted and more preferred. Past research has found that carrot yield and shape are affected by bulk density (Sri Agung and Blair, 1989) and these growth differences could also be affecting the flavor compounds in the carrots. Being a root crop, the carrot's penetrance into the soil is greater than the other crops and therefore has the potential to have a greater positive effect on degraded soils. Since the plots were located on highly degraded soils, the immediate spike of nutrients provided by synthetic fertilizer is likely to have immediate discernable effects whereas the compost will take seasons to build up the equivalent benefit. However, once established the compost is expected to provide significant net-positive soil attributes.

Untrained consumer panels can yield precise data. Using an untrained consumer panel for a sensory evaluation may be challenging because of the high degree of variability in both preferences and perception of taste (Reed et al., 2006; Njoman et al., 2017). Preferences and perceptions of taste can be affected by many things like genetic and biological differences (Jaime-Lara et al., 2023), life experiences, and diet (Nuvoli et al., 2023). It is thought that taste is affected by both genetic and environmental factors (Reed et al., 2006). This makes working with consumers challenging. A popular way to work around these individual differences in taste perception is by using a trained panel (Lawless and Heymann, 2010). However, when the goal is to find out if an average person, like a consumer, can notice a difference, training does little to answer the question. The goal of this research was to find if consumers can be used to drive the market towards more sustainable agricultural methods. All the preferences and individual differences are important because that is what the average consumer has. Using a trained panel is useful if the only goal is finding if differences exist, but those differences are only important if the general public can identify them. Therefore, utilizing an untrained consumer panel is how questions about a broad population can be answered.

The precision of the participants gives some merit to using an untrained panel, especially when the population being studied is consumers. The modified hedonic scale used in this experiment was converted to have some aspects of an analytic sensory evaluation. There are two main types of analyses in a sensory evaluation: hedonic and analytic tests. Hedonic tests determine the liking or preference of a product and typically use untrained panelists while analytic tests specifically look at differences in the products and typically use trained panelists. One example of an analytic test is a paired comparison, where participants are given two samples and asked to choose which product was stronger or more intense for a specific characteristic (Lawless and Heymann, 2010). Though the participants were not aware, the comparison to the baseline and modification made to the hedonic scale also function as a paired comparison test. Many believe untrained consumer panels to not be effective to give reliable and consistent results for analytic tests, like the paired comparison (Ares and Varela, 2017). The combination of the hedonic scale and the paired comparison test allowed for the evaluation of participant precision, perceivable organoleptic differences in the sources, and differences in source preference in one test. Overall, the untrained consumer panel was precise showing that the little discrimination between the treatments was not likely caused by variability in the panel.

Consumers can discriminate superior products but are not willing to pay. A more preferred product does not necessarily equate to a higher WTP, but a less preferred product does seem to equate to a lower WTP. The imprecision of the participant's WTP for the string beans showed that the participants were not willing to pay the market price for the string beans. When a product is disliked, as the string beans were, it was more difficult to separate the dislike from the value of the product. This is consistent with studies that show disgust contributes to consumers having a decreased WTP (Lombardi et al., 2019; Powell et al., 2019). The WTP for carrots showed no differences statistically between the synthetic and compost fertilizer treatments. However, the means for both treatments were below the baseline market price for the carrots. This means that the participants were not willing to pay a higher price for the synthetic fertilizer treatment which was the more preferred product. Therefore, consumer self-interest, such as improved product quality and taste, cannot be harnessed to encourage a more environmentally friendly agricultural market in an immature production system.

3.4.1 Things to Consider

The three soil health indicators used in this study are showing a limited picture of the overall soil health, especially in regard to chemical and biological indicators. More soil health indicators would add complexity to the data and allow for more exploration into which indicators are most important for sensory changes in products due to changes in the soil. The addition of more soil health indicators in future research would allow for a broader understanding of the soil and how it relates to the organoleptic attributes of the products grown in that soil.

Though my research does not have the breadth to properly answer if soil health affects the organoleptic and physio-chemical attributes of products grown in that soil, it is still possible that differences could be found in the treatment plots in sequential years. The first chapter found that products from established farms were more preferred from the smaller more ecologically friendly farms. The lack of differences seen in the treatment plots was not surprising as the plots were in their first growing season. Therefore, continuing down this road of exploration could help answer the question “can you taste sustainability” and better explain if consumers can be used to help drive the market towards more sustainable agriculture methods.

3.5 Conclusion

In an immature production system, fertilizer type did not have a large effect on the organoleptic properties of the products. Carrots were the only product where an effect was found, as the synthetic fertilized carrots were more preferred than the compost treatment. Though this preference did not equate to a higher willingness-to-pay. Compaction could have an effect on the organoleptic properties of carrots, as the less compacted carrots were more preferred, but more investigation into soil health indicators connection to organoleptic properties is needed.

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4. Chapter 4:

Conclusions

4.1 Summary

The goal of this research was to find if different farming practices and/or soil health influenced the organoleptic properties of different agricultural products. If more ecological friendly farming practices produce higher quality products, consumer self-interest could be harnessed to drive the market towards using these more ecologically friendly agricultural methods.

In mature production systems, farm operations affected taste more than locality. There is a chance that these differences were seen because of the differences in variety. Therefore, the second chapter controlled for varietal differences. However, taste differences were not found, which could be contributed to the immature production system. Differences in preference were found in the carrots, which were of the same variety. Suggesting that the lack of overall differences could be contributed to the immature production system rather than variety.

In neither chapter did a higher preference in taste increase the WTP. However, in both systems, any differences in preference were modest and potentially were not strong enough to increase the perceived value of the product. Therefore, an increase in the preference of taste alone may not be enough to convince consumers to buy more ecologically friendly products if those products are sold at a premium price.

Untrained consumer panels can provide reliable information for more than just personal preference. Not all products had the same degree of difference from the baseline conventional sample. Products like carrots and tomatoes seem to have a stronger signal for differences than greens like kale and lettuce. Therefore, more understanding of how robust different products are to flavor differences should be investigated.

Soil health has the potential to affect the flavor of agricultural products as seen by the carrots grown in less compacted soil being more preferred. However, this increase in preference was only seen in the carrots and not the kale or string beans. More research connecting soil health and organoleptic properties is needed, but this research has a modest signal that one element of soil health, compaction, may influence the flavor of a root vegetable like carrots.

Harnessing consumer self-interest has the potential to drive towards more ecologically friendly agricultural systems if the self-interest (i.e. better tasting products) are combined with other marketing techniques, like labeling. This would allow for the consumers to not only have a higher quality product but also increase the consumer’s knowledge of the products they are consuming.

4.2 Caveats

Overall, this research had some had limitations due to experimental design, including different varieties or an immature production system. These limitations were mostly because of circumstantial issues like a limited number of local farms wanting or able to participant. Future studies should aim to use a mature production system and grow products of the same variety to further explore if farm type or soil health effect the organoleptic properties of different food products.

Limitations were also seen in the physio-chemical analyses, as not much information was gathered from them. This could be because the analyses performed were not enough to capture the organoleptic differences found by the participants. Additional physio-chemical tests, like nutritional density, might have given a more comprehensive understanding of the physio-chemical differences of the products.

The willingness-to-pay section of the survey could have been better developed. It was originally thought that it would be another metric to describe product quality. However, the results were not what was expected with the willingness-to-pay not being influenced by the modest differences in preference of taste. Though these results were informative, it could be debated that they are inaccurate due to participants having a misunderstanding of the question. This was indicating by some of the participants indicating their willingness-to-pay was zero dollars, as they were unwilling to pay anything for a product that they did not like.

The use of only three soil health indicators was due to a delay in receiving the data and in an ideal world more soil health indicators would have been used in this research. To get a broader understanding of how soil health effects the organoleptic properties of a product, more soil health indicators should be included. Since limited research has been done to study the connection between taste of products and the soil quality the products were grown in, a more comprehensive examination into how soil health and soil health indicators effect the product’s organoleptic properties should be done.

4.3 Conclusion

This research suggests that soil health and farming practices can influence the organoleptic properties of agricultural products. More research connecting the organoleptic properties and product quality of agricultural products to farm type and soil health should be done. This kind of research has the potential to help increase the sustainability of the food system by producing products with a higher organoleptic quality that is more preferred by consumers and increasing the demand in the market. Overall, continuing down this road of exploration could help answer the question “can you taste sustainability” and better explain if consumers can be used to help drive the market towards more sustainable agriculture methods.

5. Chapter 5: Appendix

Additional Tables

Table 5.1: Chapter 2 Sensory Evaluation summary statistics (sample size (n), min, max, mean, and SD) for each product-source combination for all sensory evaluation questions.

		Cherry Tomato				Table Tomato				Lettuce					Garlic				
	Source	CON	LL2	SL3	SL2	CON	LL2	SL1	SL4	CON	LL2	LL1	SL1	SL3	CON	LL1	SL1	SL3	SL4
	n	61	61	36	24	51	51	24	27	58	35	24	24	36	24	24	24	24	24
Overall Preference	min	2	1	1	3	1	1	1	1	1	1	1	2	1	2	1	1	2	1
	max	8	9	9	8	9	7	8	9	9	9	9	9	9	8	8	9	8	8
	mean	5.41	4.80	6.22	5.20	4.79	4.59	5.52	6.26	5.15	5.39	4.76	5.88	5.59	5.28	5.20	4.36	5.32	5.20
	SD	1.48	1.59	1.86	1.52	1.75	1.78	1.58	1.92	1.59	1.74	2.05	1.82	1.90	1.69	1.85	2.10	1.76	1.88
Sweetness/ Bitterness	min	1	1	3	2	1	1	1	1	1	2	1	1	2	NA	NA	NA	NA	NA
	max	8	8	9	8	8	8	8	9	8	8	9	8	9	NA	NA	NA	NA	NA
	mean	5.20	4.15	7.06	5.56	4.63	4.96	5.60	7.15	4.62	4.69	5.04	4.68	5.72	NA	NA	NA	NA	NA
	SD	1.97	1.61	1.37	1.73	1.66	1.68	1.58	1.54	1.64	1.91	2.13	2.01	2.04	NA	NA	NA	NA	NA
Acidity	min	1	2	1	1	1	1	3	1	NA	NA	NA	NA	NA	2	1	1	1	3
	max	9	8	7	7	9	8	9	6	NA	NA	NA	NA	NA	8	7	8	8	9
	mean	4.79	5.11	3.28	4.80	5.00	4.81	5.40	3.44	NA	NA	NA	NA	NA	4.96	4.76	2.92	5.72	6.44
	SD	1.62	1.48	1.47	1.63	1.41	1.76	1.53	1.22	NA	NA	NA	NA	NA	1.74	1.79	1.80	1.65	1.50
Texture	min	1	1	3	2	2	1	3	1	2	2	1	4	3	2	1	2	3	4
	max	8	9	8	7	9	7	8	7	9	8	8	9	9	7	6	7	8	7
	mean	5.08	5.10	4.83	5.28	4.94	4.85	5.52	5.11	4.93	4.81	4.88	5.92	4.92	5.20	4.62	4.24	5.40	5.16
	SD	1.14	1.34	1.13	1.10	1.33	1.46	1.19	1.53	1.39	1.35	1.79	1.32	1.30	1.26	1.29	1.48	1.08	0.80
WTP	min	1.00	0.00	0.00	1.50	0.00	0.00	1.00	0.00	1.50	1.50	1.00	0.50	0.00	2.00	2.00	0.50	0.00	0.00
	max	8.00	5.00	5.00	4.00	5.00	3.50	4.00	7.00	4.00	5.00	4.00	4.00	6.00	10.0	10.0	6.50	7.40	7.00
	mean	2.77	2.46	2.88	2.62	2.31	2.24	2.59	3.01	2.51	2.63	2.36	2.60	2.35	5.09	4.88	4.21	4.89	4.82
	SD	1.01	0.81	0.77	0.60	0.87	0.71	0.59	1.24	0.45	0.71	0.69	0.70	1.01	1.55	1.66	1.52	1.59	1.65

Table 5.2: Chapter 2 physio-chemical summary statistics (sample size (n), min, max, mean, and SD) for each product-source combination for all tests (Penetrometer (firmness), Total Soluble Solids (TSS), Titratable Acidity (TA), pH). Each product-source combination yielded two juices and each test was replicated three times.

			Penetrometer (kg/cm^2)				TSS (Brix %)				TA (% Acid)				pH			
		n	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Cherry Tomato	CON	6	1.0	1.6	1.37	0.303	2.0	3.0	2.33	0.334	0.108	0.141	0.126	0.013	4.31	4.47	4.37	0.070
	LL2	6	1.4	2.8	1.67	1.18	2.0	3.0	2.5	0.32	0.100	0.110	0.110	0.006	4.21	4.30	4.25	0.03
	SL2	6	1.2	2.8	1.67	0.68	2.0	2.5	2.25	0.27	0.090	0.110	0.100	0.008	4.29	4.37	4.33	0.03
	SL3	6	1.0	2.2	1.77	0.43	2.5	3.0	2.92	0.20	0.100	0.120	0.110	0.008	4.29	4.43	4.35	0.05
Lettuce	CON	6	1.0	2.6	1.72	0.59	0.5	1.0	0.92	0.20	0.01	0.048	0.024	0.01	5.65	5.97	5.82	0.11
	LL1	6	1.0	2.6	1.7	0.62	1.0	1.0	1.00	0.00	0.016	0.019	0.017	0.001	5.8	6.16	6.01	0.13
	LL2	6	1.1	2.1	1.57	0.39	0.5	1.0	0.83	0.26	0.016	0.024	0.021	0.004	5.78	6.08	5.95	0.10
	SL1	6	1.2	2.2	1.7	0.41	1.0	1.5	1.17	0.26	0.011	0.027	0.017	0.006	5.58	5.94	5.82	0.13
	SL3	6	2.0	3.0	2.38	0.37	0.5	1.0	0.75	0.27	0.013	0.019	0.016	0.002	5.18	5.91	5.67	0.29
Garlic	CON	6	7.7	10.6	8.63	1.18	6.0	6.5	6.17	0.26	0.077	0.092	0.083	0.005	6.11	6.22	6.18	0.04
	LL1	6	11.2	17.0	13.7	1.95	7.5	8.0	7.92	0.20	0.074	0.090	0.082	0.006	6.28	6.43	6.37	0.05
	SL1	6	14.4	18.0	15.7	1.27	8.0	8.0	8.00	0.00	0.072	0.087	0.079	0.006	6.28	6.42	6.37	0.05
	SL3	6	11.4	15.4	13.8	1.65	7.0	7.0	7.00	0.00	0.084	0.010	0.091	0.006	6.36	6.51	6.44	0.06
	SL4	6	13.0	18.6	14.8	2.03	7.5	8.0	7.67	0.26	0.077	0.105	0.088	0.010	6.37	6.48	6.43	0.05
Table Tomato	CON	6	1.3	3.3	2.4	0.77	1.5	2.5	2	0.45	0.061	0.087	0.077	0.01	4.37	4.49	4.41	0.04
	LL2	6	1.2	2.8	2	0.6	2.0	2.0	2.0	0	0.069	0.1	0.079	0.01	4.43	4.5	4.48	0.03
	SL1	6	1.4	3.8	2.35	1.12	1.5	2.0	1.83	0.26	0.087	0.092	0.09	0.003	4.48	4.54	4.51	0.02
	SL4	6	1.2	3.0	1.9	0.81	2.0	2.5	2.25	0.27	0.072	0.085	0.078	0.004	4.43	4.64	4.54	0.08

Table 5.3: Values for titratable acidity formula for citric and malic acid from Nielson (2017). TA is calculated using the molecular weight and number of hydrogen ions of the predominant acid.

	Citric Acid	Malic Acid
Molecular weight	192.12	134.09
# of hydrogen ions	3	2

Table 5.4: Chapter 2 Sensory and WTP Shapiro-Wilks test (test statistic and p-value) for each product.

		Overall Preference	Sweetness	Acidity	Bitterness	Texture	Flavor Intensity	WTP
Cherry Tomato	Statistics	0.990	0.972	0.987	NA	0.944	0.990	0.837
	p-value	0.201	0.001*	0.092	NA	0.000*	0.235	0.000
Table Tomato	Statistics	0.974	0.964	0.986	NA	0.978	0.955	0.881
	p-value	0.005*	4e-4*	0.111	NA	0.015*	1e-4*	0.000*
Lettuce	Statistic	0.989	NA	NA	0.969	0.960	0.977	0.899
	p-value	0.174	NA	NA	4e-4*	0.000*	0.004*	0.000*
Garlic	Statistic	0.967	NA	0.982	NA	0.960	0.973	0.940
	p-value	0.003*	NA	0.101	NA	0.001*	0.013*	0.000*

Table 5.5: Chapter 2 Bartlett's Test (Bartlett's K-squared and p-value) for the sensory evaluation of each product.

		Overall Preference	Sweetness	Acidity	Bitterness	Texture	Flavor Intensity
Cherry Tomato	K-squared	2.662	6.012	0.823	NA	2.319	0.716
	p-value	0.447	0.111	0.844	NA	0.509	0.869
Table Tomato	K-squared	0.929	0.334	5.060	NA	1.891	2.37
	p-value	0.818	0.953	0.167	NA	0.595	0.499
Lettuce	K-squared	3.091	NA	NA	3.440	3.956	7.706
	p-value	0.543	NA	NA	0.487	0.412	0.103
Garlic	K-squared	1.298	NA	1.027	NA	9.266	2.885
	p-value	0.577	NA	0.906	NA	0.055	0.577

Table 5.6: Chapter 2 One-way ANOVA (source) results summary (Degrees of Freedom (df), Sum of Squares (SS), Mean Squares (MS), f-value, and p-value).

		ANOVA			
		Cherry Tomato	Table Tomato	Lettuce	Garlic
	df	3	3	4	4
Overall Preference	SS	46.38	59.44	30.52	16.11
	MS	15.46	19.81	7.63	4.03
	f-value	5.91	6.22	2.35	1.12
	p-value	7e-4*	5e-4*	0.056	0.35
Sweetness	SS	194.1	123.3	NA	NA
	MS	64.68	41.09	NA	NA
	f-value	21.96	15.4	NA	NA
	p-value	4e-12*	8e-9*	NA	NA
Acidity	SS	82.23	59.95	NA	174.2
	MS	27.41	19.98	NA	43.56
	f-value	11.41	8.56	NA	15.08
	p-value	7e-7*	3e-5*	NA	5e-10*
Bitterness	SS	NA	NA	36.58	NA
	MS	NA	NA	9.15	NA
	f-value	NA	NA	2.53	NA
	p-value	NA	NA	0.042*	NA
Texture	SS	3.17	8.34	23.19	22.67
	MS	1.06	2.78	5.797	5.67
	f-value	0.728	1.43	2.91	3.92
	p-value	0.54	0.24	0.022*	0.005*
Flavor Intensity	SS	34.1	28.63	19.03	115.8
	MS	11.37	9.54	4.76	28.95
	f-value	5.10	3.47	1.85	9.10
	p-value	0.002*	0.017*	0.12	2e-6*

Table 5.7: Chapter 2 Two-way ANOVA (source + consumer) results summary (Degrees of Freedom (df), Sum of Squares (SS), Mean Squares (MS), f-value, and p-value).

		Source				Consumer			
		Cherry Tomato	Table Tomato	Lettuce	Garlic	Cherry Tomato	Table Tomato	Lettuce	Garlic
	df	3	3	4	4	57	46	58	24
Overall Preference	SS	50.69	57.67	33.93	16.11	213.3	204.1	242.1	153.6
	MS	16.90	19.22	8.48	4.03	3.74	4.44	4.17	6.40
	f-value	8.07	7.27	3.02	1.39	1.79	1.68	1.48	2.20
	p-value	6e-5*	1e-4*	0.02*	0.24	0.004*	0.02*	0.035*	0.004
Sweetness	SS	215.3	118.4	NA	NA	251.5	164.1	NA	NA
	MS	71.76	39.45	NA	NA	4.41	3.57	NA	NA
	f-value	31.73	17.33	NA	NA	1.95	1.57	NA	NA
	p-value	3e-15*	3e-9*	NA	NA	0.001*	0.03*	NA	NA
Acidity	SS	89.31	53.12	NA	174.2	178.1	106.7	NA	104.8
	MS	29.77	17.71	NA	43.56	3.13	2.32	NA	4.37
	f-value	14.44	7.57	NA	17.30	1.52	0.99	NA	1.73
	p-value	4e-8*	1e-4*	NA	1e-10*	0.029*	0.5	NA	0.03*
Bitterness	SS	NA	NA	34.53	NA	NA	NA	277.5	NA
	MS	NA	NA	8.63	NA	NA	NA	4.78	NA
	f-value	NA	NA	2.83	NA	NA	NA	1.57	NA
	p-value	NA	NA	0.03*	NA	NA	NA	0.02*	NA
Texture	SS	5.52	10.54	29.27	22.67	103.7	104.0	119.8	42.35
	MS	1.84	3.51	7.34	5.67	1.82	2.26	2.07	1.76
	f-value	1.44	1.96	3.75	4.14	1.42	1.26	1.06	1.29
	p-value	0.24	0.13	0.01*	4e-3*	0.055	0.17	0.40	0.19
Flavor Intensity	SS	37.3	33.65	22.77	115.1	221.1	134.2	123.4	163.3
	MS	12.43	11.22	5.69	28.95	3.88	2.92	2.13	6.81
	f-value	8.51	4.19	2.04	12.71	2.66	1.09	0.76	2.99
	p-value	4e-5*	0.008*	0.09	2e-8*	3e-6*	0.35	0.88	8e-4*

Table 5.8: Chapter 2 Sensory and WTP Kruskal Wallis test (chi-squared and p-value) for each product.

		Overall Preference	Sweetness	Acidity	Bitterness	Texture	Flavor Intensity	WTP
Cherry Tomato	chi-squared	17.082	50.772	28.781	NA	4.475	13.057	11.655
	p-value	7e-4*	5e-11*	2e-6*	NA	0.215	0.005*	0.009
Table Tomato	chi-squared	18.969	41.557	23.266	NA	3.895	10.835	22.948
	p-value	3e-4*	5e-9*	4e-5*	NA	0.273	0.013*	4e-5*
Lettuce	chi-squared	8.920	NA	NA	7.494	11.421	8.900	6.497
	p-value	0.063	NA	NA	0.112	0.022*	0.064	0.165
Garlic	chi-squared	4.157	NA	39.626	NA	12.008	26.735	4.261
	p-value	0.385	NA	5e-8*	NA	0.017*	2e-5*	0.372

Table 5.9: Chapter 2 Fisher's LSD results using ANOVA (source only) (mean squared error (MS Error), degrees of freedom (df), mean, and coefficient of variation (CV)) for each product-source combination.

		Cherry Tomato	Table Tomato	Lettuce	Garlic
	df	179	152	179	120
Overall Preference	MS Error	2.62	3.19	3.25	3.36
	Mean	5.34	5.09	5.13	5.27
	CV	30.31	35.05	35.16	34.78
Sweetness	MS Error	2.95	2.67	NA	NA
	Mean	5.26	5.33	NA	NA
	CV	32.62	30.62	NA	NA
Acidity	MS Error	2.40	2.33	NA	2.89
	Mean	4.60	4.73	NA	4.96
	CV	33.67	32.29	NA	34.26
Bitterness	MS Error	NA	NA	3.61	NA
	Mean	NA	NA	4.93	NA
	CV	NA	NA	38.52	NA
Texture	MS Error	1.45	1.94	1.99	1.45
	Mean	5.07	5.03	5.03	4.928
	CV	23.79	27.66	28.05	24.41
Flavor Intensity	MS Error	2.23	2.75	2.57	3.18
	Mean	5.45	5.53	5.48	5.22
	CV	27.39	29.98	29.26	34.15

Table 5.10: Chapter 2 WTP One-way ANOVA and Fisher's LSD results for all products. The ANOVA results (Sum of squares (SS), degrees of freedom (df), mean squares (MS), F-value, and p-value). Fisher's LSD results using ANOVA (source only) (mean squared error (MS Error), degrees of freedom (df), mean, and coefficient of variation (CV)).

	ANOVA					Fisher's LSD			
	SS	df	MS	F- value	p- value	MS Error	df	Mean	CV
Cherry Tomato	3.943	3	1.31	1.79	0.152	0.736	176	2.656	32.30
Table Tomato	12.06	3	4.019	5.31	0.002*	0.757	152	2.46	35.34
Lettuce	1.742	4	0.436	0.77	0.546	0.578	179	2.478	30.68
Garlic	11.13	4	2.78	1.05	0.384	2.648	120	4.778	34.07

Table 5.11: Chapter 2 WTP Two-way ANOVA (source + consumer) and Fisher's LSD results for all products. The ANOVA results (Sum of squares (SS), degrees of freedom (df), mean squares (MS), F-value, and p-value).

	WTP- Source					WTP- Consumer				
	SS	df	MS	F-value	P-value	SS	df	MS	F-value	P-value
Cherry Tomato	3.94	3	1.31	2.53	0.06	67.21	56	1.2	2.31	7e-5*
Table Tomato	12.76	3	4.25	9.33	2e-5*	66.74	46	1.45	3.18	4e-7*
Lettuce	1.77	4	0.44	1.28	0.28	61.64	58	1.06	3.07	1e-7*
Garlic	11.13	4	2.78	1.36	0.25	121.6	24	5.07	2.48	0.001*

Table 5.12: Chapter 3 sensory evaluation summary statistics (sample size (n), min, max, mean, and standard deviation(SD)) for each product-source combination.

		Kale		Carrot		String Bean	
		C	F	C	F	C	F
Overall Preference	n	72	48	72	48	81	54
	min	1	2	2	2	1	1
	max	7	8	8	8	9	9
	mean	4.97	5.02	4.65	5.23	4.91	5.06
	SD	1.61	1.52	1.55	1.45	1.74	1.91
Bitterness	n	72	48	72	48	81	54
	min	1	1	2	2	1	1
	max	9	9	8	8	8	8
	mean	4.68	5.04	5.25	5.17	4.52	4.46
	SD	1.82	2.08	1.72	1.74	1.57	1.83
Texture	n	72	48	72	48	81	54
	min	1	1	2	1	2	2
	max	7	7	8	8	9	8
	mean	4.33	4.52	4.93	5.02	5.20	5.13
	SD	1.52	1.49	1.12	1.28	1.55	1.44
Flavor Intensity	n	72	48	72	48	81	54
	min	1	1	1	2	1	1
	max	8	8	8	8	9	9
	mean	5.32	5.33	4.82	5.69	5.27	4.93
	SD	1.81	1.73	1.71	1.49	1.47	1.78
WTP	n	72	48	72	48	81	54
	min	1	1	0.5	1	0	0
	max	6	5.5	3.5	3.5	7	7.25
	mean	2.85	2.87	2.32	2.46	4.17	4.17
	SD	0.79	0.83	0.46	0.43	1.91	1.88

Table 5.13: Chapter 3 physio-chemical summary statistics (sample size (n), min, max, mean, and SD) for each product-source combination for all tests (Penetrometer (firmness), Total Soluble Solids (TSS), Titratable Acidity (TA), pH). Each product-source combination yielded two juices and each test was replicated three times.

			Penetrometer (kg/cm^2)				TSS (Brix %)				TA (% Acid)				pH			
		n	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Kale	C	18	1.20	2.30	1.59	0.35	1.00	1.00	1.00	0.00	0.013	0.026	0.019	0.003	5.11	6.09	5.87	0.27
	F	12	1.10	2.80	1.57	0.48	1.00	1.50	1.04	0.14	0.013	0.023	0.018	0.003	5.24	5.95	5.64	0.23
Carrots	C	18	15.0	19.8	17.2	1.43	3.00	3.50	3.28	0.26	0.018	0.031	0.023	0.004	5.94	6.16	6.10	0.06
	F	12	13.2	18.4	16.2	1.51	3.00	3.50	3.33	0.25	0.015	0.026	0.021	0.003	6.01	6.18	6.11	0.06
String Beans	C	18	5.00	9.30	7.53	1.19	1.00	2.00	1.39	0.27	0.022	0.040	0.030	0.005	6.04	6.24	6.14	0.06
	F	12	6.40	8.60	7.66	0.71	1.50	2.00	1.58	0.20	0.030	0.054	0.039	0.009	5.91	6.3	6.08	0.12

Table 5.14: Participant precision using t-tests to evaluate the magnitude of baseline-duplicate deviation. Significant values ($p \leq 0.05$) indicate the mean response of the duplicate is significantly different than the baseline mean response.

Category	Kale	Carrots	String Beans
Bitterness	t(24) = 0.90, p = 0.377	t(24) = 0.11, p = 0.913	t(28) = -0.89, p = 0.380
Flavor Intensity	t(24) = -0.64, p = 0.529	t(24) = 1.10, p = 0.280	t(28) = -0.59, p = 0.558
Overall Preference	t(24) = -1.87, p = 0.074	t(24) = 0.29, p = 0.774	t(28) = -1.63, p = 0.115
Texture	t(24) = 0.16, p = 0.873	t(24) = 0.27, p = 0.788	t(28) = 0.66, p = 0.512
WTP	t(24) = 1.24, p = 0.227	t(24) = -1.64, p = 0.113	t(28) = 4.05, p = 4e-4*

Table 5.15: Chapter 3 Sensory and WTP Shapiro-Wilks test (test statistic and p-value) for each product.

		Overall Preference	Bitterness	Texture	Flavor Intensity	WTP
Kale	Statistics	0.952	0.980	0.964	0.927	0.916
	p-value	3e-4*	0.067	0.003*	0.000*	0.000*
Carrot	Statistics	0.977	0.966	0.961	0.966	0.848
	p-value	0.038*	0.004*	0.002*	0.004*	0.000*
String Bean	Statistic	0.966	0.971	0.966	0.983	0.792
	p-value	0.002*	0.006*	0.002*	0.010*	0.000*

Table 5.16: Chapter 3 Bartlett's Test (Bartlett's K-squared and p-value) for the sensory evaluation of each product.

		Overall Preference	Bitterness	Texture	Flavor Intensity
Kale	K-squared	0.209	0.935	0.100	0.740
	p-value	0.901	0.100	0.951	0.691
Carrot	K-squared	0.611	0.111	3.357	0.899
	p-value	0.737	0.946	0.187	0.638
String Bean	K-squared	0.543	1.515	0.401	2.599
	p-value	0.762	0.469	0.818	0.273

Table 5.17: Chapter 3 Sensory and WTP Kruskal Wallis test (chi-squared and p-value) for each product.

		Overall Preference	Bitterness	Texture	Flavor Intensity	WTP
Kale	Statistics	0.002	1.011	0.515	2e-4	3e-5
	Chi-Squared	0.961	0.315	0.473	0.989	0.996
Carrot	Statistics	4.333	0.037	0.377	7.007	4.698
	Chi-Squared	0.037*	0.847	0.539	0.008*	0.030*
String Bean	Statistics	0.147	0.014	5e-4	1.260	0.022
	Chi-Squared	0.701	0.907	0.982	0.262	0.881

Table 5.18: Chapter 3 One-way ANOVA (source) results summary (Degrees of Freedom (df), Sum of Squares (SS), Mean Squares (MS), f-value, and p-value).

		ANOVA		
		Kale	Carrots	String Beans
	df	1	1	1
Overall Preference	SS	0.068	9.568	0.650
	MS	0.068	9.568	0.653
	f-value	0.027	4.200	0.200
	p-value	0.869	0.043*	0.656
Bitterness	SS	3.760	0.200	0.100
	MS	3.756	0.200	0.100
	f-value	1.008	0.067	0.035
	p-value	0.317	0.796	0.851
Texture	SS	1.012	0.235	0.149
	MS	1.013	0.235	0.149
	f-value	0.446	0.167	0.066
	p-value	0.506	0.683	0.798
Flavor Intensity	SS	0.010	21.701	3.870
	MS	0.006	21.701	3.872
	f-value	0.002	8.182	1.507
	p-value	0.967	0.005*	0.222

Table 5.19: Fisher's LSD results using ANOVA (source only) (mean squared error (MS Error), degrees of freedom (df), mean, and coefficient of variation (CV)) for each product-source combination.

		Kale	Carrot	String Bean
	df	118	118	133
Overall Preference	MS Error	2.482	2.278	3.272
	Mean	4.992	4.883	4.970
	CV	31.564	30.907	36.395
Bitterness	MS Error	5.042	1.984	2.824
	Mean	4.825	5.217	4.496
	CV	40.001	33.116	37.377
Texture	MS Error	2.271	1.404	2.278
	Mean	4.408	4.967	5.170
	CV	34.185	23.854	29.189
Flavor Intensity	MS Error	3.172	2.652	2.569
	Mean	5.325	5.167	5.133
	CV	33.447	31.521	31.226

Table 5.20: Chapter 3 WTP ANOVA and Fisher's LSD results for all products. The ANOVA results (Sum of squares (SS), degrees of freedom (df), mean squares (MS), F-value, and p-value). Fisher's LSD results using ANOVA (source only) (mean squared error (MS Error), degrees of freedom (df), mean, and coefficient of variation (CV)).

	ANOVA					Fisher's LSD			
	SS	df	MS	F- value	p- value	MS Error	df	Mean	CV
Kale	0.006	1	0.006	0.009	0.926	0.647	118	2.858	28.143
Carrot	0.522	1	0.522	2.556	0.113	0.204	118	2.376	19.017
String Bean	0.000	1	0.000	0.000	0.999	3.600	133	4.172	45.475