University of Nevada, Reno

Comparison Of Nutritional and Sensory Qualities Between Hydroponic and Soil-Grown Strawberries and Raspberries

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Abstract

Hydroponic means of food production represent a possible opportunity towards sustainable crop production. Hydroponics can be defined as growing plants in soilless conditions with nutrients, water and an inert medium. Hydroponics has the potential to supply food in non-arable regions of the world, such as arid or urban areas. Along with this, hydroponics could be a means to provide food to those living in food deserts. Hydroponic food production currently has a positive connotation because of the abundant proposed environmental benefits associated with the growing method. Some of these environmental benefits include: less use of water, less pesticide usage, higher yields, increased nutritional content and better taste. For the hydroponic product to be successful, it must be equal or better than the soil-grown product in terms of environmental benefits, nutritional quality and taste. The majority of recent studies have investigated hydroponic leafy greens, peppers and tomato fruit. Limited research has been conducted for hydroponic strawberries (F*ragaria x ananassa*) and raspberries (*Rubus Idaeus*). Strawberries and raspberries contain high amounts of health promoting bioactive compounds. Consumption of these nutritious fruits is associated with decreased risk of obesity, type 2 diabetes and prevention of certain types of oxidative stress mediated diseases.

This research consists of two review papers, and four experimental studies. The objectives of the review papers were to evaluate the current literature and provide an understanding whereby future research can move forward in the quest for global sustainable food production. The objectives of the studies for both strawberries and raspberries were to examine the crop compared to their soil-grown counterpart for viability, nutritional quality, and sensory attributes.

In the review papers, it was concluded that many factors could contribute to the successes of a hydroponic crop. Currently, research on hydroponic methods is limited but preliminary research shows beneficial results in areas of ecological, economical, nutritional and sensory quality of the product. Evidence based research indicates a wide variety of study methods and designs, all which will contribute to the viability, nutrition, and sensory attributes of the hydroponic product.

The results from our experimental studies support the hypotheses that hydroponics may be able to contribute to a sustainable food production while providing food that is equal in nutrition and taste. The hydroponic strawberry and raspberries results indicated a higher yield, equal or better nutritional quality, and equal or better in taste preferences compared to soil-grown strawberries and raspberries. The results from the experimental studies suggest hydroponic food production offers numerous advantages and may be conceivable to grow nutritious and flavorsome food in non-arable regions in the world.

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Chapter 1

Introduction

Introduction

Hydroponics, or growing without soil, can be a method of contributing towards sustainable food production. Hydroponics stems from the Greek words ‘hydro’ meaning water, and ‘ponos’ meaning labor (Resh & Howard, 2012). Hydroponics offers a number of environmental advantages, which is perhaps why hydroponics seems to have a positive overtone among producers and consumers. Hydroponics may be grown in non-arable regions of the world, such as arid or urban regions. It is estimated that more than two-thirds of the world’s surface area is classified as arid regions, and more than half the of world’s population is living in urban areas (Food and Agriculture Organization of the United Nations, 2013). Currently, food transportation accounts for 16% of all energy usage and is a contributor to greenhouse gas emissions. Growing food in these regions closer to home, it would minimize transportation costs and save on greenhouse gas emissions. Further, eating food closer to home can potentially lower food prices (Pelletier et al., 2011). Additionally, growing food in these areas has the potential to stimulate the local economy by having a higher percentage of the dollar stay nearby (O’Hara, 2011). Hydroponics is limited by the high start-up cost compared to open field agriculture, costing anywhere between two and twenty times more (Coolong, 2012). Hydroponics is also limited by the use of electricity and the farmer is required to have some knowledge of the system and how to adjust the pH, nutrient solution and general system maintenance (Leonhardt & McCall, 1914). The adaption of this method could potentially be problematic for an uneducated farmer.

Nutrition

Hydroponically grown food has the potential to provide high quality food in the nutritional sense in several aspects. With the hydroponic product having the potential to be grow closer to the consumer, it can reduce the risk of spoilage and maximize the nutritional benefits since it won't have to travel the average 1,500 miles to reach the consumer's table (Jensen, 1999). When comparing the hydroponic product to their soil-grown counterpart, the majority of previous studies indicate no significant nutritional differences. However, studies differ in experimental designs, making comparison between studies difficult. Some studies show significant differences between nutritional qualities between hydroponic and soil-grown products, however, these differences may be associated with the specific methods of the growing (Buchanan & Omaye, 2013; Palermo, Paradiso, De Pascale, & Fogliano, 2012; Premuzic, Bargiela, Garcia, Rendina, & Iorio, 1998). Nutritional quality of the product is a driver of the agricultural industry; therefore, research on this topic is crucial to the success of the hydroponic product (Ho, 2004).

Sensory evaluation

Current research is exploring numerous aspects of hydroponic growing for quality factors that may affect purchasing behaviors and consumption. Although hydroponics has several environmental and economic benefits associated with them, it does not automatically guarantee a high quality product. As innovative technologies with hydroponics are being investigated, it will be important to investigate the quality of the hydroponic in terms of sensory evaluation and nutritional quality, since taste and nutrition are two drivers of consumption of the product (Kim, Lee, Kwak, & Kang, 2013). Several agricultural factors have been identified to affect the quality of the food such as: genetics, pre-harvest factors and post-harvest factors. Additionally, consumer acceptance and preference will be important for consumers as hydroponic technologies continue to develop. Currently, sensory evaluation of hydroponic produce is scant, however the demand for it has been growing (Garruti & Virginia, 2010). Some studies indicate there are no differences between hydroponic and soil-grown produce, while others showed hydroponically grown produce tastes better compared to soil-grown (Buchanan & Omaye, 2013; Ferguson, Saliga III, & Omaye, 2014; Lin et al., 2013; Murphy, 2011). Other studies illustrate factors of the hydroponic method that can alter the taste of the product, such as the growing system and nutrient solution (Gichuhi, Mortley, Bromfield, & Bovell-Benjamin, 2009; Wu, Buck, & Kubota, 2004). Research is needed on the sensory qualities for hydroponic products compared to soil-grown products to determine differences in taste. Researching the taste of the hydroponic product will need to be a priority to truly benefit from the environmental advantages the hydroponic method offers since taste is extremely important to consumers (Drewnowski, 1997).

This research consisted of two review papers and four experimental studies. The objectives of the review papers were to evaluate the advantages, limitations and quality of the hydroponic production method. The objectives of the experimental studies were to examine the differences between soil-grown and hydroponic strawberry and raspberry production. The potential of hydroponic strawberries and raspberries were compared to their soil-grown counterpart and studied for: 1) viability, 2) nutritional quality, and 3) sensory attributes.

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Chapter 2 Part A

Review of Hydroponics

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Hydroponics: Potential for augmenting sustainable food production in non-arable regions

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Abstract

Purpose – The intent of this review of the literature is to provide readers a foundation of understanding whereby future research can move forward in the quest for global sustainable food production.

Design/methodology/approach – This review includes up-to-date information from evidence based sources on hydroponics. Topics included are: advantages, limitations, nutritional quality and sensory quality

Findings –Hydroponic growing systems offer the opportunity to at least augment traditional soil based growing systems in global food production. Some benefits of hydroponic growing systems are: limitation of water waste (recirculation), crops grown in controlled environments (control of pests, nutrients, and attributes required for optimal plant growth), and ability to manipulate conditions to maximize production in limited space (vertical gardens).

Practical implications- The human population is increasing with a parallel increase in the demand for food; therefore, food production must increase to meet the need.

Originality/value- In spite of the rapid interest and proliferation of information by laypeople, evidence-based research is scant on hydroponics. This article provides a summary of the literature on hydroponics and how it may be used for sustainable food production in arid and urban areas.

Introduction

As the global population continues to rise, so does the demand for food. Demographers estimate the world's population will be 9.5 billion people by the year 2050, with each individual requiring approximately 1,500 calories per day to survive (Despommier, 2009). Traditional agriculture uses 70% of the world's freshwater for irrigation and uses 20% of the world's gasoline and diesel fuel, resulting in greenhouse gas emissions (Despommier, 2009). Other environmental concerns with traditional agricultural practices are pesticides in runoff water, ground issues such as soil-borne diseases, non-arable soil, and poor physical properties of the soil. These limiting factors are the reason only about 36% of the world's land is suitable for crop production (Food and Agriculture Organization of the United Nations, 2013) . It is evident that as the global population increases, so does the need for sustainable growing systems. Growing produce by using hydroponic methods is one of those systems. The benefits of hydroponic grown produce appear to be many. This includes efficient water use, limited pesticides, higher yields and food production throughout the year (Barbosa *et al.*, 2015).

Hydroponics can be defined as growing plants in soilless conditions with nutrients, water and an inert medium, i.e, gravel, sand, pearlite and other substrates (Resh and Howard, 2012). The word hydroponic has the Greek origin from the words 'hydro,' which means water and 'ponos,' which means labor. Many hydroponic systems use a medium, which often is termed 'soilless culture,' however the true definition of hydroponics is water culture (Resh, 2012). From the perspective of plant science, there are little differences between hydroponically and soil-grown plants (outlined in Figure 1). In both systems, before elements are bioavailable to the plant, inorganic and organic parts must be broken down and dissolved in water. In soil-grown plants, the elements stick to the soil particles and are passed into the soil solution where they can be absorbed by the roots of the plant. With hydroponically grown plants, the nutrient solution containing elements comes in contact with the plant roots where the roots can then uptake minerals and water. Therefore the limited differences allow for a comparison of soil and hydroponically grown food studies under the same environmental conditions (Gruda, 2005).

Food production with hydroponic systems has a positive connotation as consumers are becoming aware of environmental issues associated with soil-grown crops. However, as technology of hydroponic production of food is developing, it is important to determine the benefits, limitations and human health benefits of the crops produced by hydroponic systems, the primary objective of this paper. By exploring different variables associated with hydroponic food production, guidelines to form production systems for optimum environmental and human health benefits can be formulated for future research.

Advantages of hydroponically grown food compared to soil-grown food

Ecological benefits

Consumer positive attitudes of hydroponically grown produce can be attributed largely to the ecological benefits (Gruda, 2009). From an environmental perspective, the hydroponic system can be grown in non-arable areas of the world, such as dry or urban areas. It is estimated that up to 65% of the land's surface area is classified as arid, and the amount of people living in urban areas is currently 54% and is expected to increase to up to 66% by the year 2050 (Food and Agriculture Organization of the United Nations, 2013). A major advantage for producers is the hydroponic system does not require many traditional farming practices that require intensive labor such as tilling, cultivating or fumigating (Benton Jones Jr., 2004). Plant spacing in hydroponics is only limited by light and can be spaced closer together, compared to soil plant spacing, which is limited by the soil and light (Resh, 2012).

A major reason hydroponics is emphasized as an environmentally friendly food production method is the emphasis on recirculation of water as a good agricultural practice (Benoit and Ceustermans, 2004). Water use efficiency (WUE), or the weight of the harvested product per unit of water supplied, is maximized with hydroponics because there is minimal evaporation in closed systems. Hydroponics improves WUE compared to soil-grown plants by preventing runoff and evaporation from the soil. Hydroponically grown lettuce, for example, used about 10% of the water compared to open agriculturally grown lettuce (Rorabaugh *et al.*, 2002). The ultimate determination of the WUE will depend on the variety of interest. For example, the WUE lettuce has a WUE of 9.0 g/l and mustard is 7.89 g/l (Midmore and Deng-Lin, 1999). Additionally, there is potential to use recovered wastewater to add economic value, however, more research is needed to determine the exact ecological and economic benefits this would provide (Di Serio *et al.*, 2008).

Economic benefits

Several studies indicated hydroponically grown fruits and vegetables produce a higher yield per area because of the optimum growing conditions and controlled environments (temperature, humidity, light, control of root environment) (M. H. Jensen, 1999). The control over the strength and composition of the nutrient solution can be accurately approximated without the interfering in organic matter or cation exchange capacity in the soil, in turn maximizing product yield (Gruda, 2009). Another potential economic advantage of hydroponics is that growers can produce multiple crops in one year where open field agriculture crops are typically limited to one per year (Rorabaugh, 2002).

The Ohio State University developed an economic model designed to estimate revenue, expenses and profitability associated with single and double bay hydroponic greenhouse lettuce product systems (Donnell *et al.*, 2011). This model was modified in Kentucky to estimate for a 3,000 square feet greenhouse with 8 crops per year. With 5,900 lettuce heads for being sold each year, the breakeven price was $0.90 per head of lettuce (Coolong, 2012). It is estimated that a hydroponics operation can have gross returns per square foot between $10 and $25 (Coolong, 2012). A decade ago, it was estimated food prices would have to increase five times before hydroponic agronomy could break even. Since then, the food prices have more than doubled and research has indicated that only garden vegetables such as tomatoes, cucumbers and specialty lettuce can provide economic revenue for hydroponic systems (M. H. Jensen, 1999). However, this is likely to improve as we advance the technology for hydroponic food production.

Economic scenarios have been investigated as food prices continue to rise, and breakeven costs are dependent on the market value, production level and variable costs of production. One study estimated that up to 90% of the costs associated with hydroponic lettuce production are energy and labor (Daly *et al.*, 2014). Other variables, such as growing systems and media selection, will need to be investigated to determine optimum economic benefits. For example, researchers investigated three different hydroponic systems and three different medias to determine the economic benefits of the tomato (*Lycopersicon esculentum Mill.*), and determined a trough with cocopeat, gravel and silex stone were the most economically beneficial, calculated by the benefit/cost ratio (Joseph and Muthuchamy, 2014). One study investigated the minitubular hydroponic system compared to a soil system and indicated the hydroponic system showed a return on investment from 5.88% (soil system) to 195.55% (hydroponic system), and the labor cost reduced 22% (Tatoy *et al.*, 2008). The amount of space the hydroponic farm uses is also an important factor when determining cost/benefit analysis. A hydroponic farm in Taiwan showed a profit ratio increased from 4.6% with a 2000 square meter farm to 20.3% with a 4850 square meter farm (Lin, 1990). Typically, soil-grown agriculture gross margins range from 30% to 60% with several variables and can vary significantly from farm to farm (Ganguly *et al.*, 2011). A financial analysis of hydroponic kale indicated a predicted an average gross margin of 29% for kale and 65% for tomatoes (Ganguly, 2011).

Since hydroponics can be grown virtually anywhere, this can allow for the producer to grow food in their community. The public is interested in the benefits of buying locally grown food for the freshness, supporting the local economy and knowing where the product grows (Food Marketing Institute, 2009). By purchasing local foods, more money remains in the community; approximately 65% of the dollar stays with the farmer compared to grocery stores profit from only 40% (Brain, 2012). Eating food closer to home also helps lower food costs by minimizing transportation greenhouse gas emissions (O'Hara, 2011). It is common for soil-grown food to travel between 1,500 and 3,000 miles to reach the consumer. Conventional food production transportation accounts for 16% of all energy use and is a significant contributor to greenhouse gas emissions (O'Hara, 2011). Traditional agriculture uses large quantities of energy to produce food. It is estimated that 10 kilocalories of fossil-fuel derived energy are needed to produce 1 kilocalorie of food energy, and agriculture accounts for 17% of total energy expenditures (Pelletier *et al.*, 2011). By decreasing the transportation expenditures, the costs of eating food (grown by hydroponics) closer to home can potentially lower food prices.

Limitations of hydroponically grown food compared to soil-grown food

Growing food by hydroponics is limited in the cost per acre initially because of large starting overheads being much greater compared to traditional farming. This cost could be anywhere between two and twenty times more than soil agriculture, and the expenses of production in a greenhouse can cost approximately $10 per square foot (Coolong, 2012). Additionally, those taking care of the plants are required to have knowledge of the system and the principles of hydroponics, such as careful maintenance of the pH, nutrient solution and water levels (Leonhardt and McCall, 1914). Although hydroponics may be grown in non-arable land, the actual growth of hydroponics is dependent on electricity use (for pumps and light), and power outrages can cause damage to crops (M. H. Jensen, 1999). This may prove to be problematic in developing countries where electricity is scare. However, advancement in alternative energy may offer ways to reduce such costs.

For consumers and public officials, safety is one of the main concerns with local food production (Brom, 2000). Many sources of contamination of produce in open field agriculture are known, and hydroponic systems are generally grown indoors, therefore providing physical barriers to these risks. Orozco et al. indicated microbiological contamination can still occur indoors and indicated Salmonella enterica, Eschericha coli, coliforms and Enterobacteriaceae were found on hydroponic tomatoes, and were also found in cleaning cloths, sponges and puddles in the greenhouse (Orozco *et al.*, 2008). As good agricultural practices (GAP) are important for open field agriculture, GAP recommendations will also need to be developed for hydroponic farming.

If hydroponics are grown in a closed system, they are vulnerable to induced diseases and such diseases can spread rapidly. Water-based microorganisms can be easily introduced. Since research on hydroponics has only been over the past 70 years, methods of growing hydroponic plants are not an exact science and may have to be modified depending on cultivars, nutrient solutions and environmental conditions (M. Jensen, 2013). Although an advantage of hydroponics is the manipulation of the environment to allow optimum growing conditions, most plants are varieties that will require specific research to determine what those conditions are (M. H. Jensen, 1999).

Nutritional quality of hydroponic compared to soil-grown fruits and vegetables

Hydroponics can also be valuable in the nutritional sense with the luxury of hydroponics being grown in otherwise non-farmable land, providing opportunity for eating fruits and vegetables grown closer to home. This reduces spoilage and can maximize nutritional benefits (Jensen, 1999). Comparison of the nutritional content of hydroponically to soil-grown fruits and vegetables is challenging because of the fundamental differences between the two different systems. However, the most reliable method to compare them is by placing them in identical environments, each in their optimal growing conditions (Gruda, 2005). The differences in growing systems may result in variations of nutritional content such as: no differences in soil-grown compared to hydroponically grown, the hydroponic system has superior nutritional attributes, or the soil system has superior nutritional attributes. Table 1 outlines outcomes of nutritional differences between soil-grown and hydroponically grown produce. Studies differ in experimental design, cultivar, nutrient solution and climates. Although many studies indicate differences in hydroponic or soil-grown produce, comparison between the studies can be problematic because of the variation in experimental designs.

Overall, studies indicate little differences in nutrient quality between hydroponic and soil growing conditions. Ascorbic acid and α- tocopherol content was analyzed in four different cultivars of lettuce (Buchanan and Omaye, 2013). Three of the varieties (Waldmann's Dark Green, Red Lollo Antago, and Red Romaine Annapolis) indicated significant differences with hydroponically grown lettuce being higher in α-tocopherol content, while ascorbic acid content of hydroponically-grown Waldmann's Dark Green, Red Lollo Antago, and Red Romaine Annapolis were higher than soil-grown lettuce. Also, in a study quantifying ascorbic acid α-tocopherol, researchers found that hydroponically grown strawberries had higher amounts of ascorbic acid and α- tocopherol compared to soil-grown strawberries, while hydroponically grown raspberries indicated no significant differences compared to soil-grown raspberries (Treftz and Omaye, 2015). Different species of plants, as well as cultivar, likely produce different outcomes (Buchanan and Omaye, 2013; Treftz, 2015).

Inconsistent results may be due to many of the variables associated with hydroponic growing (nutrient solutions, environment, media options and hydroponic system differences). For example Rouphael *et al.* studied zucchini

(*Cucrbita pepo L.*) grown in two drip irrigation hydroponic systems and seasonal variation for nutritional quality. Results indicated the fruit was a higher quality in terms of sugars (fructose and glucose) using the drip irrigation systems in the Spring-Summer season compared to sub irrigation system (Rouphael and Colla, 2005). Gichuhi et al. analyzed ten cultivars of hydroponic carrots (*Daucus carota* L.) in two different hydroponic nutrient delivery systems (nutrient film technique and microporous tube membrane system) for differences in carotenes, moisture, ash, fat, texture and color. In general, it was concluded carrots grown in the microporous tube membrane system were the most preferred carrot for texture and color, and varied in nutritional content between cultivar of carrot during different growing periods (Gichuhi *et al.*, 2009).

Several other post-harvest factors are important when analyzing nutrition, especially concerning ripeness and the amount of time from harvesting to analysis for oxidative compounds. Post-harvest technology for hydroponic tomatoes has been shown to have an influence on the nutritional quality of the fruit. One study grew five different cultivars of hydroponic tomatoes and they were analyzed for differences in lycopene, ascorbic acid and polyphenols at the time of harvest, after 2 days and after 5 days at storage of 15°C. Upon harvest, all of the cultivars had similar polyphenols, but a wide variation between ascorbic acid and lycopene. After 2 and 5 days of storage, the lycopene content in all of the cultivars increased significantly while ascorbic acid decreased by 12% (Molyneux *et al.*, 2004). Hydroponic tomatoes were harvested and analyzed for variation of lycopene and antioxidant activity at 5°C followed by 12°C, compared to seven days at room temperature. Lower temperatures increased lycopene and antioxidant pathways during storage time. Room temperature tomatoes showed increased lycopene content but did not affect antioxidant activity (Javanmardi and Kubota, 2006). Hydroponic tomatoes ripened on and off the vine were evaluated for lycopene, β-carotene, and ascorbic acid. Tomatoes ripened on the vine showed significantly higher contents in all nutrients except ascorbic acid (Arias *et al.*, 2000). When evaluating bioactive compounds of hydroponic produce, these results indicate that the methodology of postharvest storage is an important factor to consider. These studies on hydroponic postharvest technology are useful to devise other studies to improve the quality of hydroponic produce.

Quality of food grown by soilless systems

There are many advantages of the hydroponic system compared to soil-grown produce. However, these advantages do not guarantee a high quality product. High yields, for example, do not automatically assure high quality produce. Ho et al. indicated yield would not be the driving factor of the agricultural industry, but rather, sensory and nutritional quality (Ho, 2004). Fallovo et al. demonstrated the nutrient solution, as well as the seasonal variation, affect yield and quality of baby leaf vegetables, while others indicated the concentration of the nutrient solution does not affect the quality of leafy greens (Fallovo, Rouphael, Rea, Battistelli, & Colla, 2009; Ferguson, et al, 2014). Although these studies are similar in nature, the nutrient solution brand as well as the geographical location was different, making the studies difficult to compare. Most commercial hydroponic nutrient solutions are overly optimized for plant needs and reducing the concentration by 3/5 had no effect on leafy green growth (Ferguson, et al, 2014). In the future, it would be useful to have specific nutrient solutions designed for each of the different crops based on data provided by scientific trials.

Another example is the salinity stress on hydroponic plants and the relationship to quality. It is thought that salinity stress can enhance sensory qualities of produce, such as taste (Borghesi *et al.*, 2011; Cuartero and Fernández-Muñoz, 1998; Yin *et al.*, 2010). The salinity of a nutrient solution as well as the replacement of the solution are directly associated with fruit mass and sweetness of hydroponically grown strawberries and a function of the conductivity of the solution (Sarooshi and Cresswell, 1994). Hydroponic nutrient solutions were tested in four different treatments and were found to have effects on fruit yield, berry weight and the sweetness of the berries. Heavier, sweeter berries were produced when the conductivity was reduced from 3 to 2 at early fruit set. This finding illustrates the need for more research to determine optimum growing conditions for the crop of interest, as well as the effects of seasonal, geographical and nutrient solution variations.

The consumer is interested in nutritional and sensory quality of the product and researching the best practices to guarantee environmental benefits. Therefore, to advise the consumer to purchase and consume a product needs to be evidence based. Several approaches have been proposed to manage these attributes, such as adjusting the electrical conductivity, nutrient form, temperature of the nutrient solution and pH of the solution. Gruda et al. proposed proper management of salt concentration, investigating the cationic proportions in the nutrition solution and maintain the nitrate limit in the solution are worthy areas of investigation for future research (Gruda, 2009). The investigation of various methods of improvement of product quality will be necessary as interest in hydroponic crop production continues.

Conclusion and future applications of hydroponics

Although the concept of hydroponics is not new, the technology has been rapidly evolving over the past 70 years (Benton Jones Jr., 2004). Many private and commercial establishments have, by trial and error, worked with hydroponic utilization and new applications have evolved. Hydroponics is a multifaceted technology with uses being developed for future space travel and in non-arable land (Resh, 2012). Additionally, it is proposed that glasshouses built in the desert may fulfill dual roles- 1) providing food and 2) using an installed antenna to receive energy radiation from energy collectors in space. This could be enhanced by incorporation with hydroponic food production (M. Jensen, 2013).

Hydroponic systems have been used as a model to investigate plant nutritional needs and deficiency symptoms (Jones Jr., 1982). More recently, hydroponic systems are being used as a model to investigate various phytoremediation techniques, such as the uptake of metals of zinc, lead, cadmium, nickel, arsenic and iron from contaminated soil. The control environment of the hydroponic system allows for studies to compare which plants would be most suitable for phytoremediation in soil contaminated sites (January *et al.*, 2008; Quartacci *et al.*, 2006).

Currently, the research on hydroponic systems is limited, however; preliminary research has shown beneficial results for ecological, economical, nutritional and sensory quality of hydroponically grown food. Several areas of hydroponic farming will need to be investigated to produce a product that is highly reliable, environmentally sustainable and contains equal or greater amounts of vitamins and minerals compared to soil-grown produce. Currently, hydroponic research is difficult to compare because of the variety of growing materials and methods. Future research should investigate the most feasible methods of growing, especially with hydroponic growing systems, nutrient solutions and media options. Additionally, pre-harvest and post-harvest factors should been considered for each variety of interest.

As research progresses in these areas, hydroponics may have a key role in providing nutritious food in non-arable environments and to assist in the global food sustainability.

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Conflict of Interest

There are no conflicts of interest

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Table 1: Nutritional comparisons between hydroponic and soil-grown fruits and vegetables*

Properties	No differences between hydroponic and soil	Hydroponically grown (+)	Soil-grown (+)
Ascorbic acid	Selma et al., 2012, Buchanan et al., 2013. Treftz et al., 2015	Auclair et al., 1995, Sgherri et al., 2010, Buchanan et al., 2013, Treftz et al., 2015	Premuzic et al., 1998, Selma et al., 2012
Alpha- tocopherol	Buchanan et al., 2013, Treftz et al., 2015	Sgherri et al., 2010, Buchanan et al., 2013, Treftz et al., 2015S	
Other vitamins	Granges, 1980, Simitchiev, 1983, Gilinger Pankotai et al., 1998, Abak & Celikel, 1993, Alan et al., 1993	Benoit, 1987, Lãcãtus et al., 1995, Özçelik & Akilli, 1997	
Carotenoids		Lãcãtus et al., 1995	Kobayshi et al., 1989, GRANGES, 1980, Kimura et al., 2003
Calcium	Thompson et al., 2005, Siomos et al., 2001		Premuzic et al., 1998
Other Minerals	Premuzic et al., 1998, Thompson et al., 2005, Simitchiev, 1983, Benoit, 1987, Gilinger Pankotai et al., 1998		
Fiber		Palermo et al., 2012, Almazan et al., 1997	Massantini, 1962, Almazan et al., 1997
Protein	Palermo et al., 2012	Almazan et al., 1997	

*Based on Gruda et al. (2009), modified and supplemented with results from other studies (see text and cited references).

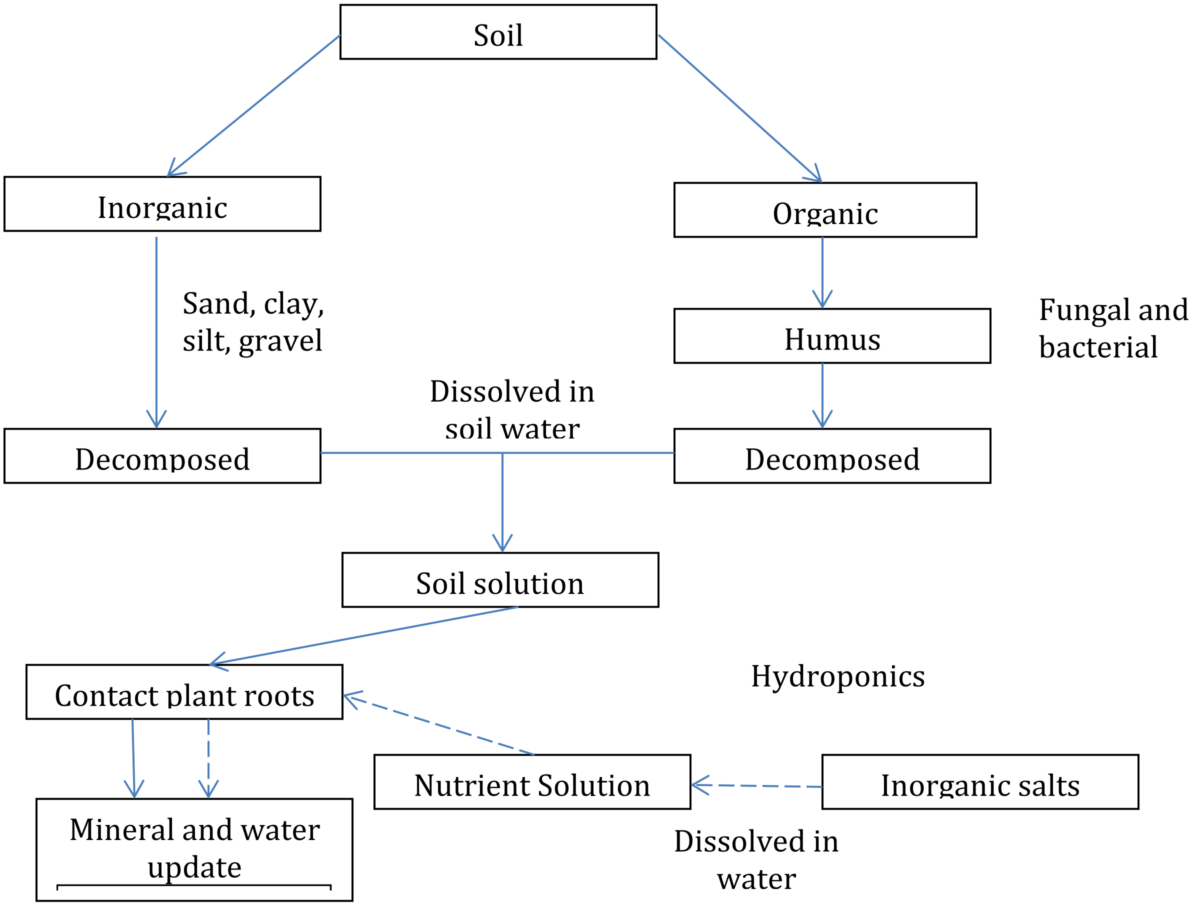

Figure 1. Essential elements of soil and hydroponics (Resh, 2012). Solid line depicts soil-grown plants and dashed line depicts hydroponically grown.

Chapter 2 Part B

Review of Sensory Evaluation and Hydroponics

Published in Part as

The proof of fruits and vegetables grown hydroponically is in the eating: sensory attributes of hydroponic grown fruits and vegetables

Chenin Treftz and Stanley T. Omaye

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Abstract

Hydroponic food production or food grown under soilless conditions is growing in popularity, with increasingly more farmers interested in the environmental benefits, i.e., less water and pesticides used and the economic benefits that result from higher yields and lower labor costs. Ultimately, it's the taste and other sensory attributes that will determine whether a product is accepted by people. Providing high quality hydroponic produce that is attractive and with positive sensory aspects will likely increase consumption, benefiting both the consumer and the producer. Sensory evaluation methods for produce development have been established and are undergoing development. The goal of growing fruits and vegetable hydroponically is to be at least equal to or better in quality and in sensory attributes as the soil grown counterparts. Hydroponic and the sensory evaluation of such produce will bring improvements and enhance global opportunities for sustainable food sources.

Introduction

Hydroponic food production or food grown under soilless conditions is growing in popularity, with increasingly more farmers interested in the environmental benefits (i.e., use of less water and pesticides) and the economic benefits that result from higher yields and lower labor costs (Resh & Howard, 2002). Worldwide availability of hydroponic produce is continuing to increase with over 50,000 acres currently being utilized for hydroponic growing (Resh & Howard, 2002). Current research is investigating various aspects of hydroponics, such as: growing methods, nutritional composition and sensory evaluation (Ferguson, Saliga III, & Omaye, 2014; Murphy, 2011; Stamatakis, Papadantonakis, & Kefalas, 2003).

Providing high quality hydroponic produce that is attractive and with positive sensory aspects (i.e., flavor) will likely increase consumption, benefiting both the consumer and the producer (Kader, 2008). Consumers consider sensory attributes to be the most significant factor when choosing to buy produce and are willing to pay more money for a product they perceive will taste better (Thybo, Bechmann, & Brandt, 2005). As innovative methods of technology and new cultivars of hydroponic growing are developed, sensory evaluation of the produce will be an important factor, encouraging consumption among consumers and production for the farmer. Produce sensory evaluation has unequivocal importance as it can improve production systems, formulate new technologies, determine shelf life, contribute to nutrient enhancement, and develop quality standards (Garruti & Virginia, 2010).

Sensory evaluation methods for produce development have been established (Garruti & Virginia, 2010). Sensory quality of the product is measured by human perceptions and therefore, taste, smell, sight, touch and hearing are the main measuring instruments. For instruments to be accurate, one must practice strict control of the tests and methodology in order to avoid psychological errors (Garruti & Virginia, 2010). Sensory science gives strict guidelines of sample preparation, judge selection, and sample administration so biases are minimized from the behavioral sciences perspective. These processes are necessary since sensory science involves a series of complex processes utilizing a wide variety of sensory organs, as well as, the brain.

The primary objective of this paper is to review the methods by which hydroponic produce has been evaluated, and describe current sensory science practices. Secondly, we review the current literature dealing with sensory perception of hydroponically grown fruits and vegetables compared to their soil grown counterparts and lastly, we make recommendations for future hydroponic sensory evaluation.

Background of Sensory Evaluation

Sensory Impression of Food

Sensory evaluation, as described by Stone and Sidel is, “a scientific discipline to evoke, measure, analyze and interpret the response to products that are perceived by the sense of sight, smell, touch, taste and hearing” (Stone & Sidel, 2004). In all aspects of food development, from industry, food processing and technology, as well as agriculture, sensory science is a necessary part of the process that has been long recognized as a distinct scientific area. It has been recognized more recently that without organized plans, procedures and management that sensory evaluation methods are rarely impactful and difficult to interpret. Opportunities to use sensory evaluation methods arise from developing new foods and new markets for the consumer. In agriculture, sensory science opportunities arise as we develop new methods of growing produce, trying to optimize production with minimal environmental impact. There is a high failure rate with new products, up to 98%; for this reason, among others, many producers are open to the idea of new approaches and new ways to measure the success of a product (Stone & Sidel, 2004). Sensory evaluation of food is one way we can help measure the potential success of a new product, such as produce grown hydroponically.

Despite these advantages many companies and product developers fail to utilize advances in the sciences because many professionals are unable to demonstrate the benefits of sensory science (Stone & Sidel, 2004). Additionally, there seems to be a general confusion of accepted methods and information each sensory evaluation test provides. Many businesses use sensory evaluation methods, but use different types of tests and are not able to properly utilize them for the correct situations.

Sensory science outlines a clear flow chart of the development of new products and comparison against similar products (Figure 1). However, within the literature evaluating hydroponic produce, there seems to be no pattern of evaluation methods. Subsequently, it is difficult to draw conclusions about the products and it is difficult to compare between studies. Additionally, there seems to be confusion for the type of panel that is appropriate for each test. It is crucial that sensory evaluation be administered properly and the results clearly communicated by a sensory science professional. Achieving this will establish reliability and validity with their studies as well as give creditability to the future of hydroponic food production. With sensory science having a clear role in the development of new agricultural systems, it is important to consider factors known to have an impact on the sensory quality of food in combination with nutrition. Sensory attributes that are the most important to consider are intrinsic (using the five senses) and extrinsic (other product information).

Agricultural factors affecting the quality of food

Several factors have been known to influence the agricultural production and composition of the food. Among those factors, most established are: genetics, pre-harvest, and post- harvest practices (Bourn & Prescott, 2002). It is a combination of all of these traits that will produce the best quality product. Flavor is a complex interaction of all five senses that will involve subjective evaluation (Stone & Sidel, 2004).

Genetics

Cultivar selection is of the most important factors when considering all aspects of sensory evaluation. Cultivar selection can range from different sizes, shapes, colors, flavors and textures. Genetic variations can have a wide impact on the pest resistance to the crop, the environment it thrives in, the amount of deformities it produces and its taste. When researching genetic variation in plants, identifying factors which will produce a favorable product is recommended using sensory analysis along with objective instrumental analysis (Mattheis & Fellman, 1999a). Pech et al. investigated genes in plants to optimize sensory quality. Genes targeted to improve sugar content are those which catalyze hydroperoxidation of lipid precursors such as hydrolyzing enzymes of aroma compounds which have been studied. Another example is the alcohol acyltransferase enzyme with ethylene can regulate ester formation, fatty acids and amino acids. Future research is needed to determine how all of these factors can influence produce quality. As research on hydroponic produce is being developed, research on these traits along with many other genetic traits affecting sensory attributes will be important to understand how to produce the product with the optimum flavor.

Pre-Harvest Factors

Environmental factors, such as light, temperature, moisture and wind can affect the appearance, texture, aroma and taste of the produce.

Climate is one of the major contributions to variations within produce. Several studies have cited that produce grown in two different geographical locations can affect the size, shape flavor and nutritional composition of fruits and vegetables (Cano et al., 1997; Kanahama, 1989; Simon, Peterson, & Lindsay, 1982). Even seasonal variation within a climate zone can affect the fruit quality and flavor attributes (Kays, 1999; Mattheis & Fellman, 1999b). Although extreme cold conditions, otherwise known as chilling periods, are often associated with post-harvest factors. Extensive exposure to cold can affect fruit appearance, texture and taste in an undesirable way. The extent of the damage is determined by the cultivar being studied since some crops can withstand extreme cold temperatures (Yelenosky & Guy, 1989), while others cannot. For example, the cold will affect the quality of the fruit (Kays, 1999). High temperatures can also contribute to appearance differences in fruit and like the cold temperatures, it is highly dependent on species and cultivar of interest. High temperatures have the potential to damage membranes, proteins, inhibit or cause premature ripening and cause changes in moisture content (Hong et al., 2013; Lopez, Johnson, & DeJong, 2008; Peet, Sato, & Gardner, 1998; Richardson et al., 2004).

Wind, hail and moisture can also contribute to variations of sensory attributes in produce. Wind damage, especially damage caused by high intensity winds can result in harm that reduces fruit size, leaf damage in leafy vegetables and poor color in various fruits and vegetables. In some agricultural areas, use of wind breaks have been a popular method to reduce the stress caused by these conditions (Cataldo, Durañona, Pienika, Pais, & Gravina, 2013; Kays, 1999; Peri & Bloomberg, 2002).

Light intensity can alter product sensory attributes that can be the result of insufficient light. A surplus of light can result in sun damage to the produce that can cause a problem to a wide range of produce. This results in the degradation of the pigmentation, bleaching of the chlorophyll, scalding or even collapse of the plant biomass leading to a less desirable appearing produce. This is notable in tomatoes, berries, pineapples and bananas (Kays, 1999; Ma & Cheng, 2003; Montanaro, Dichio, Xiloyannis, & Celano, 2006). Scarce light can also negatively affect produce quality, as seen in the strawberry where shading decreases yield, fruit size, and surface glossiness (Osman-AB & Dodd-PB, 1994; Tabatabaei, Yusefi, & Hajiloo, 2008). Light intensity can also alter the volatile compounds produced in the fruit; thereby, affecting the aroma and flavor attributes (Miller, Fellman, Mattheis, & Mattinson, 1998).

Water stress is a common problem many producers face that can affect sensory attributes of the produce. Water stress can cause an abundance of problems such as reduction of yield, reduced size, and alterations of appearance through discoloration. Flavor differences have also been observed in alterations through irrigation of produce. Sensory ratings have varied with sweet potatoes, muskmelon, and melons with different irrigation amounts. It is documented that sugar content can increase or decrease in response to water stress and can affect the sensory analysis on preference (Mattheis & Fellman, 1999b).

Pruning and thinning practices can significantly affect appearance of the fruit products, especially by their yield and size. This has been extensively studied in peaches, but has also been shown to be beneficial for pears, certain berries and apples (Corelli-Grappadelli & Coston, 1991; Costa & Vizzotto, 2000; Dennis, 2000; Link, 2000).

Bagging of tree fruit during the development is commonly used as a form of integrated pest management in commercial production facilities. Bagging can affect the pigment synthesis of the fruit, affecting the overall appearance. Additionally, fruit that has been bagged is considered to be substandard in flavor compared to fruit that has not been bagged, because of the decrease in favorable volatile aromas (Hofman, Smith, Joyce, Johnson, & Meiburg, 1997; Jia, Araki, & Okamoto, 2005).

After genetic considerations, maturity and ripeness are the second most important factors influencing the sensory attributes of food (Kader, 2008). The ideal ripeness of the produce depends on the product of interest. Fruit tastes best when it is harvested mature, and vegetables taste best when they are immature (Kader, 2008). This is because the biosynthesis of the volatile compounds that influence aroma and flavor occur during ripening and maturation. This can greatly affect the smell and taste of the product. Fruit picked early has been described as sour, not sweet of flavor (Kader Morris,L.L., 1977). If fruit is harvested before it is mature, it may never reach acceptable quality, even when stored in controlled environments (Fellman, Rudell, Mattinson, & Mattheis, 2003).

Immature fruit can have distinct differences in appearance compared to fruit harvested at full maturity. For example, raspberries undergo drastic changes in color, and these changes occur when still attached to the raspberry bush. When harvested immaturely, the pigments cannot be synthesized, therefore making the appearance inferior to one ripened on the parent plant (Kays, 1999).

Post-Harvest Factors

The goal of postharvest management of produce is to deliver optimum flavor when the product reaches the consumer; however, this presents a variety of challenges since flavor and volatiles can change over the course of storage and marketing (El Hadi, Zhang, Wu, Zhou, & Tao, 2013). In general, it is assumed that the more time between farm and table, the more losses of favorable aroma, texture and taste caused from losses in sugars, volatiles and organic acids (Kader, 2008). Producers are generally concerned about time for the product to change colors during storage time. However, it would be beneficial to the consumer and the producer to consider the optimum flavor in relation to storage time, since better tasting produce is likely to lead to increased consumption.

Several value-added products are on the market today to enhance appeal to the consumer. Examples include, ready to eat salads, pre-sliced apples, using strategies to minimize browning. Research is needed to optimize this growing market to study the best strategies to maintain desirable sensory attributes such as flavor, taste and texture (Kader, 2008).

Fruits and vegetables are subject to processing to increase their shelf life, with the goal being to maintaining their original sensory qualities and achieve optimum food safety. Processing foods can alter sensory attributes, important attributes to consider for future research, because processing foods can provide year round availability. Identifying times that sensory attributes are most desirable and coordinating with the time of processing of foods provides good framework to preserving optimum sensory attributes.

Consumer acceptance and preference

With food product evaluation, there are two main measurements of consumer testing: measurement of acceptance and measurement of preference (Lawless & Heymann, 2010). For the purpose of this paper, consumer acceptance will be defined as, "how much a product is liked", and consumer preference will be defined as, "which product a consumer would choose (i.e., prefer)" (Lawless & Heymann, 2010). As hydroponic food production and agricultural biotechnology in this field advances, the consumer acceptability and preference towards hydroponically grown produce will only be realized if consumers perceive these emerging technologies to be safe, useful and accepted in terms of sensory evaluation. Many drivers of acceptance have been historical indicators and will be important issues to address to optimize production.

Usefulness and Safety

Survey research has measured and approximated consumers' attitudes toward biotechnology. Large studies, from the United States and five European countries with over 18,000 participants, found that 70% showed a positive attitude toward agricultural biotechnology, indicating that the participants feel that they may have already benefited from emerging technologies or that they will in the future (Hossain, Onyango, Adelaja, Schilling, & Hallman, 2004; Wagner, 1997). A critical review study, mentioned above, noted the positive attitudes of biotechnology are limited, because as many as 50% of the respondents were unaware of the definition of agricultural biotechnology (James, 2008). The acceptance and preferences of agricultural biotechnology and the associated products is multifaceted. Many drivers of liking such as sensory attributes, nutritional and environmental benefits of products increase positive attitudes, while other factors such as safety concerns can negatively influence perceptions of agricultural biotechnology usefulness.

Consumers have expressed interest in learning about the benefits of biotechnology. Survey results suggest that providing education about new products will increase product acceptance, and acceptance will continue to rise if the safety of products have been endorsed by reliable sources such as the Food and Drug Administration (Hoban & Nations, 2004). In addition, if consumers are aware of environmentally sustainable food products, the acceptability can also be positively influenced (Hoban & Nations, 2004). Educating consumers on the benefits of growing food hydroponically has the potential to increase the product acceptance; however additional research on the best methodologies to accomplish this is necessary. The goal of the education is to improve consumer acceptance and should focus on the safety, environmental benefits, cost and taste of food produced by hydroponic systems.

Drivers of liking (DOL) can influence a product's acceptance and preference (Bi, 2012). Most DOL are focused on intrinsic factors, however, both intrinsic and extrinsic factors can influence a consumer's acceptance and preference for a food, including loyalty and purchasing behaviors (Bi, 2012). Intrinsic attributes generally involve the five senses and cannot be changed without altering the food product (i.e., appearance, aroma, taste, feel, sound), and extrinsic attributes generally involve external influences of quality that are often influenced by culture (i.e., brand, labeling, satiety, price) (Kim, Lee, Kwak, & Kang, 2013). A combination of both intrinsic and extrinsic attributes have a great influence on a product's success, and will ultimately influence the consumer to repeat purchasing, which a main indicator for product success. When developing hydroponic produce, knowledge of intrinsic and extrinsic attributes will provide a framework for understanding hydroponic acceptance and preference.

Extrinsic Product Attributes

To accurately comprehend a food product, one must study all of the related elements that guide the decisions a consumer makes in addition to sensory related attributes that involve the five senses (intrinsic factors). It is now recognized that when a consumer makes a decision to purchase food, it is influenced by several external environmental, emotional, and expected intrinsic cues that can guide the decision making process (Grunert, 2005). Among these are things that have found distinct correlations on purchasing behavior: satiety, brand information, price of the product, and emotional responses when seeing the product (Li, Jervis, & Drake, 2015). In addition to these four attributes, it is also now recognized that extrinsic factors such as demographic information can greatly influence the purchasing of a product. Specific areas of interest of previous studies have been age, sex and ethnicity. The eating and purchasing behaviors of men and women are different, as well as consumption patterns between young adults compared to the elderly. Previous studies have investigated the differences between these food products and demographic variances (Cardello, 2003; Drake et al., 2009; Drake, Gerard, & Drake, 2008). Assessing these demographic differences, along with other extrinsic DOL, such as satiety, labeling, price and emotions, will be an imperative factor to consider as research advances with hydroponic growing systems.

Perceived satiety, otherwise known as expected satiety, has been shown to impact purchasing behavior of consumers as if the product will be large enough to satisfy the hunger craving. In research settings, this has been investigated and results have shown food that had higher satiety ratings were classified as more rewarding, and many consumers, especially with those with higher BMIs, were more likely to make food choices based on the expected satiety (Brunstrom & Shakeshaft, 2009). Expected satiety has been correlated with purchasing behavior, even more so than overall liking of the food (Brunstrom & Rogers, 2009). Therefore, when investigating hydroponic produce, investigating the cultivars to produce appropriate fruit and vegetable sizes that will satisfy satiety will be a potential indicator of product acceptance and preference.

Branding and Packaging

The brand name of a product can influence perceived sensory attributes of a product, implying the importance for understanding brand and labeling as a key DOL in external sensory attributes (Roy & Banerjee, 2007). Emphasizing this point, it has also been recognized that consumers' brand preferences can actually be a reflection of their perception of the product, indicating trust is placed more in the name-brand of the product instead of the product itself (Bronnenberg, Dhar, &

Dubé, 2007). If hydroponic branding is to become popular, this branding effect may be difficult to measure since it is thought to occur subconsciously (Li et al., 2015).

Labeling and packaging will also be an important factor to investigate when marketing hydroponic produce. Branding can play an important role in purchasing because it can set up expectations for quality. The consumer will then purchase the product again after the expectations are met (Deliza & Macfie, 1996). Ng and others investigated how packaging and labeling a product influenced conceptualizations of a product defined as emotion, foundational and abstract attributes (Ng, Chaya, & Hort, 2013). Results indicated that labeling and packaging of a product did not evoke emotional responses, however, was associated with abstract and foundational attributes of a product, and that these attributes can influence a liking score.

Price

The price of the product can influence sensory perception of a product since it can provide information about product quality (Rao, 2005). The price of a product can also influence the performance of an actual product subconsciously, which is why price is known as the best extrinsic indicator of quality. In general, the higher the price of an item, the higher the item will be scored (Oude Ophuis & Van Trijp, 1995). This theory has been reviewed using different methodologies and food products, indicating price having a key factor in consumers' purchasing behavior (Li et al., 2015).

Decision making and emotional impacts can influence desires and beliefs as to what the product can do for them if the product meets their expectations upon consumption. A shopper's emotional state when purchasing a product can be an indicator of how the consumer will make a decision. For example, if a shopper is experiencing intense negative emotions, they are more likely to consume high caloric food choices (Macht, 2008). Emotions such as these or others have been shown to affect eating patterns and can directly affect purchasing behaviors (Li et al., 2015).

When assessing DOL for hydroponic produce, things such as satiety, branding and labeling, price, and emotional impacts should be considered since all of these factors have shown meaningful impacts on other food options. This will be important to consider as hydroponic produce is being developed, but will be the most important when the product is fully developed and understood (Li et al., 2015). The influence of these DOL along with brand information should be tested in blind studies with hydroponic and non-hydroponic produce options to fully understand the impact of these factors. Finally, it is important to recognize that to correctly assess all of the extrinsic factors of hydroponic produce, one must understand the complexity of the experiments required and that it will require several types of tests and methodologies to produce a successful product that will result in consumer acceptance and preference.

Intrinsic Product Attributes

The most critical factor of food appearance is color because it can prompt the mind to expect certain flavors, establishing expectations for a certain product (Jaros, Rohm, & Strobl, 2000). For example, if a product is a deep red, consumers will expect a strawberry flavor, or if a pudding is a creamy color, consumers will expect a rich vanilla flavor. Additionally a classic study has demonstrated that adding color to a particular food can also increase taste sensitivity (green), while other colors (yellow) can decrease taste sensitivity (Maga, 1974). Adding color has also been shown to increase intensity to sweeteners in beverages. Subjects tasting two identical drinks, one colored red and one clear, indicated a higher sweetness score compared to the uncolored (Johnson & Clydesdale, 1982). Color has been studied intensively in food products (Spence, Levitan, Shankar, & Zampini, 2010), and the most desirable attributes for specific cultivars of hydroponic produce will need to be investigated as research progresses.

In addition to color, appearance can be judged by other product attributes. For example, surface glossiness of fudge has been rated higher compared to fudge with a dull top. The interior appearance of a product is just as important to appearance as the external appearance (Imram, 1999). In hydroponic produce, the inside of the product, color, color uniformity and surface lumps will all be important characteristics to assess.

The aroma of foods is an important intrinsic factor of sensory evaluation of food because it can influence the overall acceptability and preference of a product. Investigating the development of moderate odor volatiles will produce a desirable product (Kader, 2008). Foods that yield a desirable aroma will appeal to consumers, while strong, unfavorable aroma will discourage consumers from eating this food product (El Hadi et al., 2013). Further, aroma will influence the taste and therefore, flavor of the food product. Aroma and taste interactions can result from a variety of mechanisms including physiological and psychological.

The effects of volatile and non-volatile compounds have been studied, and because of their importance on intensifying flavor, should be studied when developing new products (Noble, 1996). This evaluation should be done in a variety of settings and investigate the food served in multiple ways. For example, volatile compounds increase in intensity when heated. Cabbage is an example of this. The aroma of a cabbage is more intense when it is boiled compared to raw. Since many people eat cooked cabbage, investigating this aspect of the prepared food will be important when developing cultivars hydroponically. When evaluating aromas, it is most beneficial to evaluate them at the temperature they are to be served. Another example, hydroponic berries, may be served in a variety of different ways (i.e., raw, in baked goods), and therefore aroma sensory analysis will need to be investigated in a variety of different preparation techniques.

Taste, according to consumer survey reports, is the most important attribute to influence food selection (Glanz, Basil, Maibach, Goldberg, & Snyder, 1998). Taste is the sense of a dissolved substance mediated by taste buds on the tongue (Merriam-Webster, 2013). Taste preferences are mediated by many physiological variables. Several theories on taste preferences have been explored, including endogenous opiate peptides, genetic inheritance, body mass index, chronic disease status and even educational level (Drewnowski, 1997). In general, it is thought that food preferences are predicted by taste preferences. However, as discussed previously, many extrinsic factors influence a customer's purchasing decision other than taste. Most research of the psychophysics of tastes focus on sweet, sour, salty and bitter (Drewnowski, 1997). In the literature, there are studies on consumer preferences for tastes of these attributes, which can be referenced during the development of hydroponic produce development. When evaluating taste preferences for hydroponic produce, it is important to consider different demographic variables that influence taste preferences, such as sex and age.

Flavor, by definition, is the composite of taste and odor in the mouth, or in more technical terms, the psychological interpretation of a physiological response to a physical stimulus (McWilliams, 2012; Noble, 1996). This sensory attribute is often difficult to assess since there are several mechanisms that can contribute to the overall impression of food apart from taste and odor- such as mouth feel, astringency, or chemical heat. In any of those interactions, flavor perceptions are influenced. Although these have been investigated using various methods and trained judges, the overall flavor of food remains a difficult attribute to assess, and most likely will also be difficult with hydroponic produce evaluation. Although difficult to accurately assess this process is worthy of investing time and resources since if the overall flavor of hydroponic produce is not pleasant, there will be limited consumption.

Texture is a complicated term that relies on the mouth feel of a food quality as perceived in the mouth. There are several aspects of textural properties a product can encompass, and these specific attributes may need to be defined during descriptive testing when analyzing hydroponic produce for textural properties. Some of these attributes may include: tenderness, dryness, roughness or wetness (Guinard & Mazzucchelli, 1996). These attributes need to be clearly defined to the participant.

Hydroponic growing systems

Differences between Soil and Hydroponic Systems

Hydroponics, or plants grown in water without soil, offer many benefits compared to soil grown produce. Hydroponics' main advantage is that it can be grown in non-arable land areas, such as deserts (Benton Jones Jr., 2004). Increased availability in plant nutrition is also an advantage of hydroponics. In soil, plant nutrition is highly variable because of soil conditions (pH, non-organic matter, inefficient essential nutrients, poor structure) (Benton Jones Jr., 2004). With hydroponics, the water serves as the nutrient reservoir and the grower is able to control vital plant conditions for optimal growth. The water in the nutrient reservoir is delivered to the root system, which the plants can then uptake the nutrients. This is the opposite of how plants take up nutrients in natural situations because soil is acting as the main nutrient reservoir for plants.

Hydroponic systems are advantageous in that it is possible to control the nutrient levels, pH and aeration in the reservoir, reducing the risk of complications that could arise from plants growing in natural conditions (Resh & Howard, 2002). Plant spacing also inhibits soil culture. Hydroponic plants are only limited by light and can therefore be spaced closer together and also do not require crop rotation.

Soil-grown plants often have increased pest issues compared to hydroponic plants, since pest can reproduce and lay eggs in the soil medium. Since hydroponic plants do not have the beneficial microbes available for the pests to thrive on that soil plants have, the use of pesticides generally tends to be less (Resh & Howard, 2002).

Types of Hydroponic Systems

Hydroponics can be divided into medium culture and water culture. Water culture has roots suspended in water with the plant crown being supported by a cover. Medium culture has the roots and plant crown supported. Examples of medium are gravel, sand, rockwool, hydroton, and pearlite (Jensen, 2013).

Hydroponics can further be divided into circulatory and static systems. The chief difference is that circulatory systems have water moving past the root systems. Static systems are generally grown in containers and can be aerated or un-aerated. Each system has advantages and limitations and these should be carefully considered when choosing which system to use. Two popular systems are the drip system and the ebb and flow system.

The drip system is one of the most widely used hydroponic systems because it recycles water. Drip systems can be set up to be automated, which gives more accurate and precise control over the moisture level of the medium used for hydroponics and could also allow for specialized plant production. The medium does need to be checked regularly as it can become saturated with unabsorbed nutrients from the nutrient solution. The ebb and flow is known for its simplicity and reliability. The system floods the medium rooting the plants for a fixed time (i.e., 5 minutes). This system is limited in that is requires frequent maintenance to check nutrients and pH. Compared to other hydroponic systems, this system is less efficient with water use (Resh & Howard, 2002).

Methodologies of sensory evaluation of hydroponically grown fruits and vegetables

When evaluating hydroponic produce, every test of sensory analysis should have a clear research question and procedures outlined to answer the question(s) at hand. These procedures and strategies should include the test method, the subjects to participate in the study, experimental design, conduction the experiment and methodology for analysis. These procedures are outlined in Figure 1. Ultimately, this type of organization will have the most efficient analysis and will ultimately be able to answer a variety of research questions at hand.

Step 1 is to define the research question. This should include expectations as to what is to be expected from the different samples. For example, is there a difference in hydroponic produce compared to soil grown produce, different growing systems, lighting, nutrient solution, or post-harvest technologies? Does the hydroponic produce vary in one or more different attributes? These will be important considerations for the following steps.

Step 2 in Figure 1 is to select the appropriate sensory evaluation method (outlined in Figure 2). Depending on the research question, specific sensory methodologies should be used. For example, if we are merely trying to establish if a difference exists between two different growing systems, the ‘difference test’ would be appropriate. Sensory analyses are typically evaluated by 1) difference testing, 2) preference testing, 3) descriptive testing, and 4) central location testing. A difference test is to determine if a panelist can detect a variance in the product overall. Examples of difference testing are: duo-trio test, triangle test, and tetrad test. If the difference test observed significance, a descriptive test can then monitor specific attributes of a product. Without a detectable difference in the overall product (difference test), descriptive/preference tests would not need to be performed if no significant difference was observed. Difference tests should be conducted before descriptive tests. A preference test can be as simple as a paired comparison test (i.e., which product do you prefer?), and a descriptive test asks to which degree a panelist likes a product, usually in the form of a hedonic scale. Central location or home tests are used at the end of product development in real-world situations, such as in the consumer’s home. This step ensures that results in the sensory laboratory match results found outside of the sensory laboratory. Finally, the last step is to evaluate post-harvest technologies. Packaging and shelf life can help determine the optimum time for consumer purchasing and consumption. Packaging can influence extrinsic product attributes, which can influence purchasing behavior (Li et al., 2015).

Step 3 outlines the selection of the appropriate panel. Panels can be classified into trained and untrained. Untrained panelists do not have sensory training and trained panelists have special training designed to detect certain flavors or attributes of the product. Trained panelists are typically selected for descriptive testing, and untrained panelists can be used in difference testing (‘which product is different?’), preference testing (‘which product do you prefer?’), or central location testing (‘would you buy this product?’).

Step 4 in Figure 1 refers to conducting the experiment. This will involve selecting a site where the participant can evaluate the products of interest. This site selection will involve the specific objectives of the research question. For example, will the product be evaluated in a sensory evaluation laboratory? If so, will lights be used? Will the subject have ‘rules’ to follow when testing the food? If the research question is to monitor purchasing behaviors, perhaps the experiment should be conducted in the grocery store. If the question is to monitor actual consumption, perhaps the consumers should be allowed to take both products home and then report back on consumption. The sensory scientists will have several options when it comes to the site selection and the protocols, and it will be important to weigh the pros and cons of each option before making a decision.

Step 5 involves analyzing the results of the experiment. For the sensory evaluation method chosen, an appropriate statistical methodology should be selected. After results are analyzed, **Step 6** will involve accurately reporting the results. From there, future research questions can be formulated.

Current Trends in Sensory Science

Current trends in sensory science have attempted to address the major challenges of 1) to improve methodologies to improve efficiency while maintaining statistical power, and 2) to provide accurate descriptions of food products (Carlisle, 2014; Garruti & Virginia).

To increase efficiency in research, the tetrad is a difference test that has been gaining popularity and is being used to replace the triangle test (O'Mahony, 2013). With the traditionally used triangle test, the subject is presented with three samples, two the same, and one different. The subject is then asked to identify which sample is the 'odd'. With tetrad testing, the subjects are given 2 pairs of 2 samples (4 samples total), and are asked to group the samples based on similarity. The tetrad test offers the same statistical modeling as the triangle test but the tetrad test has increased sensitivity. The triangle test and the tetrad test both have a probability of 1/3, but the tetrad test offers advantages by decreasing the effect size and decrease variations in samples as explained by the Thurstonian theory (O'Mahony, 2013). These advantages can save companies money by using fewer panelists and samples (Ennis & Christensen, 2014). Recognized industrial companies such as General Mills have converted over to using the tetrad test (Gelski, 2013). This trend is likely to continue to gain popularity and the tetrad test should be employed when researching sensory evaluation on hydroponic produce.

Getting the consumer to accurately describe the food product by descriptive testing has historically been evaluated by hedonic scaling. These tests are recommended to be conducted with trained panelists (Figure 3), however, this process is expensive and time consuming. Recently, research has been trending towards using untrained panelists on descriptive tests. Some research has indicated no significant difference between results conducted by untrained panelists and trained panelists (Worch, Lê, & Punter, 2010). More research would have to be conducted on this subject for untrained panelists to be accepted among the sensory science community.

Free listing is an open ended question that asks consumers to describe the samples. If similar words or trends are observed, they can be grouped in a matrix. This type of analysis can reveal similar words to the consumer, such as crispy and crunchy, which can in turn lead the direction of product development and study relationships between sensory data and consumer descriptions (Ares, Giménez, Barreiro, & Gámbaro, 2010).

Sensory evaluation of hydroponic produce

Sensory evaluation on hydroponic produce is limited, however, the demand for it has grown substantially around the world (Garruti & Virginia, 2010). Traditional research on hydroponic produce has primarily focused on the nutritional composition of the crop compared to soil grown produce (Almazan, Begum, & Johnson, 1997; Auclair, 1995; Buchanan & Omaye, 2013; Kimura & Rodriguez-Amaya, 2003; Palermo, Paradiso, De Pascale, & Fogliano, 2012; Premuzic, Bargiela, Garcia, Rendina, & Iorio, 1998; Rouphael & Colla, 2005; Selma et al., 2012; Sgherri, Cecconami, Pinzino, Navari-Izzo, & Izzo, 2010; Thompson et al., 2005). Hydroponic produce has several environmental and nutritional benefits, as previously described in the literature. However, the taste needs to be comparable or better than soil grown produce for consumers to purchase and consume the product. In other words, it needs to be able to compete with other reputable produce options. As described previously, taste is one of the most important factors that affect the consumption of food (Drewnowski, 1997; Glanz et al., 1998). Research on produce grown hydroponically that has a preferable taste compared to soil grown produce needs be a priority to truly benefit from the environmental and nutritional benefits hydroponic food production has to offer.

As sensory evaluation continues with this new product development, it is important to remember that sensory evaluation should focus on standardizing methodology and following standard operating procedures to accurately compare data across different studies. The flow chart as outlined in Figure 2 for methodology procedures with hydroponic produce could be a means of accomplishing this. In the current literature, there seems to be no trend as to how hydroponic produce has been evaluated, just that is has been evaluated using sensory analysis, as outlined in Table 1.

Selma et al. used a trained panel of five to evaluate visual quality, flavor, texture, and browning effects using a descriptive 9 point hedonic scale of hydroponically grown and soil grown varieties of lettuce (Selma et al., 2012). Out of three lettuce varieties studied, the hydroponically grown lettuce had higher ratings on two out of three of the varieties compared to the soil grown lettuce. Typically when comparing similar produces without an obviously noticeable difference,

difference testing should be first used to establish a difference in the hydroponic compared to the soil grown lettuce. After a difference has been established, it would then be appropriate to conduct descriptive testing as Selma et al. did with trained panelists to save time and money since the training uses resources. Since Selma et al. did use trained panelists, the results of this study are more likely to be accurate than other studies using descriptive sensory techniques with untrained panelists.

In another study, panelists evaluated hydroponic compared to soil and organically grown lettuce using a five point hedonic scale (Murphy, 2011). Results indicated no significant differences found. In another study, untrained panelists was used to evaluate hydroponic lettuce grown under different light treatments using a 6 point hedonic scale and fifty untrained consumer panelists (Lin et al., 2013). However, both of these studies used untrained panelists, and therefore the accuracy of these results are subject to interpretation. Using humans as instruments to rate descriptive characteristics is subject to extreme variation, which is why it is recommended to use only trained panelists for descriptive evaluation since it is possible to orient them to sensory attributes of interest.

Also evaluating hydroponic and soil grown lettuce, other authors themselves have self-reported taste and color subjectively, without a trained or untrained panel (Buchanan & Omaye, 2013; Ferguson et al., 2014). Although these authors commented positive characteristics such as ‘pleasant tasting’ of the hydroponic lettuce, these results are subjective and the need to be repeated with a larger sample size.

Hydroponic strawberries, tomatoes and carrots have also been evaluated for sensory quality. Hydroponic strawberries were evaluated for overall flavor, as well as aroma, sweetness, acidity and texture in berries grown in different levels of electrical conductivity in the solution(EC). The results were evaluated using a linear scale between one and fifteen and then those scores were converted to a score out of 10. The panelists were untrained staff members employed at the research and agricultural center where the berries were grown. Results from this study indicated when the EC decreased from 4 EC to 2 EC, there was a stronger aroma (Sarooshi & Cresswell, 1994). However, these results are to be viewed with caution since the panel was untrained. The panelists were also part of the worksite where the crop was being grown. This can lead to biases in the evaluation. Future research should avoid panelists directly associated with the growing conditions of the crop.

Hydroponic carrots grown by two different hydroponic systems (nutrient film technique and microporous tube membrane system) were evaluated for six attributes using untrained consumers. The panelists were using a 9-point hedonic scale and results indicated that many consumers preferred the microporous system. (Gichuhi, Mortley, Bromfield, & Bovell-Benjamin, 2009). However, since the carrots were most likely similar appearance and the panelists were untrained, a difference test followed by a preference test would have been more appropriate for this study. After a difference was established, descriptive testing using a trained panel would be ideal for determining specific attribute differences between the carrots. Another study using untrained panelists evaluated hydroponic tomatoes ripened off and on the vine to determine the differences in texture, flavor, color, and overall acceptability using a linear line scale. Results indicated two out of the six attributes studied had significantly higher ratings towards tomatoes ripened on the vine (Arias, Lee, Specca, & Janes, 2000). These results are also to be interpreted with caution, since a trained panel would be the most valid methodology for measuring descriptive characteristics.

Trained panelists evaluated hydroponic tomatoes between different varieties and harvest times for firmness and texture quality of the tomatoes using a linear scale (Thybo et al., 2005). Because correct testing methodologies were used with this study by using trained panelists to evaluate descriptive characteristics of the tomatoes, we can be more confident in the accuracy of the results compared to similar studies using untrained panelists. Thybo et al. concluded that the hydroponic tomatoes were crisper and firmer compared soil grown tomatoes.

Conclusion and needs for future research

Hydroponic produce needs an immense amount of research before the product can become successful. Cultivars of interest should first be compared to the soil grown counterpart to determine if a difference or a preference exists. Research on different types of hydroponic systems should also be conducted. All hydroponic systems are not the same, and it has been shown that sensory differences can exist in the taste of produce grown by two different hydroponic systems (Gichuhi et al., 2009). Investigating various hydroponic systems to yield the most desirable product in terms of sensory, nutrition and environmental benefits will all be important goals to attain. Since the hydroponic farmer has a vast majority of options when choosing how to grow hydroponic produce, research on different growing media and nutrient solutions should also be investigated and determined if the sensory quality of the product affects consumer preference. This research will ultimately benefit both the producer and the consumer, ensuring a profit for the producer and providing delicious, nutritious fruits and vegetables for the consumer.

There is much potential for hydroponic produce, and sensory scientists should use previously established methodologies to evaluate new products to ensure accurate and reliable results. This will offer those researching hydroponic produce to compare results between studies as well as, recommendations for future research. Additionally, with the established statistical modeling previously established methodologies offer, this will increase sensitivity and reduce the risk of Type II error.

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Table 1. Sensory evaluation of hydroponic produce in the literature.

Crop evaluated	Sensory analysis goal	Type of sensory tested used	Type of Panel used	Outcomes	Reference
Lactuca stavia L.	Study 3 varieties of soil and hydroponic lettuce to compare quality and storage effects	Descriptive, hedonic scale	Trained panel	2/3 lettuces hydroponic had higher hedonic ratings compared to hydroponic. 1/3 hydroponic lettuce had higher ratings after storage	Selma et al., 2012
Lactuca stavia L.	Compare 5 hydroponic, soil and organic lettuce varieties for taste, odor, visual quality and texture	Descriptive, hedonic scale	Untrained panel	No significant differences found	Murphy et al., 2011
Lactuca stavia L.	Test concentrations of nutrient solutions on hydroponically grown lettuce	Descriptive, no scale	Self-reported	Reported ‘good flavor’	Ferguson et al., 2014
Lactuca stavia L.	Evaluate 3 varieties of hydroponic compared to soil grown lettuce	Descriptive, no scale	Self-reported	Hydroponically grown lettuce were larger and richer in color compared to soil grown lettuce	Buchanan, et al., 2013
Fragaria ananassa	Compare variances of electrical conductivities (EC) of hydroponic strawberries	Descriptive, linear line scale	Untrained panel	Stronger aroma in berries when EC decreased from 4 to 2	Sarooshi et al., 1994
Daucus carota subsp. sativus	Evaluate sensory attributes of carrots grown by two	Descriptive, hedonic scale	Untrained panel	Significant preferences seen towards microporous tube	Gichuhi et al., 2009

	different hydroponic systems (nutrient film technique and microporous tube membrane system) and soil grown carrots			membrane system	
Solanum lycopersicum	Hydroponic tomatoes ripened on and off the vine were compared for 6 attributes	Descriptive, linear line scale	Trained panel	2/6 attributes were rated higher on tomatoes ripened on the vine	Arias et al., 2000
Solanum lycopersicum	Compared hydroponic and soil grown tomatoes	Descriptive, linear line scale	Untrained panel	Hydroponic tomatoes were crisper and firmer compared to soil grown tomatoes	Thybo et al., 2005

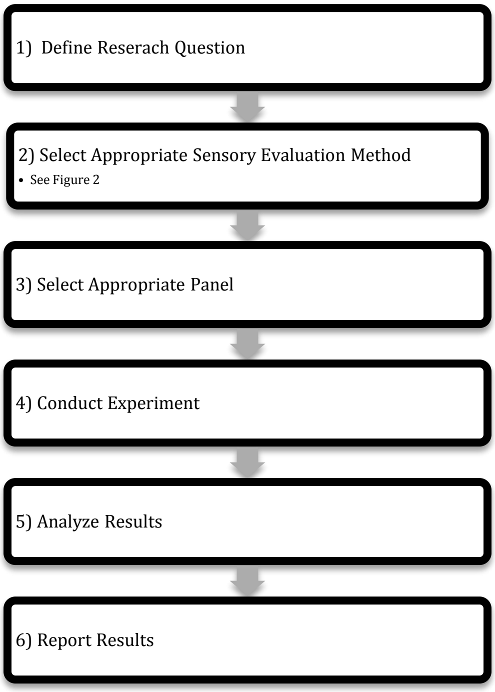

Figure 1. General guidelines for sensory evaluation procedures. Modified from Sensory Evaluation in Fruit Product Development (Garruti & Virginia, 2010)**.**

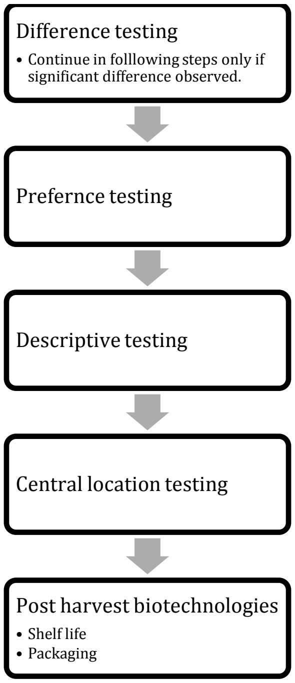

Figure 2. Sequencing recommendations for sensory evaluation methodology. Modified from Fruit Product Development (Garruti & Virginia, 2010)**.**

Chapter 3

Feasibility of Hydroponic Strawberries

Published in Part as

Comparison between hydroponic and soil systems for growing strawberries in a greenhouse

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In

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Abstract

Consumption of strawberries has been asserted to have many health promoting bioactive compounds including antioxidants. Growing fruits and vegetables hydroponically represent a possible opportunity towards sustainable crop production; it would be beneficial to examine the feasibility and the potential ability to replace soil systems for growing strawberries. Unlike leafy greens, the root structures, stalk, and fruit are more complex and require more physical support. In this study, hydroponic strawberries were higher in terms of fruit yield and plant survival rate. In soil-grown strawberries, the overall mass was significantly higher by 23%, but there was a larger variation of fruit size indicated by a large standard deviation. Startup costs for growing strawberries in hydroponic systems can be more than soil systems. Growing strawberries in hydroponic systems are feasible, at reasonable cost and more sustainable compared to traditionally soil grown systems. Future research should investigate various hydroponic growing methods and the feasibility of growing at the commercial level.

Introduction

Hydroponic food production, or growing food without soil, is increasing worldwide and seem to have a positive overtone as consumers are becoming more aware of the environmental benefits (Jensen, 1999). Hydroponics can be grown in arid or urban conditions regardless of soil quality, making hydroponics advantageous for growing food closer to the consumer (Bellows et al., 2003). The hydroponic system has several advantages such as; conserving water, allowing for year-round production, increasing yields, and minimizing use of pesticides (Resh & Howard, 2012). Additionally, hydroponic fruits and vegetables have been documented in the literature as having higher nutritional value and more desirable sensory attributes compared to soil grown produce (Buchanan & Omaye, 2013; Gichuhi, et al. , 2009; Selma et al., 2012; Sgherri et al., 2010).

The majority of previous hydroponic research has focused on leafy greens, peppers and tomato fruit (Arias et al., 2000; Buchanan & Omaye, 2013; Gruda, 2009; Koyama et al., 2013). However, research evidence regarding hydroponic strawberry production under hydroponic systems have been seen as scanty. Strawberries are nutritious fruits containing high antioxidant concentration and health promoting bioactive compounds such as vitamin C, flavonoids and polyphenolic compounds. The consumption of strawberries is associated with several health benefits including: lowering of cholesterol, improvement of vascular endothelial function and anti-inflammatory biomarkers, and reduction of oxidative stress mediated diseases such as cancer (Giampieri et al., 2012; Hannum, 2004; Meyers et al., Zhang et al., 2008). Therefore, growing strawberries hydroponically would have several health advantages to the consumer and be environmentally resourceful, *i.e.*, less water and pesticide consumption.

There are some limitations for comparing soil and hydroponic growing systems because they are fundamentally different. However, the most reliable way for comparison is to place both systems under optimal growing conditions (Gruda, 2009). The goal of this one-year study was to compare the feasibility of growing strawberries as measured by, the differences in yields, monthly distributions of fruit production, and plant survival rates in hydroponic conditions compared to conventionally soil-grown strawberries. We compared the differences between start-up costs, maintenance costs, and upkeep time between the two systems.

Methodology

Hydroponic and soil plants were grown and maintained at the University of Nevada, Reno (UNR) Agricultural Experimental Station Greenhouse Complex. The Agricultural Experimental Station Greenhouse Complex is a state of the art facility, equipped with automatic heating and cooling systems. No supplemental light was used for either system due to the 340 days of sunlight that Northern Nevada experiences per year. The greenhouse temperature was maintained at 70°F during the day (5:30 AM to 6:30 PM) and 60°F (6:31 PM to 5:29 AM) at night with relative humidity averaging at 30%. Sixty bare-root, ever-bearing strawberry plants ('Ozark Beauty,' *Fragaria x ananassa)* were purchased from Stark Brothers Nurseries & Orchard Company (Louisiana, MO). Thirty strawberries were planted in hydroponic conditions and thirty strawberries were planted in soil conditions. The soil plants and the hydroponics plants were randomized and placed in eight rows on two

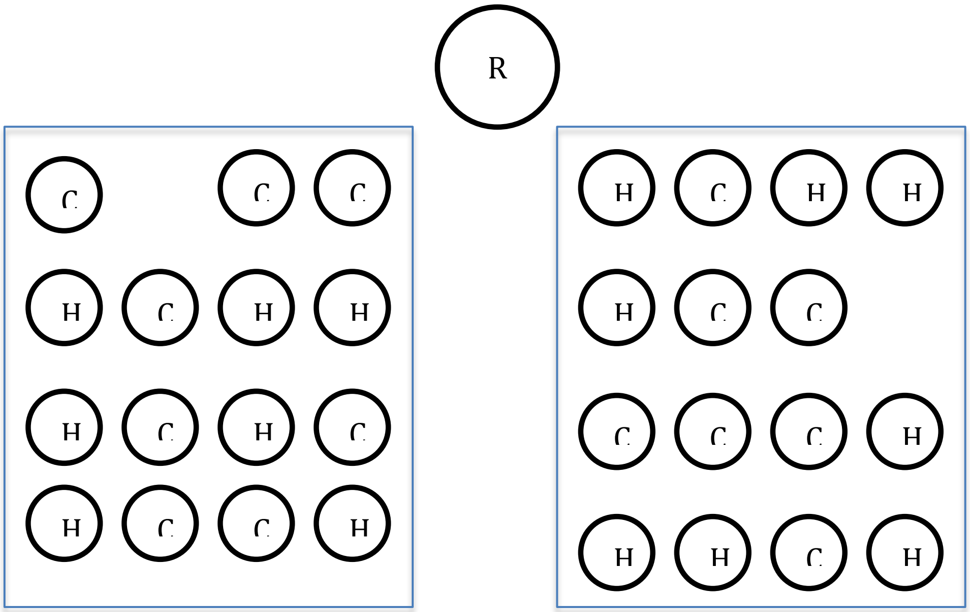

Figure 1: Design for experimental treatments. Schematic illustrates the randomization of the hydroponic (H) and soil-grown (C) growing conditions. Water reservoir is indicated by 'R'.

tables, as outlined in Figure 1. Both the hydroponic and the soil-grown plants were numbered for recording and monitoring plant health. In both growing conditions, first-buds and runners were manually removed to increase fruit production.

Soil system

The Ozark Beauty strawberries were planted according to manufacturing instructions, in 3-gallon black plastic nursery pots with drainage holes in the bottom of the pots. Two strawberries were planted in each pot, approximately 10” apart. The soil was a mixture of 1:1 ratio of Miracle-Gro potting soil (Marysville, OH) and Nevada topsoil. The pH of the soil was monitored using a portable pH meter before planting and during the season (Oakton Instruments, Vernon Hills, IL). The pH of the soil was between 5.5-5.7 and was measured and recorded three times weekly. The plants were watered using a drip-irrigation system for 15 minutes three times a week. The plants were fertilized with Miracle-Gro all-purpose fertilizer (Marysville, OH) every six weeks.

Hydroponic system

The hydroponic strawberry systems were grown in recirculating hydroponic bucket systems. A series of 15 buckets were constructed. Orange, five-gallon paint buckets were purchased from a local hardware store and spray-painted black to decrease light transmission that may promote algae growth within the system. Fifteen 8-inch net pots were purchased from the local hydroponics store, along with perlite used as the growing medium (Reno, NV). The bare-root strawberries were planted in the perlite according to the instructions provided by the nursery.

Hydroponic plants can generally be planted closer together compared to soil grown plants (Resh & Howard, 2012); for this reason, two strawberries were planted in each 8-inch net. The roots were fanned out with the crown at the line of the pearlite. The Waterfarm® system was used to deliver water from the bucket to the plants by utilizing a pumping column and drip ring (Reno, NV).

The plants were aerated using an all-purpose hydroponics pump (Active Aqua AAPA 15L, Reno, NV). The systems were aerated 23 hours a day. One hour per day, the system was stopped to decrease algae growth that is produced with continuous water movement. The pH of the plants was maintained between 6.0 – 6.4 and adjusted, if necessary, three times a week using General Hydroponics pH Up Solution and pH Down Solution. The nutrient solution used was a commercial General Hydroponics Flora series solution (Sebastopol, CA). During initial stages of growth, the nutrients were added in a volume of 1:1:1 ratio. During the early bloom phase, the nutrients were added in a volume of 3:1:5 ratio; during the late bloom phase, the nutrients were added in a 1:0:2 ratio. The average concentration of the dissolved salts (mg/L) in the water was 400 mg/L, adjusted three times weekly if necessary. This is considerably lower than manufacturer instructions; however, previously reported literature indicated that a lower nutrient solution concentration does not affect plant growth (Ferguson, Saliga III, & Omaye, 2014). Every four weeks, the systems were cleaned by spraying off any algae buildup in or around the buckets or media, and the nutrient solutions were replaced.

Pest Control

In the UNR greenhouse, aphids and spider mites infected the plants. Spider mites, when present, were sprayed with PyGanic® insecticide (MGK, Minneapolis, MN) bimonthly. Fungas gnats were present in both soil and hydroponic plants because they feed off of algae and plant roots. The gnats were effectively controlled by yellow sticky whitefly trap (Seabright Laboratories, Emeryville, CA) placed around and above the tables.

Aphids were treated first by physical methods of integrated pest management by attempting to dislodge them with water. However, more aggressive approaches were necessary; thus, one teaspoon of Dawn® dish soap was mixed with one liter of water and sprayed on the plants with the aphid infection once per month. The solution was allowed to sit on the plants for 30 minutes, and then thoroughly rinsed with water.

Statistical analysis

Statistical analysis was conducted with Graph Pad Prism Version 6.0f. The independent t-test was used to determine differences in berry mass, with a significance level set a $p<0.05$. Results are expressed as mean ± standard deviation (SD).

Results and discussion

Fixed and variable cost comparisons

The fixed and variable costs for the hydroponic plants compared to the soil-grown plants are outlined in Table 1 and Table 2. The hydroponic system has a higher startup cost compared to the soil system. It is important to note that the hydroponic system would last through multiple seasons without the need to replace the soil. The soil for the soil system would eventually have to be replaced, fertilized and other efficient management practices, such as crop rotation, would need to be considered. These are factors that could be avoided with hydroponic farming. The soil system had a lower cost, but used 30% more water compared to the hydroponic system. Another important factor to consider when choosing a growing system is labor costs. Soil-grown produce is more often cited for having increased labor costs because of weeding, watering, and spraying of pesticides (Resh & Howard, 2012). With our system, we found the soil strawberries to have increased weeds compared to hydroponic strawberries. However, the hydroponic system overall was more labor intensive because of the time required to check and monitor the pH and ppm of the solutions. Additionally, each month it took about 1.5 hours to change and replace the nutrient solutions in the hydroponic buckets; the soil strawberries did not necessitate extra monthly maintenance routines.

Economic models have been developed to estimate profitability associated with hydroponic lettuce, and some have been modified to fit different scenarios (Coolong, 2012; Donnell et al., 2011). When considering hydroponic food production on a commercial scale, developing an economic model to determine cost-benefit analysis for optimum economic feasibility would aid both the commercial and small-scale farmer. A decade ago, it was assumed hydroponic lettuce and tomatoes would be the only crops to be economically feasible for hydroponic food production (Jensen, 2013). However, since then, food prices have more than doubled and the economic revenue for different crops should be investigated for the commercial and small scale farmer (Jensen, 2013).

Table 1. Fixed and Variable Costs for Hydroponic Grown Strawberries

Fixed Costs:			
Item	N	Price	Sub Total
5-gallon paint bucket	15	$2.97	$44.55
Hydroton	1- 50 L bag	$87.00	$87.00
pH and ppm meter	2	$55.00	$110.00
8-inch netting	15	2.25	$33.75
Drip ring	15	5.95	$89.25
Pumping column	15	5.95	$89.25
Air pump	4	$20	$80
Electric cords and power strips	MISC	$60	$60
Total			$593.80
Variable costs:			
Item	N	Price	Sub Total
Nutrients[a]	2 liters	$4.20/liter	$8.40
pH adjuster	0.1/liter	$8.20/liter	$0.82
Bare root plants	30	$11.99/25 plants	$14.39
Electricity[b]	201.48 kWh	$0.118/kWh	$23.77
Water[c]	360 gallons		
Heat	Unknown		
Total			$47.38

[a] Amount estimated from General Hydroponic Nutrients, Flora series

[b] Energy cost was estimated by the following equation $\text{Cost}_{(\$/\text{day})} = E_{(\text{kWh/day})} \times \text{Cost}_{(\text{cent/kWh})}$
, where E= .552 kWh/day (4 air pumps operating at 6 watts/air pump) and Cost= Northern Nevada is about $0.118 kWh/hour. Electricity was estimated at 24 watts (6 watts/air pump) operating at 23 hours/day for a total energy usage of 0.552 kWh/day. 0.552 kwH/day x 365 days/year x $0.118 kWh = $23.77.

[c] Water was calculated by adding 2 gallons/bucket x 15 buckets, replacing water 12 times yearly.

Table 2. Fixed and Variable Costs for Soil Grown Strawberries

Fixed Costs:			
Item	N	Price	Sub Total
3-gallon buckets	15	$1.91	$28.65
Potting soil	2/2.5 cubic feet	$13.97	$27.94

Plumbing	MISC	MISC	$125.00
Water reservoir	1	$20	$20
Water pump	1	$69.00	$69.00
Electric cords and power strips	MISC	$20	$20
Total			$270.59
Variable costs:			
Item	N	Price	Sub Total
Fertilizer[a]	1 pound	$5.98	$5.98
Bare root plants	30	$11.99/25 plants	$14.39
Electricity[b]	0.93 kWh	$0.118/kWh	$0.11
Water[c]	520 gallons		
Heat	Unknown		
Total			$20.48

[a] All-purpose Miracle Gro fertilizer was used, once every 6 weeks.

[b] Energy cost was estimated by the following equation: $\text{Cost}_{(\$/\text{day})} = E_{(\text{kWh/day})} \times \text{Cost}_{(\text{cent/kWh})}$
,where E= 0.018 kWh/week, and Cost= Northern Nevada is about $0.118 kWh/hour. Electricity was estimated at 24 watts operating at 0.75 hours/week for a total energy usage of 0.018 kWh/weeks x 52 weeks/year x $0.118 kWh = $0.11.

[c] Water was estimated by visual inspection of the water level of from the 25 gallon reservoir, approximately 10 gallons/week.

Strawberry yields and weights

The strawberry yields and weights are outlined in Table 3, and shown in Figure 2. The total yield of the soil-grown strawberries was 70 strawberries. The hydroponic strawberries had a 17% higher yield compared to the soil grown strawberries. The distributions of the monthly weights from the strawberries are shown in Figure 3. In general, the average weight of the strawberries was at its highest at the beginning of the harvesting season and decreased as the season progressed, with its lowest point being at the end of the season. In August, hydroponic strawberries had a mean weight of 6.2 g/strawberry and decreased to 4.1 g/strawberry in March. The same trend was seen in soil-grown strawberries, with a mean mass of 9.9 g/strawberry in August decreasing to 3.1 g/strawberry in

March. Strawberry weights were significantly higher in those soil-grown, with a mean mass of 7.1 g/strawberry compared to 5.4 g/strawberry in those hydroponically grown. In the totality of strawberries grown both conventionally and hydroponically, the standard deviation was large, indicating a wide variation of weights in all harvested strawberries; however, standard deviation in weight was smaller comparatively between hydroponic strawberries (3.0 vs. 3.7) and soil-grown strawberries.

Hydroponically grown plants are thought to have increased fruit production because of the precise control over the nutrient solution and the ability for them to be in their optimum growing conditions. Stress may be an important factor for hydroponic strawberry production since it increases fruit size. Hydroponic plants are generally less stressed than soil-grown plants since the plants are in their optimum growing conditions all the time. Further research, such as investigating stress factors, should be conducted to discover the variables in hydroponic strawberry production that may yield larger fruit sizes.

Table 3. Yields and Mean Mass of Hydroponic and Soil Strawberries

	Total yield (n)	Mean mass (g) ± SD	t	p
Soil-grown Strawberries	70	7.1 ± 3.7	3.03	0.0028
Hydroponic Strawberries	85	5.4 ± 3.0		

Plant survival

Plant survival rates for both growing conditions are shown in Table 4. Hydroponic plants had a higher survival rate at 80% compared to the soil-grown strawberries, which survived less than 50%. Lower soil-grown plant survival rates are attributed to increased pest issues with the strawberries grown in soil compared to the hydroponic. Although both growing systems received identical integrated pest management treatments, the soil plants suffered more and the pests thrived in the soil-grown strawberries, especially the aphids and spider mites. This can be attributed to increased beneficial bacteria and microbes that pests thrive on in soil conditions (Resh & Howard, 2012). Although the pests did affect some of the hydroponic plants, the pests did not thrive in the hydroponic conditions. With the higher plant survival rate, the hydroponic system could save money in the long run since our study showed hydroponics are more resistant to aphids, spider mites and fungus gnats. Pest infections are a large source of economic losses for farmers, and research for best pest management methods for hydroponic food production is warranted. Pesticide usage is a concern for many consumers – buyers are health and environmentally conscious regarding pesticide usage. The results found in this study suggest that using hydroponic systems on a large scale has the potential to reduce pesticide usage. Accomplishing this would provide the farmer with higher economic benefits.

Table 4. One-year plant survival rate

	Starting plants (N)	Plants surviving 1 year (N)	% survival rate

Soil-grown Strawberries	30	14	46%
Hydroponic Strawberries	30	24	80%

Conclusion and Recommendations

Although hydroponic food production seems to have a positive overtone because of the numerous environmental benefits, it is important to consider the obstacles that small scale commercial farmer may encounter. The initial higher investment may be a barrier for the adaptation of hydroponic food production for business owners. Further research should investigate economic and crop yields feasibility – determining these factors can provide resources to farmers interested in hydroponic food production. Agricultural extensions can play a key role in the adaption of hydroponic growing methods by providing evidence-based educational tools in a clear language to farmers who do not have a formal education. Agricultural extension can also play a vital role in educating business owners on the economic and environmental benefits of growing hydroponically.

Although hydroponic strawberries seem to be a feasible option in otherwise non-farmable land, other factors can influence the quality of the produce and should be considered for further research. The hydroponic farmer has vast choices when growing, such as media, different system types and nutrient solutions. Our method was chosen for the simplicity of design and relatively low costs compared to a large, custom-built system. However, other designs with perhaps one reservoir could potentially lower labor, saving time and money. In addition to researching multiple growing systems in hydroponic strawberry production, future research should also compare the nutritional composition and sensory attributes of the strawberries for each system.

Quality is one of the most important factors consumers consider when buying a product (Gruda, 2009). Different aspects of product quality, such as nutritional or sensory attributes of the soilless product, should be considered for future research. Nutritional information, such as health promoting bioactive compounds, are important to the health conscious consumer (Glanz et al., 1998). Sensory evaluation data should be collected to standardize the methods yielding the most favorable product in terms of consumer acceptability; for example, the electrical conductivity of a nutrient solution has been shown to influence the quality of the hydroponic strawberry, along with plant spacing, salinity stress and shading (Keutgen & Pawelzik, 2008;Sarooshi & Cresswell, 1994; Tabatabaei et al. , 2008). Collecting data on these important variables, along with product quality variables such as aroma, appearance and taste, has the potential to generate standard operating and marketing procedures to benefit the hydroponic grower (Ferguson et al., 2014; Murphy, 2011).

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Conflict of Interest

There are no conflicts of interest.

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Table 5. Mass distributions of hydroponic and soil berries by month

	Hydroponic Strawberries (g ± SD)	Soil Strawberries (g ± SD))	t	p
August	6.2 ± 0.72	9.9 ± 4.95	1.27	0.22
September	*	*		
October	*	*		
November	7.45±1.43	9.8±1.41	0.96	0.35
December	7.36±0.93	7.19±0.50	0.13	0.89
January	7.71±1.29	5.86±0.51	1.72	0.101
February	4.51±.059	2.69±1.14	1	0.12
March	4.18±0.44	3.19±1.05	0.52	0.60

*indicates low yield

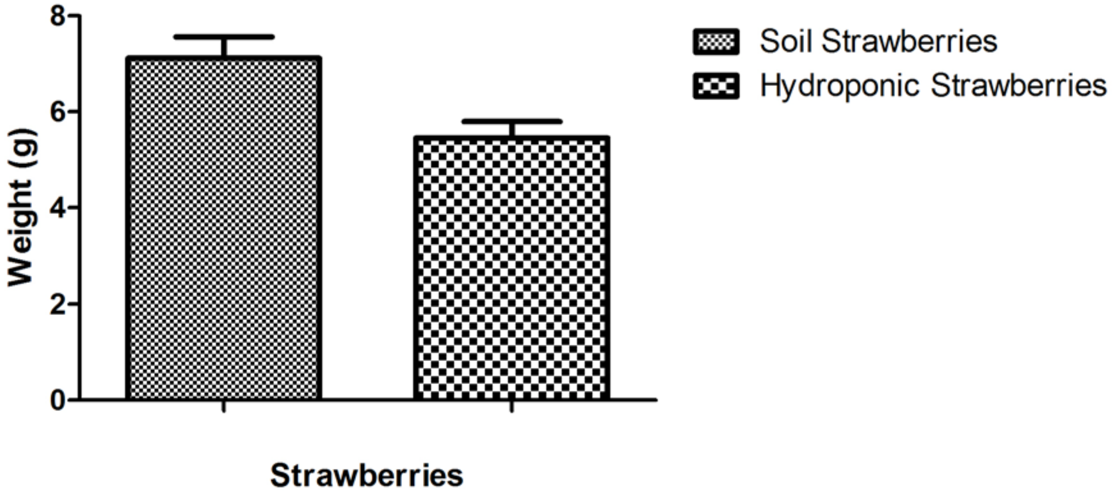

Figure 2. Hydroponic and Soil Weights

Chapter 4

Nutrient Analysis Study

Published in Part as

Nutrient analysis of soil and soilless strawberries and raspberries grown in a greenhouse

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In

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Abstract

Soilless (hydroponic) vegetables and fruits grown in greenhouses are gaining popularity and potentially represent a complement toward sustainable food sources. Only a few studies have examined at the nutrient quality of strawberries (*Fragaria x ananassa*) and raspberries (*Rubus idaeus*) grown in soilless systems. Dry weights, content of ascorbic acid, tocopherol, total polyphenolic compounds, glucose, fructose, and soluble solids (BRIX) of strawberries and raspberries grown in soilless systems were compared their counterpart grown in soil. There was no change in dry weights but BRIX values (28-31%), glucose (158-175%), and fructose (75-102 %) content for strawberries and raspberries respectively were significantly higher for the soil grown berries compared to soilless grown berries. Content of ascorbic acid, tocopherol and total polyphenolic compounds were significantly higher in soilless grown strawberries compared to soil grown strawberries by 74, 53, and 22% respectively, and content of ascorbic acid and total polyphenolic compounds were significantly higher in soil grown raspberries by 83 and 67% respectively compared to soilless grown raspberries. Soilless grown produce warrants future research to strive toward the potential to provide nutrient dense crops and opportunities toward optimized sustainable production.

Introduction

The United States Department of Agriculture estimates that 23 million people live in food deserts with inadequate access to healthy, affordable and fresh food [1]. Inadequate access to food, especially fresh fruits and vegetables, is a public health concern because the consumption of fruits and vegetables is associated with a decreased risk of certain chronic diseases such as cardiovascular disease, type 2 diabetes, obesity and certain types of cancer [2, 3]. Growing fresh produce in soilless systems may be a potential solution to food insecurity issues regardless of soil quality, climate or space [4]. Additionally, soilless growing systems can provide several other environmental benefits such as reduction of water, increased product yields, and less pesticide use. These advantages allow soilless systems to address several environmental issues while providing sustainable systems in food deserts, in arid or urban regions.

Recently, several studies have focused on the nutritional content of soilless produce. As soilless food production grows in popularity, researching the nutritional composition of soilless compared to traditional farming methods will be important because nutrition is one of the main drivers of purchasing and consumption [5]. Some studies indicate soilless systems provide superior nutrition compared to traditionally grown produce [6–9], while others indicate either no differences or soil grown produce is higher in selected nutritional parameters [10, 11]. The majority of previous research has focused primarily on lettuce, leafy greens and tomato fruit. Additionally, several of the previous studies have limitations on the findings because the comparison was conducted with produce grown in different environments known to affect bioactive compound production in the plant [12, 13]. The comparison of soilless and soil systems must occur in identical environments [14].

Limited research is available on soilless strawberries and raspberries. The aim of this study was to compare the differences in nutritional quality, as defined by bioactive compounds, Brix (total soluble soilds) and moisture content of strawberries and raspberries grown in soil and soilless conditions. Strawberries (*Fragaria x ananassa*) and raspberries (*Rubus idaeus*) are a rich source of bioactive compounds and can provide a plethora of health benefits to the consumer[15–17].

We chose to determine ascorbic acid, α-tocopherol and total polyphenolics because of their role in antioxidant protection [17–19]. Glucose and fructose were determined because these two nutrients are the primary sources of sugars in strawberries and raspberries [20]. Research on sugar content is necessary since it can affect the taste of the fruit as well as consumer preferences [21]. We determined moisture content and Brix in the fruit, which is an important quality indicator that can influence the texture and flavor of a fruit, as well as shelf life [22].

Methods

Chemicals

Thiourea, copper sulfate, and orthophosphoric acid (85%) were purchased from Fischer Scientific (Fair Lawn, NJ). Sulfuric acid, trichloroacedic acid, 2,4 dinitrophenylhydrazine, L-ascorbic acid, ferric chloride, xylene, 4,7-diphenyl-1,10-

phanthroline (bathophenanthroline), (±)α-tocopherol, sodium carbonate, Folin-Ciocalteu, tryptamine hypochloride, hydrochloric acid (HCl), fructose, dinitrosalcylic acid, sodium hydroxide, D(+)-glucose, potassium sodium tartrate, and sodium sulfite were purchased from Sigma-Aldrich Cooperation (St. Louis, MO). ACS/NSP grade (200 proof) absolute ethanol was purchased from pharmco-AAPER, Kentucky.

Growing conditions and plants

Bare root strawberries and raspberries were ordered from Stark Brothers Nurseries & Orchard Company (Louisiana, MO). In both soilless and soil plants, they were planted on the same day in late Winter 2014. Plants were grown at the University of Nevada, Reno (UNR) Experimental Station. Throughout the growing season, the greenhouse temperature was maintained at 70°F (5:30 AM to 6:30 PM) during the day and 60°F (6:31 PM to 5:29 AM) at night with a relative humidity averaging at 30%. Soil and soilless buckets were numbered and randomized with the available space in the greenhouse at the UNR Experimental Station. The strawberries were placed in 8 rows between two tables, and the raspberry barrels were placed on cinder blocks (Reno, NV), in 3 rows of 4 barrels.

Strawberries

Thirty bare root Ozark Beauty (*Fragaria x ananassa*) strawberry plants were planted in soil conditions grown in three-gallon nursery pots. Berries were planted in Nevada topsoil mixed with Miracle-Gro potting soil (Maryville, OH) in a 1:1 ratio. The plants were watered by a drip irrigation system for 15 minutes, three times weekly. The plants were fertilized with all-purpose Miracle-Gro fertilizer every six weeks. The pH and the dissolved salts in mg/L, or parts per million (ppm) of the soil plants was measured with a portable electrical conductivity meter before planting and quarterly, averaging at 5.6 and 400 ppm (Oakton Instruments, Vernon Hills, IL).

Thirty bare root strawberry plants were planted in soilless systems. The berries were planted in a bucket system using five-gallon paint buckets from a local hardware store (Reno, NV). The buckets were spray painted black to minimize algae growth. Hydroton, 8-inch netting, a Waterfarm® system pumping column and drip ring for construction of the bucket system was purchased from a local hydroponics store in Reno, Nevada. The plants were aerated using an all-purpose pump (Active Aqua AAPA 15L, Reno, NV). The pH of the plants was maintained between 6.0-6.4. The nutrient solution was a commercial General Hydroponics Flora Series, consisting of FloraBloom, FloraGrow and FloraMicro (Sebastopol, CA). Throughout the growing season, the nutrient ratios were changed to match the plant development, as indicated by the manufacturer instructions. The dissolved salts averaged at 400 mg/L. The pH and mg/L were monitored and adjusted three times weekly.

Raspberries

Six bare root Heritage (*Rubus idaeus*) raspberries were planted in 50 gallon barrels. A combination of Nevada topsoil was mixed with Miracle-Gro potting soil in a 1:1 ratio. The berries were watered one to three times weekly for 15 minutes with a drip irrigation system. The plants were fertilized with all-purpose Miracle-Gro fertilizer every six weeks. The pH and mg/L of the soil was checked before planting and quarterly, averaging a pH of 5.6 and ppm averaging at 600 mg/L.

Six bare root Heritage varieties of raspberries were planted in 19 gallon buckets (United Solutions, TU0014, Reno, NV) using hydroton as the growing medium. Holes were drilled at the bottom of the buckets and were placed on top of the empty fifty-gallon barrel to create a large-scale version of a bucket system described with the strawberries. From the 50 gallon barrel, the water drains into a large water reservoir where a water pump distributes the water to the six soilless buckets via polyvinyl chloride (PVC) and drip tubing (Reno, NV). The water in the reservoir was maintained at a pH between 5.8 - 6.2. This pH was monitored and adjusted if needed three times weekly. The nutrients added to the berries were FloraGrow, FloraBloom and FloraMicro and maintained averaging at 500 mg/L.

To support the berries, a T-hedgerow system was built with string and PVC pipe. A T-hedgerow system has been shown to have a comparable yield compared to the V-trellis system.

Harvesting strawberries and raspberries

The berries were harvested promptly when they visually reached 100% surface red color. The fruit was harvested between 7 AM and 8 AM for consistency, placed in a plastic laboratory bag, and immediately brought in a -70°C Thermo Scientific™ Revco™ high performance lab freezer (ThermoFisher Scientific, Waltham, MA). The berries were stored in the freezer until analysis. All berries analyzed for comparisons were harvested on the same day. Nutrients with time sensitive oxidative properties were analyzed within thirty days of harvest, and others (i.e., glucose, fructose) were analyzed within sixty days of harvest.

Sample preparation

Samples were randomly selected for analysis by hand. Before analysis, berries were rinsed with deionized water, dried with a paper towel and the stems were manually removed. For all assays, samples were homogenized using a Brinkmann Instruments Polytron homogenizer (Kinematica, Bohemia, NY).

Brix (refractive index) and moisture content

Brix, or soluble solids, is a common measurement of total dissolved solids in the juice, wine and soft drink industry, and can be used to approximate total sugar content. An automated digital refractometer (Milwaukee MA871, Rocky Mount, NC) was used. Procedures have been described previously [23]. Briefly, 10 grams (g) of berry samples were homogenized with a pestle and mortar. A double-dilution with an equal part by weight of distilled water was added to the homogenized berries. The berries were filtered using cheesecloth to remove seeds and pulp. After the samples were filtered, 1000 μL was extracted and the results were read in triplicate.

Moisture content in fruit was estimated by using a modified version of the Official Methods of Analysis of AOAC 934.06 for moisture in dried fruit [24]. The protocols' drying portion was lengthened to 20 hours to account for higher moisture content in fresh fruit compared to dried fruit. Briefly, three 10 g portions of samples were taken and homogenized with a pestle and mortar. The samples were placed in a Lab Line incubator, model 120 (Kerala, India) for 20 hours at 140°F. After drying, the moisture content can be expressed as a percentage of mass determined by the following equation: $W = \frac{M_1 - M_2}{M_1 - M_0} x\ 100$ where W is the moisture content, M_0 is the mass of the weight dish, M_1 is the mass of the dish and sample before drying, and M_2 is the mass of the dish and the test portion after drying.

Ascorbic acid analysis

Ascorbic acid content was determined using a modified protocol from measuring ascorbic acid in animal tissues [25]. Ten grams of berries were randomly selected and homogenized with 10 mL cold 20% trichloroacetic acid (TCA). This mixture was placed into a flask wrapped in aluminum foil with 0.1 grams of activated carbon to remove color intensity and agitated for 15 minutes, and then was allowed to sit overnight [26]. The mixture was then filtered using Whatman no. 2 filter paper. A stock solution was created using L-ascorbic acid and standards were made using 5% TCA with a serial dilution of 0-120 μg/mL. After filtering, 100 μL of the liquid was removed and added to new test tubes containing 900 μL of 20% TCA. One mL of a mixture of 2,4 dinitrophenylhydrazine (DNPH), thiourea, copper in the presence of sulfuric acid was added to all samples, standards and blank. The copper in the solution oxidized the ascorbic acid to dehydroascorbic acid. The DNPH, thiourea and the sulfuric acid yielded a colored product with minimal interference from other chromogens. The samples, standards and blank was incubated in a 20 L Fischer Water Bath (Fischer Scientific, New Lawn, NJ) at 37°C for three hours. After incubation, 1.5 mL of cold 65% sulfuric acid was added to the samples, standards and blank, and a 30 minute waiting period was observed at 25°C to allow the color to stabilize. The absorbance of the samples, standards and blank were read at 520 nm with a 110 voltage Finstruments Microplate Reader (Model 314, McLean, VA) in triplicate. The samples were compared to a linear regression created from the known standards ($y=0.0102x + 0.0316$, $R^2 = 0.9957$). The reproducibility was measured by adding a known amount of a standard to a sample and determining the recovery, which was 110% ± 2.1%. [27].

Tocopherol analysis

Alpha-Tocopherol (α-tocopherol) method was derived from Fabinek et al., 1968, using Fe(III)-bathophenanthroline spectrophotometry [28]. Ten grams of berries were randomly selected for analysis and homogenized with 10 mL of absolute ethanol. Xylene (1.2 mL) was added to extract the tocopherols from the samples. The samples were then centrifuged for 20 minutes at 3500 rpm in a Sorvall RT6000B refrigerated centrifuge at 7°C. After centrifugation, 100 μL of the organic layer was removed and was added to new test tubes containing 0.4 mL of bathophanthroline. Ferric chloride (0.4 mL) was then added to the tubes and 0.4 mL of orthophorsphic acid (85%) was then added to these test tubes to stabilize the color. In similar fashion, standards were made using a serial dilution between 0 – 50 μg/mL to create a linear regression to estimate α-tocopherol content in the samples ($y= 0.0081x - 0.0053$, $R^2 = 0.9927$). All samples, standards, and blank were read at 530 nm in triplicate with a 110 voltage Finstruments Microplate Reader (Model 314, McLean, VA). The reproducibility was measured by adding a known amount of a standard to a sample and determining the recovery, which was 95% ± 2.5% [6].

Total polyphenolics

Total polyphenolics were determined by using the Folin-Ciocalteu assay. This method has been used in measuring the total reducing capacity in berries by gallic acid equivalents (GAE) [17, 29, 30]. Raspberries (10 g) were homogenized with 10 mL of ethanol. A volume of 1.58 mL of deionized water was added to all samples along with 100 μL of the Folin-Ciocalteu reagent. A series of standards were made using the same method ranging from 0 - 300 mg GAE/L. The solutions were allowed to sit for one minute and then mixed thoroughly. A volume of 300 μL of 25% sodium carbonate solution was added to the samples, standards and blank and was placed into a 40°C 20 L Fischer Water Bath (Fischer Scientific, New Lawn, NJ) for 15 minutes and recorded in triplicate at 690 nm against a 0 GAE mg/L solution Finstruments Microplate Reader, 110 voltage (Model 314, McLean, VA). The GAE in the samples was estimated using the linear regression line created from the standards ($y=0.0021x - 0.0099$, $R^2=0.9988$).

Fructose

Ten grams of samples were homogenized with 10 mL of deionized water. Samples were then centrifuged for 15 minutes at 3500 rpm in a Sorvall RT6000B centrifuge. Into new test tubes, 100 μL of the supernatant was extracted and 100 μL of a tryptamine reagent (concentration of 10 mM tryptamine hypochloride in 0.1M HCl) was added to each test tube along with 3 mL 36% HCl. For the standards, a series of fructose solutions were made using serial dilutions ranging from 0 to 1000 μg/mL. All samples and standards were then placed in a 60°C water bath for 15 minutes. The samples and standards were then allowed to stand for forty minutes and then the absorbance was read at 520 nm with Finstruments Microplate Reader, 110 voltage (Model 314, McLean, VA) in triplicate using deionized water as the blank [31]. Fructose was determined from the calibration curve created from the standards ($y=0.0008x - 0.0525$, $R^2=0.98528$).

Glucose

Glucose was estimated from the reducing sugars assay developed by Miller et al. [32]. Ten grams of berries were homogenized with 10 mL of deionized water. Samples were centrifuged for 15 minutes at 3500 rpm in a Sorvall RT6000B centrifuge. Dinitrosalicylic acid, sodium sulfite, and sodium hydroxide were combined to make the 1% dinitroslicylic acid reagent solution [32]. A series of standards using a serial dilution were made with glucose with concentrations ranging 0 – 1000 μg/mL. All samples, standards and blank were heated in a 90°C water bath for 15 minutes to yield a red-brown color. After heating, 300 μL of 40% potassium sodium tartrate solution was added to all samples, standards and blanks to stabilize the color. The solutions were allowed to stand at room temperature for 30 minutes and then the absorbance was read at 560 nm with a Finstruments Microplate Reader, 110 voltage (Model 314, McLean, VA) in triplicate. Glucose concentration was determined from the linear regression created from the standards ($y=0.0006x - 0.0315$, $R^2=0.9923$).

Statistical analysis

Statistical analysis was conducted with Graph Pad Prism Version 6.0f. The independent t-test was used to determine differences in soilless and soil grown berries, with a significance level set at $p<0.05$. Results are expressed as mean ± standard deviation (SD).

Results

Brix and moisture content

The results for the moisture content and Brix are shown in Table 1 and illustrated in Figure 1 and Figure 2. Both the soil strawberries and raspberries had a significantly higher Brix value compared to the soilless strawberries and raspberries. The soil grown strawberry had a Brix value 28% higher compared to the soilless strawberry. The raspberry grown in soil had a Brix value 31% higher than the soilless raspberry. There were no significant differences between the percent moisture content between soilless strawberries and raspberries.

Ascorbic acid, α-tocopherol, and total polyphenolic compounds

For ascorbic acid, α-tocopherol and total polyphenolic compounds analyzed, soilless grown strawberries were significantly higher compared to soil grown strawberries ($p<0.05$). For the raspberries, soil grown berries had higher amounts of bioactive compounds compared to the soilless grown raspberries (Table 2, Figure 3, Figure 4 and Figure 5).

Ascorbic acid content for the soilless grown strawberries contained 74% more compared to the content found in soil grown strawberries. The soilless grown raspberries contained 14% less ascorbic acid content compared to the soil grown raspberries. The α-tocopherol content of soilless grown strawberries was 53% higher compared to the soil grown strawberries. The soil grown ascorbic acid content of raspberries compared to the ascorbic acid content of soilless grown raspberries was a 7% higher amount but was not significant, $p>0.05$. A significant difference was observed in total polyphenolics, with soilless grown strawberries having significantly higher amounts of total polyphenolics and soilless grown raspberries having significantly less total polyphenolics. The soilless grown strawberries contained 22% higher amounts of total polyphenolic compounds compared to the soil grown strawberries. The opposite trend was seen with the raspberries. The soilless grown raspberries contained 23% less compared to the soil grown raspberries.

Fructose and glucose

Fructose and glucose results are illustrated in Figures 6 and 7. The results indicated soil grown strawberries and raspberries contained significantly higher amounts of sugars compared to the soilless grown fruit. The soil grown strawberry contained 75% higher amount of fructose than the soilless grown strawberry. The soil grown raspberry contained 102% higher amount of fructose compared to the soilless grown raspberry. The soil grown strawberries contained 158% higher amount of glucose compared to the soilless grown strawberries. The raspberries showed a similar trend with the soil grown raspberry containing 175% higher amount of glucose compared to the soilless raspberry.

Discussion

Strawberries grown in soilless conditions have higher amounts of bioactive compounds compared to strawberries grown in soil, similar to those who compared bioactive production in produce (Buchanan & Omaye, 2013; Claudia Kiferle, Mariella Lucchesini, Anna Mensuali-Sodi, Rita Maggini & Pardossi, 2011; Palermo, Paradiso, De Pascale, & Fogliano, 2012; Premuzic, Bargiela, Garcia, Rendina, & Iorio, 1998a). However, bioactive compound contents of raspberries were equal to or greater than soil grown raspberries agreeing with others [10, 11], reiterating that the nutrient density of plants grown by soilless systems is likely highly dependent on the cultivar of interest, environmental conditions (i.e., water stress) and fertilizer bioavailability.

Differences in ascorbic acid may be due to the amount of oxidative stress the plant endures, e.g. ascorbic acid in the biologically active role as an antioxidant. Soilless systems optimize growing conditions, therefore, soilless grown plants are less likely to undergo oxidative stress endured by environmental causes [33]. Ascorbic acid and α-tocopherol work together for antioxidant protection. When tocopherol is oxidized to the tocopheroxyl radical, ascorbic acid can donate electrons to rejuvenate α-tocopherol. Because of the interaction between ascorbic acid and tocopherol, concentration changes in one should be reflective of concentration changes in the other. Lighting (i.e., shading) and fertilizer application can affect ascorbic acid production in plants. Ascorbic acid is created during photosynthesis, however, both of our plant growing systems had the same exposure to light therefore it is more likely the causes were induced by differences in nutrient content. Soilless and soil grown systems are fundamentally different, with soilless having more nutrients bioavailable to the plants all the time.

In agreement with our findings previous research has expressed higher rates of fertilizer increased ascorbic production at the expense of decreasing carbohydrates in the plants [34]. In our soilless system, strawberries, had significantly higher amounts of ascorbic acid but lower amounts of fructose and glucose ($p<0.05$). Another possible reason for the lower sugar content in the soilless plants compared to soil plants is the potential for higher osmotic pressure in soil plants, increasing the sugar content of the plants. This can commonly occur when plants are drought stressed since plant survival largely depends on carbohydrates [13]. Although our plants were never intentionally drought stressed, it is possible that compared to the soilless plants, which were continuously immersed in water, they may have endured some degree of drought stress with being watered three times weekly. Previous research has indicated a relationship to fertilization and nutritional outcomes in the crop [35–39]. Both soil and soilless fertilization concentration was checked using portable ppm meters. The average of the soilless grown strawberries averaged around 400 ppm, and the soil grown plants averaged around 600 ppm. The soilless grown raspberries averaged about 500 ppm and the soil grown plants averaged about 600 ppm, which may influence the differences in nutritional variation within the produce.

Conclusion

Other research has shown a difference between soilless growing systems and nutritional content of the plant [40]. In order to optimize plant production as well as provide a nutrient dense crop, more research should be conducted to determine the best methods for strawberry and raspberry production. Further research should evaluate feasibility as well as nutritional value of soilless raspberries. We have seen that soilless strawberries have the potential to provide a superior nutrient dense crop compared to soil grown plants. The soilless system has many environmental benefits to provide sustainable food in arid or urban regions. This, added with superior nutrition quality, may contribute significantly to environmental and public health issues we are currently facing.

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We thank Eric Horton for greenhouse technical and maintenance assistance. We thank Kevin Hong for laboratory assistance. We acknowledge the Nevada Agricultural Experiment Station, University of Nevada, Reno for the support of this study. HATCH #0745. The research was done and reported to partially fulfill dissertation requirement of C. Treftz.

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Table 1. Brix measurement and % moisture content (mg/100 g) of soil and soilless berries (mean ± SD)

	Soilless Strawberries	Soil Strawberries	t	p
Brix (%)	7.5 ± 0.18	9.6 ± 0.23	7.09	<.0001
% moisture	90.74 ± 1.06	89.3 ± 0.88	1.05	0.34
	Soilless Raspberries	Soil Raspberries	t	p
Brix	11.7 ± 0.47	8.9 ± 0.25	5.28	<.0001
% moisture	86.4 ± 0.61	85.8 ± 0.98	0.55	0.61

N = 3 with 3 replicates

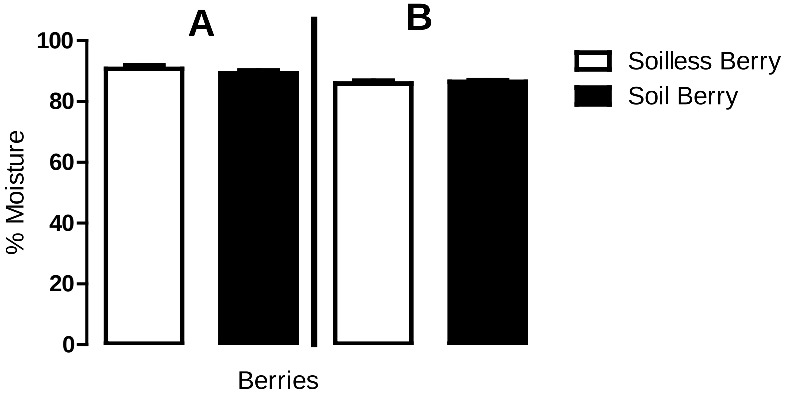

Figure 1. Percent moisture. 'A' indicates soil-grown and soilless-grown strawberries. 'B' indicates soil-grown and soilless-grown raspberries. Star (*) indicates significant differences.

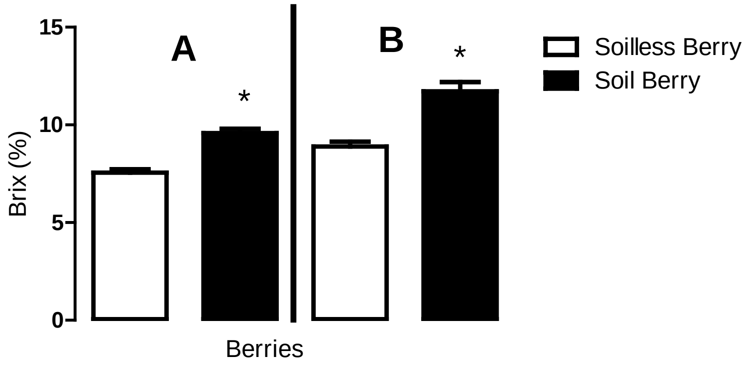

Figure 2. Brix %. 'A' indicates soil-grown and soilless-grown strawberries. 'B' indicates soil-grown and soilless-grown raspberries. Star (*) indicates significant differences.

Table 2. Ascorbic acid, tocopherol and total phenolic content (mg/100 g) of soil and soilless berries (mean ± SD)

	Soilless Strawberries	Soil Strawberries	t	p
Ascorbic Acid	37.62± 0.49	21.52 ± 0.95	15	<.0001
α-tocopherol	2.19 ± 0.12	1.40 ± 0.05	6.05	<.0001
Total phenolics	317 ± 2.35	259 ± 1.97	18.76	<.0001
	Soilless Raspberries	Soil Raspberries	t	p
Ascorbic Acid	31.47 ± .074	36.74 ± 0.97	4.3	.0006
α-tocopherol	1.90 ± 0.85	1.78 ± 0.19	6.05	0.53
Total phenolics	622 ± 20.06	818 ± 19.28	7.03	<.0001

N = 3 with 3 replicates

Figure 3. Ascorbic acid concentration. 'A' indicates soil-grown and soilless-grown strawberries. 'B' indicates soil-grown and soilless-grown raspberries. Open bar shows soilless-grown berries and dark bar shows soil-grown berries. Star (*) indicates significant differences.

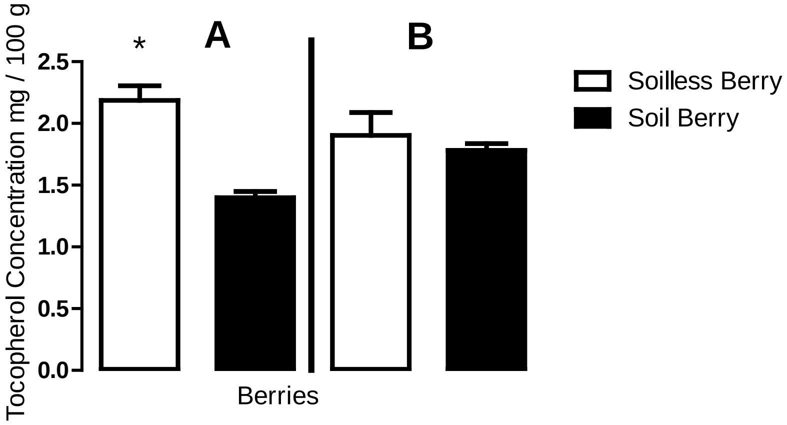

Figure 4. α-Tocopherol concentration. 'A' indicates soil-grown and soilless-grown strawberries. 'B' indicates soil-grown and soilless-grown raspberries. Star (*) indicates significant differences.

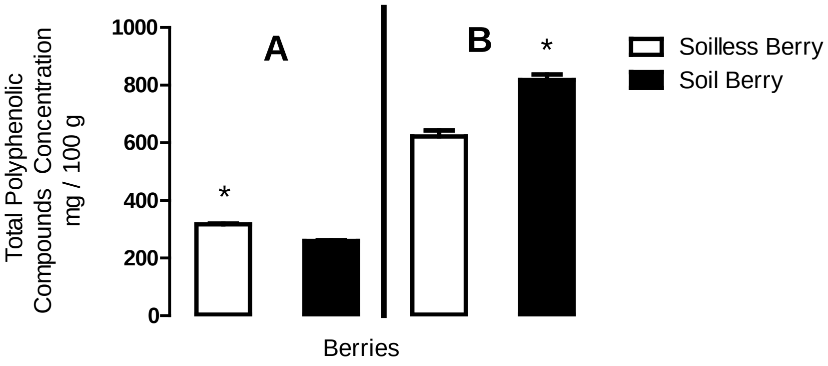

Figure 5. Total polyphenolic compound concentration. 'A' indicates soil-grown and soilless-grown strawberries. 'B' indicates soil-grown and soilless-grown raspberries. Open bar shows soilless-grown berries and dark bar shows soil-grown berries. Star (*) indicates significant differences.

Table 3. Fructose and glucose content (mg/100 g) of soil and soilless berries (mean ± SD)

	Soilless Strawberries	Soil Strawberries	t	p
Fructose	2.76 ± 0.43	4.83 ± 0.28	7.29	<.0001
Glucose	1.71 ± 0.03	4.42 ± 0.07	33.1	<.0001
	Soilless Raspberries	Soil Raspberries	t	p
Fructose	3.48 ± .096	7.04 ± 0.044	33.8	<.0001
Glucose	3.02 ± 0.16	1.10 ± 0.15	8.87	<.0001

N = 3 with 3 replicates

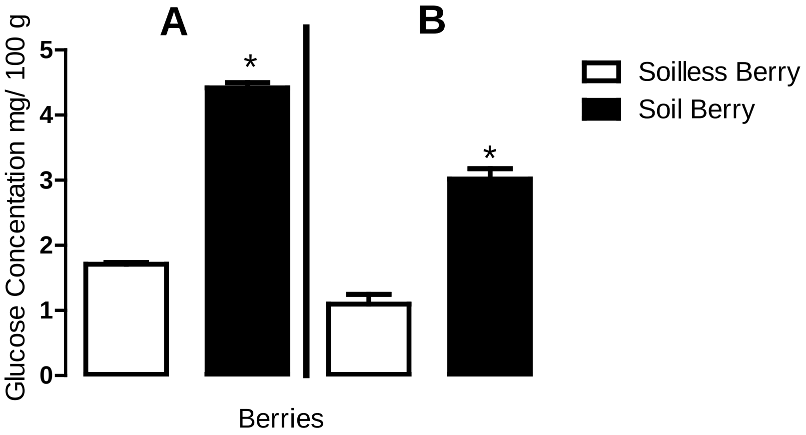

Figure 6. Glucose concentration. 'A' indicates soil-grown and soilless-grown strawberries. 'B' indicates soil-grown and soilless-grown raspberries. Star (*) indicates significant differences.

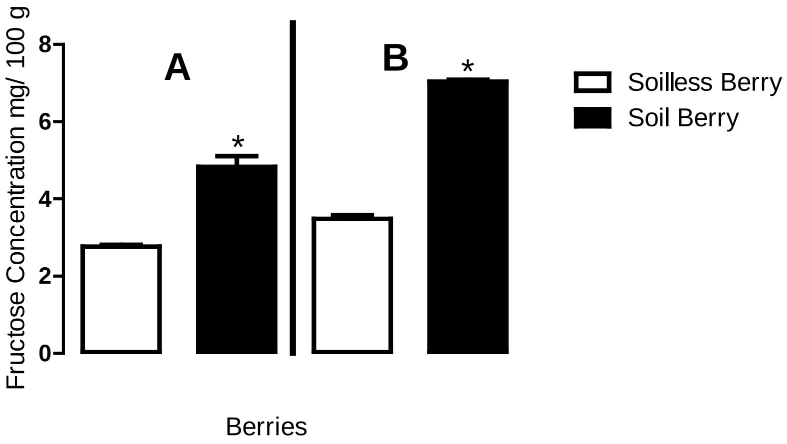

Figure 7. Fructose concentration. 'A' indicates soil-grown and soilless-grown strawberries. 'B' indicates soil-grown and soilless-grown raspberries. Star (*) indicates significant differences.

Chapter 5

Hydroponic Strawberry Sensory Study

Published in Part as

Comparison between hydroponic and soil-grown strawberries: Sensory attributes and correlations with nutrient content

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In

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Abstract

Hydroponic growing methods are growing in popularity and seem to have numerous benefits (i.e., environmental, increased product yields, year round growing) compared to soil grown crops. Although these advantages are attractive, they do not guarantee a high quality product. Taste is a driver of consumer acceptance. Therefore, sensory analysis of the hydroponic product will be an important indicator in its success. In this study we evaluated the sensory differences and preferences in hydroponically grown and soil-grown strawberries (F*ragaria x ananassa*) using unspecified discriminatory and preference analyses, and descriptive testing correlated with nutrition content data. Most (87%) of participants could identify differences between hydroponically and soil-grown strawberries. The nutrient composition of the strawberries significantly influenced several sensory analysis categories (sweetness, overall flavor and overall taste ($p<.05$)). The use of sensory studies in relation to consumer acceptance and nutrient quality will be an important factor to consider for exploring growing methods and techniques in hydroponic technology.

Introduction

Consumers are becoming more aware of nutritious and sustainable food options. Soilless grown fruits and vegetables have been gaining momentum and have caught the attention of many producers, consumers and scientists because of the plethora of benefits offered by soilless growing methods [1]. Hydroponics is one type of soilless growing method. Among others, are aquaponics, aeroponics and fogponics. For soilless products to be successful, the environmental, nutritional quality and sensory attributes must be equal to or better than soil grown produce. From an environmental perspective, soilless food production offers increased yields, higher plant survival rates, decreased water use and decreased pesticide use. From a producer standpoint, these environmental benefits offer greater profits resulting from increased yields and decreased use of resources (i.e., water, pesticides, labor). Nutritionally, some studies have indicated that soilless growing methods have superior nutritional quality, while others indicate no significant differences [2–4].

Few studies have investigated the sensory comparison between hydroponically grown produce and soil grown produce. Sensory evaluation can be affected by several factors such as genetic composition, pre-harvest factors (light, temperature, moisture and wind) and post-harvest factors [5–7]. Other influences (price, branding and the mood of the consumer) have been shown to affect the sensory evaluation of a product [8–10]. All of these are important factors to consider when evaluating a hydroponically grown product for sensory attributes. Previous sensory analyses of hydroponically grown produce have predominately focused on lettuce or tomatoes. Some of these studies indicate higher ratings for hydroponically grown produce, while others indicate no significant differences. Little research has focused on sensory evaluation of hydroponically grown strawberries. Strawberries are rich in health promoting bioactive compounds and the consumption of them is associated with decreased risk for obesity, cardiovascular disease and certain types of cancer [11, 12].

The goal of this study was to evaluate the sensory differences in hydroponically grown and soil grown strawberries (F*ragaria x ananassa*). First, unspecified discriminatory and preference tests were conducted. Then, descriptive evaluation of 13 sensory attributes between the hydroponic and soil grown strawberries were conducted to determine if an association existed with nutritional composition of the strawberries.

Methods

Growing conditions

The growing conditions have been described previously [3]. Briefly, soil and hydroponically grown strawberries were grown at the University of Nevada, Reno (UNR) Experimental Station. During the growing season, the greenhouse temperature was kept at 70°F during the day and 60°F at night. The humidity averaged at 30%. Hydroponic and soil strawberries were randomized within the available space in the greenhouse. Soil grown strawberries were planted in a 1:1 ratio of Miracle-Gro® potting soil (Maryville, OH) and Nevada top soil. The strawberries were watered by a drip irrigation system three times weekly. General

Hydroponics Flora Series (Sebastopol, CA) was the nutrient solution used for the hydroponic strawberries and nutrient ratios were adjusted according to the manufacturer instructions during different stages of plant development. The pH and parts per million concentration (ppm) of the nutrient for the strawberries was maintained between 6.0 – 6.4 and 400 ppm, respectively. These strawberries were adjusted three times weekly, as needed.

Harvesting and sample preparation

Strawberries were harvested between 7 AM and 8 AM for consistency by hand when they reached 100% visual red surface color. The strawberries were placed in a plastic laboratory bag and immediately transported to the UNR sensory laboratory. UNR sensory evaluation booths were designed according to the American Society of Testing Materials standards. The sensory evaluation laboratory booths were 34” x 60” x 72” and were designed to ensure participation privacy during testing. These booths were built with an 11” sliding door serving hatch to serve participants.

The strawberries used for sensory evaluation were harvested on the same day they were evaluated by participants. These strawberries were rinsed with tap water before serving and allowed to dry on a paper towel. Berries were served at room temperature in two ounce, clear plastic cups coded with a three digit random number. The average sample size for each portion was bite size, approximately 10 grams.

Participant selection

The study was approved by the UNR Institutional Review Board (project number: 583149-1). Participants were untrained in sensory evaluation and were undergraduate or graduate students at UNR. Participants were recruited through word of mouth as well as undergraduate nutrition classes and asked to come to the UNR sensory analysis laboratory to give their preferences on locally grown strawberries.

Surveys for sensory evaluation

Unspecified discriminatory tests, unspecified preference tests, and descriptive tests using 13 descriptive attributes were used to evaluate the strawberries. The discriminatory test used to determine a difference in the strawberries was the tetrad test. The students were presented with four samples (two hydroponically grown strawberries and two soil grown strawberries) and were asked to group the samples into two groups of two based on similarity. The tetrad test offers advantages compared to other discriminatory tests because it allows for increased statistical power explained by the Thurstonian theory [13]. The tetrad also has advantages because it decreases effect size and reduces unexplained variations within the samples, therefore using less panelists and samples [13].

Preference tests were conducted after the discriminatory test was completed. Volunteers participating in the preference tests were given two coded samples (one hydroponically grown berry and one soil grown berry). The participants were asked to circle the sample they preferred, or to circle ‘no preference’ if they did not have a preference between the two samples.

Descriptive analysis was conducted using a 5-point hedonic scale using a 'smiley face' which depicted cartoon faces with smiles to frowns [14]. The cartoon faces were labeled from 'very satisfied' to 'vey unsatisfied'. The following attributes were evaluated: overall color, color uniformity, overall appearance, overall aroma, aroma intensity, amount of sweetness, amount of sourness, fruit juiciness, overall taste, fruit firmness, overall texture, overall mouthfeel and overall flavor.

Statistical analysis

Data for the tetrad and preference tests were analyzed using IBM SPSS Statistics®, version 23.0 (IBM, Armonk, New York, USA). Data for the correlation analysis were analyzed using SAS®, version 9.4 (Cry, N.C., USA). The tetrad test was analyzed by calculating the test statistic (d') and used to determine the effect size [15]. A d' of 1 can be considered as a threshold value for psychophysics [16]. Sample sizes for the tetrad test was calculated at α- level = 0.05 and power = 0.8 [17]. Preference tests were first evaluated by chi-square analysis and then by binominal statistics. Descriptive tests were first compared using the independent t-test (p<.05) and correlated to existing nutritional data ordered linear regression. Results were adjusted for sex, age, ethnicity, and fresh strawberry consumption.

Results

Discrimination test

Sensory evaluation for the discrimination determined if volunteers could detect an overall difference between hydroponically and soil grown strawberries. Descriptive characteristics for all tests are outlined in Table 1. The panel included

15 participants, aged 17 – 64 with the majority of volunteers between the ages 17 – 29. Results indicated, out of 15 participants, 87% completed the questionnaire correctly. Typically a d’ of greater than 1.0 indicates consumers can discriminate between the two products. By using the Thurstonian theory, a d’ was calculated at 2.0, and with a threshold of d’=1.0, the majority of participants were generally able to discriminate between hydroponically and soil grown strawberries.

Preference test

Preference test data results are outlined in Table 2. The chi-square was first used to determine significance in distributions between prefer hydroponic, prefer soil and no preference (p<.05). Zero participants chose the ‘no preference’ option and binomial statistics were used to determine significance between preference for hydroponically grown strawberries and soil grown strawberries. However, the preference was not significantly different (p = 0.06).

Descriptive test

The results for the descriptive tests between hydroponically and soil grown strawberries are outlined in Table 3. Of the 13 attributes studied, overall aroma and aroma intensity were the only attributes that reached statistical significance (p<.05). Hydroponically grown strawberries showed higher mean ratings for these two categories. Among the other 11 attributes assessed, nine of the attributes showed higher mean scores for hydroponically grown strawberries compared to soil grown strawberries. Overall appearance and fruit firmness showed higher ratings for soil grown strawberries compared to hydroponically grown strawberries; however, results were not significant.

Correlation between sensory analysis data and nutrient

Methods and quantification of nutrient composition of the soil and hydroponically grown strawberries have been previously reported [3]. Additional nutrient data was collected for matching the correlational analysis. The updated results are reported in Table 4. It was assumed the nutrient data matched the sample for sensory analysis. For the soil grown strawberries, the correlational analysis indicated no significant association between sourness, appearance, aroma, color uniformity, fruit firmness, overall mouthfeel, fruit juiciness, or overall texture (Table 5). Significant associations were observed with amount of sweetness and ascorbic acid, α- tocopherol, % moisture and Brix. Aroma intensity and overall color were significantly correlated with ascorbic acid. Overall flavor was significantly associated with ascorbic acid, α- tocopherol and percent moisture. Overall taste was significantly associated with ascorbic acid and α- tocopherol. For the hydroponically grown strawberries, the correlational analysis indicated no significant association between sourness, appearance, aroma, aroma intensity, color, color uniformity, fruit firmness, fruit juiciness, or overall texture (Table 6). Significant observations were observed with amount of sweetness and moisture content, overall mouthfeel and glucose. Overall taste and α- tocopherol, percent moisture and fructose were also significantly associated.

Discussion

Hydroponic growing methods are growing in popularity because of the numerous environmental benefits of soilless methods compared to soil grown crops [1]. Although there are numerous benefits to the hydroponic system, it does not automatically guarantee a high quality product. As this technology is advancing, it is important to consider the sensory attributes of the hydroponic product since taste is one of the main drivers of consumption [18]. Our study indicated 87% of the participants could correctly identify unspecified differences between hydroponically and soil grown strawberries. Since our participants were untrained, it can be assumed that consumers, in general, may also be able to identify unspecified differences. Unspecified preference tests indicated that the results were not significant ($p=0.06$). Additionally, the majority of the sensory analysis categories indicated higher ratings for hydroponically grown strawberries, but significance was reached only with aroma and aroma intensity. Our study sample was limited to students enrolled in classes at UNR and the majority of study participants were between the ages of 18 – 29 years old. Larger studies from the general population should be conducted with a random sample to diversify the demographics and make the results more generalizable.

The correlational analysis showed several significant associations with the amount of sweetness in soil and hydroponic strawberries. Additionally, significant associations were observed with overall flavor and overall taste with soil grown strawberries and overall taste with hydroponic strawberries. Although there is a high level of variability in consumer acceptance and preference with fruit, it is essential to identify key sensory properties that drive preference. In the correlational analysis, it appears sweetness, flavor and taste correlated with several nutrients and sensory ratings. The results indicate the nutritional composition of the berry may influence sensory scores. With hydroponic food production, it is possible to change parameters in the solution to encourage the plant development of sugars or bioactive compounds. Identification of nutrition factors driving sensory ratings may aid in the development in hydroponic produce production. Additionally, researching these factors in future studies will be important in determining the success of the hydroponic product.

Although this study shows significant findings for nutrient and descriptive sensory data, it is limited with the use of untrained panelists. Untrained panelists are generally considered to be less accurate than trained panelists when using descriptive testing, since they are not oriented to the sensory attributes of interest and there will likely be high variability in the data [19]. However, recent research has suggested this variation might not be as large as previously thought and indicated untrained panelists may be appropriate for descriptive testing [20]. Additional research should be conducted with trained panelists to confirm the findings of this study.

Conclusion

Findings from this study suggest that consumers do not have significant preference between hydroponic and soil grown strawberries. However, due to the small sample size, further research should be conducted with larger panels of different demographics to verify findings. With the environmental benefits of hydroponic produce production combined with the favorable descriptive sensory analysis ratings, it may be desirable to the consumer and beneficial to the environment to grow strawberry cultivars in non-arable regions to provide fresh fruit. However, much more research should be done to determine the optimum feasibility as well as methods to improve sensory evaluation scores.

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Table 1. Demographics of participants participating in the discrimination test, preference test and descriptive test

	Tetrad Test (N = 15)	
	Number	**Percent**
Sex		
Male	7	47
Female	8	53
Age		
17-29	7	47
30-49	7	46
50-64	1	7
65+	0	0
Fresh Berry Consumption		
More than once per day	0	
Once a day	0	
Two to four times per week	3	20
At least once per week	5	33
Once per month	7	47
Rarely	0	
Ethnicity		
American Indian	0	0
Asian	4	27
African American	0	0
Hispanic	3	20
White	8	53
Other	0	0
	Preference Test (N = 20)	
	Number	**Percent**
Sex		
Male	8	40
Female	12	60
Age		
17-29	11	55
30-49	6	30
50-64	2	10
65+	1	5
Fresh Berry Consumption		
More than once per day	1	5
Once a day	0	0
Two to four times per week	3	15
At least once per week	7	35
Once per month	5	25
Rarely	4	20
Ethnicity		
American Indian	1	5
Asian	4	20
African American	0	0
Hispanic	2	10
White	13	65
Other	0	0
	Descriptive Survey (N = 20)	
	Number	**Percent**
Sex		
Male	9	45
Female	11	55
Age		
17-29	15	75
30-49	3	15
50-64	1	5
65+	1	5
Fresh Berry Consumption		
More than once per day	1	5
Once a day	2	10
Two to four times per week	3	15
At least once per week	10	50
Once per month	3	15
Rarely	1	5
Ethnicity		
American Indian	0	0
Asian	4	20
African American	1	5
Hispanic	6	30
White	9	45
Other	0	0

Table 2. Preference test results between hydroponically grown berries and soil grown berries

	Number	Preferred Hydroponically Grown	Preferred Soil Grown	Proportion preferred hydroponic	p
Strawberries	20	14	6	70%	0.06

Table 3. Sensory analysis results of hydroponically compared to soil grown strawberries

	Hydroponically Grown	Soil Grown	t	p
Overall Color	3.7 ± 0.2	3.3 ± 0.2	1.4	0.163
Color Uniformity	3.8 ± 0.2	3.6 ± 0.2	1.2	0.235
Overall Appearance	3.5 ± 0.2	3.4 ± 0.3	0.3	0.758
Overall Aroma	4.6 ± 0.1	3.3 ± 0.2	4.8	<.001
Aroma Intensity	4.3 ± 0.1	3.1 ± 0.2	4.4	<.001
Amount of Sweetness	3.7 ± 0.2	3.8 ± 0.2	0.3	0.725
Amount of Sourness	3.7 ± 0.1	3.6 ± 0.2	0.6	0.547
Fruit Juiciness	4.4 ± 0.2	4.0 ± 0.2	1.6	0.100
Overall Taste	3.8 ± 0.2	3.7 ± 0.2	0.2	0.734
Fruit Firmness	3.9 ± 0.2	4.1 ± 0.2	0.6	0.517
Overall Texture	4.2 ± 0.2	4.0 ± 0.2	0.6	0.541
Overall Mouth feel	3.9 ± 0.2	3.8 ± 0.2	0.6	0.580
Overall Flavor	4.0 ± 0.2	3.6 ± 0.2	1.1	0.194

Means ± standard deviations are based 20 judges' scores on 5-point hedonic scale (5 = very satisfied, 4 = satisfied, 3 = neutral, 2 = unsatisfied, 1 = very unsatisfied)

Table 4. Selected nutrients, Brix and % moisture content of soil and hydroponic strawberries (mean ± SD)

	Hydroponic Strawberries	Soil Strawberries	t	p
Brix (%)	7.6 ± 0.29	8.5 ± 0.23	1.39	0.17
% moisture	86.9 ± 1.36	88.6 ± 0.61	1.36	0.18
	Hydroponic Strawberries	Soil Strawberries	t	p
Ascorbic Acid (mg/100g)	32.32± 1.27	18.62 ± 0.92	8.82	<.0001
α-tocopherol (mg/100g)	1.80 ± 0.12	0.99 ± 0.10	5.11	<.0001
Total phenolics (mg/100g)	344 ± 6.72	268 ± 2.90	18.76	<.0001
	Hydroponic Strawberries	Soil Strawberries	t	p
Fructose (g/100g)	2.89± 0.06	5.10 ± 0.15	14.27	<.0001
Glucose (g/100g)	1.67 ± 0.03	4.43 ± 0.06	36.92	<.0001

N = 20 with 3 replicates

Table 5. Soil grown strawberries sensory ratings vs. nutritional attributes (odds ratio point estimates)

Nutrient	Sourness	Pr>Chi Sq	Overall appearance	Pr>Chi Sq	Sweetness	Pr>Chi Sq	Aroma	Pr>Chi Sq	Aroma intensity	Pr>Chi Sq	Color	Pr>Chi Sq
Ascorbic Acid	0.857	0.2744	1.234	0.1356	0.595	0.022	0.801	0.1338	0.677	0.0254	1.996	0.0064
Tocopherol	0.035	**	0.473	0.4978	0.003	0.0101	0.325	0.3268	0.129	0.0999	10.062	0.0704
Total Phenolics	1.029	0.5545	1.113	0.0568	1.141	0.0612	1.049	0.3443	1.072	0.1719	1.007	0.8806
Moisture	0.871	0.5433	1.138	0.5502	2.293	0.015	0.886	0.5876	1.183	0.4586	1.006	0.9782
Glucose	0.08	0.2906	1.225	0.9253	0.158	0.4468	12.544	0.2807	4.355	0.5131	1.891	0.7723
Fructose	2.547	0.365	3.344	0.2211	0.253	0.1991	1.004	0.9966	0.431	0.3927	0.654	0.6488
Brix	0.942	0.805	1.37	0.203	0.535	0.0408	0.694	0.1572	0.779	0.3024	2.166	**

Table 5 cont.

Nutrient	Color Uniformity	Pr>Chi Sq	Overall flavor	Pr>Chi Sq	Fruit firmness	Pr>Chi Sq	Overall Mouthfeel	Pr>Chi Sq	Fruit Juiciness	Pr>Chi Sq	Overall Taste	Pr>Chi Sq	Texture	Pr>Chisq
Ascorbic Acid	44.35	0.3999	0.654	0.0476	0.95	0.7197	0.836	0.2193	1.037	0.8092	0.563	0.039	0.915	0.5411
Tocopherol	93.955	0.0681	0.005	0.0107	0.427	0.4599	0.016	**	1.245	0.8608	0.004	0.0138	0.035	**
Total	0.923	0.292	1.035	0.530	0.954	0.349	1.075	0.186	0.995	0.927	1.052	0.448	1.061	0.2758

Phenolics		2		5		9		7		9		4		
Moisture	0.831	0.5106	3.006	0.0219	1.434	0.2269	1.286	0.294	0.506	0.0726	1.259	0.3928	1.238	0.3812
Glucose	8.811	0.4019	5.898	0.4825	0.052	0.2169	0.314	0.6197	199.339	0.0894	2.031	0.7813	0.058	0.2606
Fructose	<0.001	0.1682	3.945	0.2599	3.951	0.2217	36.503	**	0.406	0.3814	4.477	0.2685	16.444	0.0546
Brix	2.962	0.1754	1.315	0.2964	1.427	0.1746	1.093	0.7161	0.749	0.2918	1.128	1.853	1.107	0.6797

** indicates p>.05, globe model is not significant

Table 6. Soil grown strawberries sensory ratings vs. nutritional attributes (odds ratio point estimates)

Nutrient	Sourness	Pr>Chi Sq	Overall appearance	Pr>Chi Sq	Sweetness	Pr>Chi Sq	Aroma	Pr>Chi Sq	Aroma intensity	Pr>Chi Sq	Color	Pr>Chi Sq
Ascorbic Acid	1.06	0.616	0.87	0.1981	0.89	0.3242	1.08	0.6587	0.94	0.5455	0.90	0.293
Tocopherol	8.80	0.1822	0.18	0.2521	0.09	0.125	0.90	0.9566	0.44	0.5824	0.14	0.2146
Total Phenolics	0.97	0.1794	1.01	0.6031	0.98	0.4775	1.00	0.9027	0.98	0.4405	1.02	0.4413
Moisture	0.62	0.1756	1.82	0.1278	1.93	0.0219	3.68	0.6137	75.84	0.4572	1.21	0.4208
Glucose	43.74	0.5573	*	0.3273	0.19	0.7595	*	0.6764	12.82	0.6889	*	0.2318
Fructose	0.45	0.8136	*	0.069	116.29	0.2195	*	0.539	4.81	0.6459	*	0.3293
Brix	1.12	0.8486	0.48	0.2759	0.14	0.0567	1.58	0.6747	*	0.3557	2.166	**

Table 6 cont.

Nutrient	Color Uniformity	Pr>Chi Sq	Overall flavor	Pr>Chi Sq	Fruit firmness	Pr>Chi Sq	Overall Mouthfeel	Pr>Chi Sq	Fruit Juiciness	Pr>Chi Sq	Overall Taste	Pr>Chi Sq	Texture	Pr>Chisq
Ascorbic Acid	0.23	0.1088	0.69	**	1.04	0.6835	0.91	0.3975	0.53	0.0678	0.82	0.0852	0.84	0.1933
Tocopherol	*	0.244	*	0.105	0.50	0.5736	0.08	0.1178	*	0.065	0.01	0.0263	0.12	0.2086
Total Phenolics	1.00	0.9202	1.30	0.2075	1.01	0.6938	1.03	0.2886	1.04	0.1425	1.03	0.2587	1.03	0.2863
Moisture	17.96	0.097	1.43	**	1.23	0.1577	1.32	0.0925	1.38	0.0562	1.86	0.008	1.20	0.258
Glucose	*	0.1314	*	0.1731	*	0.0554	*	0.0431	*	0.1862	0.01	0.417	*	0.1582
Fructose	*	0.1404	*	**	0.02	0.2032	0.85	0.9578	*	**	*	0.0254	2.92	0.7727
Brix	*	0.3928	1.54	0.522	2.30	0.2204	1.46	0.5919	0.37	0.163	0.92	0.9065	0.97	0.9605

* extreme value, model not well fit
** indicates p>.05, globe model is not significant

Chapter 6

Hydroponic Raspberry Study

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Comparison between hydroponic and soil-grown raspberries (*Rubus Idaeus*):

Viability and sensory traits

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Abstract

Raspberries are known to have an abundant amount of the health promoting bioactive compounds, and increasing consumption has been associated with prevention of several chronic diseases. Growing fruits hydroponically compared to soil-grown has several environmental benefits and could be an option of sustainable food production in non-arable regions of the world. This research investigated the viability, unspecified sensory differences, ascorbic acid, tocopherol, total polyphenolic bioactive compounds and catechins of hydroponic raspberries compared to soil-grown raspberries. Overall, plant survival rate for hydroponic raspberries was 2/3 and for soil-grown raspberries it was 4/6. Fruit yield per plant was 10% higher in hydroponic raspberries compared to soil-grown. Sensory evaluation results by untrained participants illustrated that they were unable to differentiate between hydroponic and soil-grown raspberries. Nutritional analysis indicated similar values except for ascorbic acid, which was significantly higher in soil-grown raspberries. Growing raspberries hydroponically is feasible and sensory qualities are equal to soil-grown raspberries. Future research should investigate different methods of growing hydroponic raspberries for higher plant survival rates and eventually to determine if hydroponic raspberries may be grown on a commercial scale.

Introduction

Growing food hydroponically, or without soil, has a positive connotation among consumers and producers because of the purported environmental benefits it can offer (i.e., less use of water, less pesticide use and higher yields) [1]. Growing hydroponic produce is being investigated to determine optimum environmental, nutritional and sensory attributes of the hydroponic product [2–6]. Optimizing growing systems, different types of crops, use of nutrient solution, lighting and other factors will be important when determining the crops that will be successful from environmental, economical, nutritional and sensory perspectives.

Raspberry fruits are a nutrient dense food, high in vitamin C, manganese, fiber, and copper. Additionally, raspberries are high in bioactive compounds that have known antioxidant and anti-inflammatory benefits such as: anthocyanins, flavonols, flavanols, flavonoids, tannins, hydrobenzoic acids, hydroocycinnamic acids, and stillbenoids. The consumption of raspberry fruits are thought to play a role in obesity prevention, the management of blood sugar, and the prevention of cancer by reducing oxidative stress [7, 8].

Previous literature has focused on various hypotheses of growing lettuce, tomatoes, carrots, peppers and strawberries hydroponically [6, 9–13]. With the hydroponic technology being used more frequently, it will be important to determine which crops are suitable to be grown in hydroponic systems. Research on growing hydroponic raspberries in the literature is scant. In addition to the viability of growing raspberries hydroponically, it will also be of interest to address the differences in taste between the hydroponic and soil-grown product since taste is one of the main drivers of consumption. For hydroponic food production to be effective, it must be equal or better to the soil-grown product in terms of environmental benefits, taste preferences and nutritional content. The goal of this one-year study was to investigate the viability, sensory and nutritional differences between hydroponic and soil-grown raspberries. Therefore we determined the differences between product yields, plant survival and mass of the fruit were studied. Additionally, sensory evaluation using an unspecified difference test between the hydroponically grown and soil-grown raspberries was assessed. The raspberries were also evaluated for differences in ascorbic acid, α-tocopherol, total polyphenolic bioactive compounds and catechins.

2. Methods

2.1. Growing methods

Growing methods have been described previously and are outlined in Figure 1 [3]. Hydroponic and soil-grown raspberries were grown at the University of Nevada, Reno (UNR) Experimental Station[3]. Both hydroponic and soil-grown plants were planted in the spring of 2015. Throughout the growing season, the temperature in the greenhouse was kept at 21°C between 5:30 AM to 6:30 PM and 16°C between 6:31 PM to 5:29 AM[3]. The relative humidity was 30%. Bare-root raspberry plants ('Heritage,' *Rubus idaeus)* were ordered from Stark Brothers

Nurseries & Orchard Company (Louisiana, MO). Six raspberries plants were placed in soil conditions according to instructions provided by the nursery. The soil conditions consisted of 1:1 ratio of ratio of Miracle-Gro® potting soil (Marysville, OH) and Nevada topsoil [3]. The bare-root plants were placed in the soil mixture in 50-gallon barrels with drainage holes at the bottom. The raspberries were watered three times weekly for 20 minutes using a drip-irrigation system.

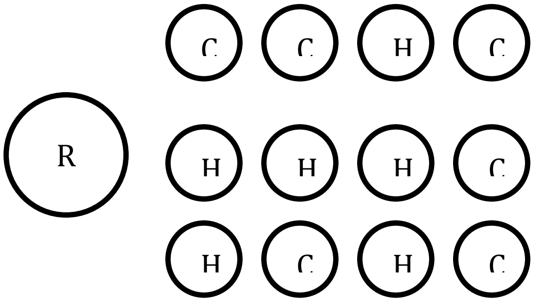

Figure 3: Design for experimental treatments. Schematic illustrates the randomization of the hydroponic (H) and soil-grown (C) growing conditions. Water and nutrient reservoir is indicated by 'R'.

For the hydroponic system, bare-root plants were planted with hydroton (clay pebbles) (Reno, NV) and placed in 19-gallon buckets (United Solutions, Reno, NV). Water was pumped from the water reservoir using 500 gallon per hour Pro Pump (Hydrofarm, Denver, CO) by means of polyvinyl chloride and the drip tubing then distributed water over the hydroton. The 19-gallon buckets had holes drilled in the bottom and were placed on top of fifty-gallon barrels where the water could then drain back into the water reservoir. The pH and parts per million (ppm) was measured using Hanna Instruments 9813-6N waterproof pH/EC/TDS meter (Carrolton, TX). The pH of the water in the reservoir was kept in slightly acidic conditions, between, 5.8-6.2 and adjusted triweekly [3]. The nutrient solution was General Hydroponic Flora Series (Sebastopol, CA) and the concentration averaged at

500 parts per million (ppm). To support the berries, a T-hedgerow system was constructed from polyvinyl chloride.

2.2. Pest management

Pests are prevalent in greenhouse settings since the favorable growing climates provide optimum conditions for breeding and reproduction of the pests. In the UNR greenhouse, spider mites infected the plants. To generally manage the infestation, all plants were sprayed with water three times weekly to prevent dry, hot growing conditions spider mites thrive in. The spray solution was made with one teaspoon of dish soap mixed with one liter of water and sprayed on the plants. The solution was allowed to sit on the plants for 30 minutes, and then thoroughly rinsed with water. This method was used up to once per month and was marginally efficient at controlling the infection on the plants. For a more aggressive approach, PyGanic®(MGK, Minneapolis, MN) was used. PyGanic® is a pyrethrum containing, organic broad-spectrum contact insecticide, sprayed twice a month as spider mites were detected on and around the plants.

2.3. Sensory analysis

Participants in the sensory analysis were undergraduate or graduate students at UNR. The study (project number:583149-1) was approved by the Institutional Review Board. The participants were recruited using an approved recruitment script and asked to taste raspberries. Participant demographics are outlined in Table 1. Eighty percent of the students were female, 73% were between the ages of 17-29 years old. As noted from questionnaires, raspberry consumption of the participants varied between ‘once per day’ and ‘rarely.’ The majority (81%) of the participants were of White ethnicity. The unspecified tetrad test was used to determine if participants could differentiate between the hydroponic and soil-grown raspberries. This method has advantages compared to other discriminatory tests by increasing power and reducing variation among samples as explained by the Thustonian theory [14, 15]. The analysis was conducted in the UNR sensory analysis laboratory on campus. The laboratory was designed according to American Society of Testing Materials standards. The raspberries used for evaluation were harvested on the same day they were sampled by participants. The raspberries were rinsed with tap water and served in a two ounce clear plastic cup coded with a random three digit number.

2.4. Nutritional analysis

2.4.1. Materials and equipment

The raspberries were stored at -70°C Thermo ScientificTM RevcoTM in a high performance lab freezer (ThermoFisher Scientific, Waltham, MA) until ready for nutrient analysis. Raspberries were randomly selected for analysis by hand. Raspberries were rinsed with deionized water to removed dirt residue and allowed to dry on a paper towel before analysis. For all assays and high performance liquid chromatography (HPLC) analysis, a Brinkmann Instruments Polyton homogenizer (Kinematica, Bohemia, NY) was used for homogenization of the raspberries. Chemicals purchased from Fischer Scientific (Fair Lawn, NJ) were: thiourea, copper sulfate, and 85% orthophosphoric acid. Chemicals purchased from Sigma-Aldrich Cooperation (St. Louis, MO) were: sulfuric acid, trichloroacetic acid, 2,4-

dinitrophenylhydrazine, L-ascorbic acid, ferric chloride, xylene, bathophenanthroline, (±)α-tocopherol, Folin-Ciocalteu, catechin, methanol, hydrochloric acid and acetic acid. Absolute ethanol was purchased from pharmco-AAPER, Kentucky.

2.4.2. Ascorbic Acid and Tocopherol analysis

Procedures have been described in detail previously [3, 16]. Briefly, 10 grams (g) of berries were homogenized with 10mL of cold 20% trichloroacedtic acid (TCA). Activated carbon (0.1 grams) was added to the mixture to remove color intensity and the mixture was allowed to sit overnight and then filtered using Whatman no. 2 filter paper [17]. L-ascorbic acid was used to create a stock solution with 5% TCA between 0-120 μg/mL. The liquid after filtering was extracted into new test tubes containing 900 μg/mL 20% TCA and 1mL of a mixture of 2,4 dinitrophenyl-hydrazine (DNPH), thiourea, copper in the presence of sulfuric acid was added to all samples, standards and blank. All tubes were incubated at 37 °C for three hours and then 1.5 mL of 0° Fahrenheit 65% sulfuric acid was added to all samples, standards and blank and allowed to sit for 30 minutes. The absorbance was read at 520 nm. The samples were compared to the linear regression created from the known standards and the reproducibility was measured added by adding a known amount of the sample to determine recovery, which was 113% ± 2.0.

For the tocopherol analysis, 10 g of raspberries were homogenized with ethanol and then 1.2 mL of xylene was added. Samples were centrifuged at 7°C for 20 minutes at

3500 rpm. The organic layer was removed and added to new test tubes with 400 µL of bathophanthroline. Ferric chloride (400 µL) was added to new tubes with 400 µL of orthophorphic acid. Standards with α-tocopherol were made in a similar fashion between 0 – 50 µg/mL for the linear regression to compare the samples [3]. All samples, standards and blanks were read in triplicate at 530 nm [18].

2.4.3. Total Polyphenolics

Ten grams of raspberries were homogenized with 10 mL ethanol. Deionized water (1.58) mL and Folin-Ciocalteu reagent was added to all samples, standards and blanks. Standards were made using the same method with gallic acid ranging from 0 – 300 mg GAE/L [3]. Sodium carbonate (25%) was added to all samples, standards and blank and was incubated at 40°C for 15 minutes and measured at 690 nm [19].

2.4.4. Catechin analysis

Procedures for extraction and detection have been described previously [20]. Ten grams of raspberries were homogenized and extracted with ethanol, water and 0.12 M hydrochloric acid (70:29:1 ratio) for four hours. The extracts were centrifuged and the extracts were purified through a Sep Pak Plus C-18 cartridge (Alltech, Grace Davison, Baltimore, MD). The extract was then diluted in a 1:5 ratio with water and filtered though a 0.45 µm cellulose filter (ThermoScientific, Waltham, MA) after it was washed with water and eluted with 2 mL of methanol. A reverse phase C18 column (Agilent 250x4.6mm) was used for the HPLC system with a visible/UV detection (Agilent HPLC 1100). The samples were processed using ChemStation A10.02 (Agilent Technologies, Folsom, CA) software package. The system was eluted with water, methanol ,and acetic acid to detect the catechins with a flow rate of 0.8 mL min^{-1} with a 20 μL injection volume. Samples were compared against the retention times of the standard and quantified by the linear regression equation created from the standards (R^2=0.99).

3. Statistical analysis

Data were analyzed using IBM SPSS Statistics®, version 23.0 (IBM, Armonk, New York, USA). Differences between masses and nutritional content of the raspberries were determined by the independent t-test. The tetrad test results were analyzed by calculating the d' test statistic. Since d' of 1 is considered the threshold for psychophysics, a d' of less than 1 was considered a value where the majority of students could not tell the differences between the two products. Sample sizes for the tetrad test was calculated at α- level = 0.05 and power = 0.8 [21].

4. Results

4.1. *Viability of raspberries*

Plant survival rates are outlined in Table 2. Soil-grown raspberries had a much higher survival rate (66%) compared to hydroponic raspberries (33%). The raspberry yields and weights are outlined in Table 3. Both plants produced fruit during the months of August and September. However, the hydroponic plants started producing fruit two weeks prior to soil-grown plants. Both of the growing systems stopped producing fruit during the last week of September. During the month of August, the hydroponic raspberries and soil-grown raspberries had similar weights. During September, the hydroponic raspberries had a significantly higher mass compared to the soil-grown raspberries. The yield of raspberries was calculated per surviving plant. Results are shown in Figure 2. Hydroponic raspberries produced 10% more raspberries per plant compared to the soil-grown plant. Overall, the soil-grown plants produced more raspberries because of the higher plant survival rate.

4.2. Sensory analysis

Results for the tetrad test are shown in Table 4. Findings indicate 42% of participants could correctly identify the unspecified differences between hydroponically and soil-grown raspberries. A d' of 0.8 was calculated at the 5% level of significance. From this, it can be concluded that the majority of participants could not discriminate between hydroponically and soil-grown raspberries.

4.3. Nutritional analysis

The results of the nutrient analysis are outlined in Table 5. Ascorbic acid was the only nutrient that showed statistical differences, with the soil raspberry significantly higher amounts ($p<.05$). Tocopherol, total polyphenolic compounds and catechin content were similar in the hydroponic compared to the soil-grown raspberry.

5. Discussion

Growing produce by hydroponic methods is gaining momentum and more consumers are becoming aware of the plentiful advantages of soilless growing. This study showed that hydroponic raspberries yielded a higher number of berries compared to soil-grown plants. However, our overall plant survival rate for both soil and hydroponic conditions was less. Part of our low plant survival rate can be attributed to an aggressive spider mite infection. Low plant survival rate of the hydroponic raspberry plants may be attributed to the growing system and the supports we provided for the plant, which was large and prone to maintenance technicality issues. For instance, the system was prone to leaks and not efficient at adjusting and monitoring pH and ppms because of using a single reservoir. In the future, other growing systems for hydroponic raspberries should be investigated. If hydroponic raspberries could be grown with a high survival rate for several growing seasons, it may be possible to grow hydroponic raspberries on a commercial scale.

A previous study investigating nutritional quality of hydroponic compared to soil-grown raspberries indicated significant differences in sugars, ascorbic acid, and total polyphenolic compounds [3]. These study results were grown in a similar system but during a different growing season. The results in the previous year showed the soil-grown raspberries having higher amounts of ascorbic acid and total polyphenolic compounds. This study showed differences only with the ascorbic acid content and similar nutritional values among the other nutrients studied. Previous literature has indicated nutritional content variation across seasons and factors influencing nutritional composition of a product are multi-variant. Some of these factors include: weather, climate, geographical region, sunlight, and post-harvesting factors [22]. The differences in the current study compared to the nutritional value of the previous study can be attributed to the differences between the two growing years.

Among investigating differences in feasibility, determining the growing system which yields a higher or equal nutritional content compared to soil-grown produce will be important for the success of hydroponic farming. Along with determining nutritional factors, sensory ratings equal to or better than soil-grown produce will be essential, because taste is one of the most important factors a consumer will consider when purchasing and consuming a food product [23]. The participants contributing to the sensory panel for hydroponic compared to soil-grown raspberries were untrained, and study results showed that 42% could discriminate between the different raspberries. From these results, it can be concluded that in general, consumers are not able to differentiate between the two berries. However, more research should be done to confirm these findings. Although our panel sample size was somewhat small (N=113), the tetrad test offers advantages of increased statistical power and requires a smaller sample size compared to the traditionally used triangle test to achieve statistical significance [14, 21]. The tetrad test has a psychometric function that is intermediate between two commonly used sensory tests (i.e., triangle and 3-alternative forced choice test) and because of this, it has been confirmed the tetrad test has a higher power compared to others [21]. The sample size for this study was 113 participants and is large enough to confirm a d’ of 0.85 at a power at 80% [21]. This study is limited in that results cannot be confirmed until the next harvest season. Further, when the study is repeated, larger sample sizes with different demographics should be considered. Our panel was limited to students enrolled at the UNR, and the majority of the participants were female, aged 17-29 and White. Future research should use a larger sample size and a wider demographic to ensure results are generalizable.

6. Conclusion

Sensory evaluations results show student volunteers may not be able to tell the taste differences between the hydroponic and soil-grown raspberries. This could be particularly advantageous in non-arable regions of the world, such as arid or urban regions to produce an attractive and flavorsome product to consumers. Although more research is warranted, growing fruits such as raspberries using hydroponic growing systems in greenhouses can complement sustainable local food production.

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Conflict of Interest

There are no conflicts of interest.

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Table 1. Study participant demographics

	Tetrad Test (N = 113)	
	Number	**Percent**
Sex		
Male	23	20
Female	90	80
Age		
17-29	83	73
30-49	19	17
50-64	10	9
65+	1	<1
Fresh Berry Consumption		
More than once per day	0	0
Once a day	1	<1
Two to four times per week	14	12
At least once per week	11	10
Once per month	39	35
Rarely	48	42
Ethnicity		
American Indian	1	<1
Asian	8	7
African American	8	7
Hispanic	8	7
White	81	72
Other	7	6

Table 2. One-season plant survival rate

	Starting plants (N)	Plants surviving 1 season (N)	% survival rate
Soil-grown Raspberries	6	4	66%
Hydroponic Raspberries	6	2	33%

Table 3. Mass distributions of hydroponic and soil-grown raspberries by month

	Hydroponic Raspberries (N)	Soil Raspberries (N)	Hydroponic Raspberries (g ± SD)	Soil Raspberries (g ± SD)	t	p
August	50	92	2.4 ± 0.08	2.5 ± 0.09	1.02	0.30
September	287	505	2.2 ± 0.07	1.9 ± 0.03	2.24	0.01

Table 4. Unspecified tetrad test results

Number of participants	Number of correct responses	Number of incorrect responses	Proportion correct	d’
113	48	65	43%	0.85

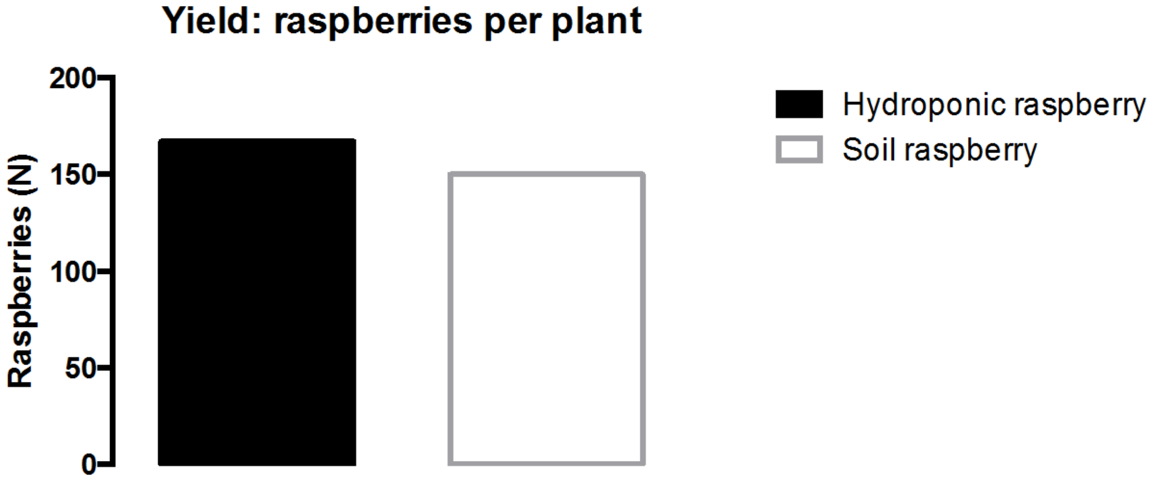

Figure 4. Number of raspberries produced per surviving plant

Table 5. Bioactive compounds in hydroponic and soil-grown raspberries (mg/100g berries)

	Hydroponic Raspberry	Soil Raspberry
Ascorbic Acid	30 ± 1	37 ± 1.5*
α-tocopherol	1.9 ± 0.1	1.8 ± 0.3
Total Polyphenolic Compounds	834 ± 24	820 ± 20
Catechins	1.95	1.90

N = 3 with 3 replicates

* indicates $p<0.05$

Chapter 7

Summary, Conclusions and Recommendations

Summary

Hydroponic reviews

The objective of the reviews was to provide a foundation of the current understanding of hydroponic research whereby we can move forward towards producing food in sustainable systems. Advantages, limitations, nutritional quality and sensory quality of hydroponically grown food were explored. Chief advantages of hydroponic systems are: can grow food year round, grows in arid or urban regions, reduces water usage and does not require traditional farming practices such as tilling. Economically, models have been investigated to determine the viability of growing various crops at the commercial level. Limitations of hydroponics include: high startup cost, dependency on electricity, and the needs for the development of safety standards. Nutritionally, the majority of hydroponic studies have indicated no significant differences between nutritional attributes compared to soil-grown produce. However, outcomes vary based on crop and experimental design of the study.

Of the many advantages to consider for the hydroponic system, these do not guarantee a high quality product. Quality of the hydroponic product will be important when determining the purchase and consumption behaviors of the consumers. Overall, the goal of growing fruits and vegetables hydroponically is a product that is equal to or better than the soil-grown equivalent. Research is warranted to determine the crops, growing systems, and other harvesting factors that play a role in producing a high quality product.

Feasibility of Hydroponic strawberries

This study was conducted to examine the differences of feasibility with hydroponic strawberries compared to soil-grown strawberries as measured by: differences in yields, fruit mass, plant survival rates, start-up costs, maintenance costs, and upkeep times between the two systems. Hydroponic strawberries had a higher individual berry yield and plant survival rate. Soil-grown strawberries showed a significantly higher mass but a wider variation compared the more consistent masses of the hydroponic strawberry.

Nutrient analysis

The goal of this study was to analyze the differences between the nutritional attributes among hydroponic and soil-grown strawberries and raspberries. Hydroponically grown strawberries showed significantly higher amounts of ascorbic acid, tocopherol, and total polyphenolic bioactive compounds but significantly lower amounts of fructose and glucose compared to soil-grown strawberries. Similarly, soil-grown raspberries had higher amounts of fructose and glucose compared to hydroponically grown. These results provide a starting point for future research to strive towards producing nutrient dense crops in sustainable food production systems.

Hydroponic strawberry sensory study

Taste is one of the main drivers of consumption, and for the hydroponic product to be successful it must have equal or better taste compared to soil-grown produce. The goal of this study was to determine the sensory differences and preferences between hydroponically and soil-grown strawberries. Overall, participants could discriminate between the two strawberries. However, the preferences between the two berries were not statistically significant. Correlations between sensory analysis descriptive scores and nutrient analysis data showed the categories of sweetness, overall flavor, and overall taste significant. The use of sensory studies in relation to consumer acceptance and nutrient quality will be important when optimizing hydroponic food production.

Viability of hydroponic raspberries

This study investigated the viability and unspecified sensory differences between hydroponically and soil-grown raspberries. Viability was measured by plant survival rate, yields, and masses of the fruit. Overall, soil-grown raspberries had a much higher survival rate compared to the hydroponically grown raspberries. However, individual raspberry yields per plant were higher for the hydroponic raspberry. Masses of the berries were similar at the beginning of the season; at the end of the season the hydroponic raspberry had a significantly higher weight. Sensory analysis results showed that overall, students could not discriminate between the hydroponic and soil-grown berry.

Conclusion and recommendations

Growing strawberries and raspberries hydroponically may be a feasible option for sustainable food production. Nutritional quality of the hydroponic strawberries and raspberries, in general, were comparable to their soil-grown counterpart. Sensory analysis results showed that scores were equal or better than soil-grown sensory scores.

Although the results of this research are promising, more research is warranted to optimize hydroponic food production on a commercial scale. This research investigated one type of crop and growing system. Future research should investigate different cultivars, growing systems, nutrient solutions, media, lighting and different geographical locations. Further, starting a hydroponics operation may have barriers to the farmers because of the high startup cost. For hydroponics to be successful the small and large-scale farmer must know the benefits and limitations of the hydroponic food production system. A plan for education to promote hydroponics will help with the adoption. Continuing to research the hydroponic growing method will bring advances and develop global prospects for sustainable food sources.

Appendix 1

University of Nevada
Cooperative Extension

Fact Sheet-08-00

Hydroponics – a brief guide to growing fruits and vegetables in northern Nevada

By Chenin Treftz, Graduate Assistant; Heidi Kratsch, Northern Area Hortculture Specialist; Stanley Omaye, Department of Agriculture, Nutrition and Veterinary Science

What is hydroponics?

Hydroponics comes from the Greek word ‘hydro’ meaning water and ‘ponos’ meaning labor. In other words, hydroponics is gardening without soil. Growing food in a desert such as northern Nevada can be difficult because of the extreme temperatures, low natural precipitation and limited arable soil. Hydroponics can be a viable option to reliably grow fruits, vegetables and herbs, regardless of climate, soil availability or space.

Advantages of hydroponics

- Can be grown anywhere and year round
- Greater control over growing conditions for increased crop yields and faster growing time
- No weeding required
- Save water, up to 90%
- No need for crop rotation
- Can be spaced closer together compared to soil-grown plants and stacked vertically
- Materials can be reused

Limitations of hydroponics

- Higher start-up costs compared to soil
- Diseases, if present, can spread easily
- Requires some basic skills and knowledge to maintain

Growing crops hydroponically

Hydroponic produce can be grown at your home, apartment, greenhouse or office space. The six things needed are light, air, water, nutrients, heat and space.

Site selection

Hydroponic growing can be done indoors or outdoors. In either setting, the system will need 5 to 6 hours of sunlight per day, access to electricity and an area that is level and without excessive wind. Optimal temperature depends on the plant type and variety.

Hydroponic growing systems

Hydroponic systems can be classified as either water culture or medium culture. Water culture does not use a medium to support the roots, only the nutrient solution. Medium culture uses a solid substrate, such as sand, to support the plant root structure. Additionally, systems can be either open or closed. In open systems, the nutrient solution flows past the roots, and the solution is not recycled. In closed systems, the surplus nutrient solution is recovered, recharged and recycled through the system. Water culture systems are usually closed; medium culture systems can be classified as either open or closed.

Water culture uses one of the following three methods:

- Nutrient film technique (NFT): Plant roots are placed in a small-diameter PVC tube or trough, and the nutrient solution flows across the roots forming a nutrient-dense film of water around them.
- Raft or floating system: Plants are supported by sheets of Styrofoam floated on aerated nutrient solution. The roots hang through small holes in the Styrofoam and are suspended in the solution.
- Aeroponics: Plant roots are placed in a supporting container and are suspended in the air. The plants are misted with the nutrient solution rather than being immersed in it.

Medium culture (open):

Rockwool: Derived from basaltic rock, it is a fibrous material and the most popular hydroponic medium. It provides rapid crop turnaround and minimal risk of crop failure. The open rockwool system limits diseases in the system.

Sand: Plants are supported in sand and the nutrient solution flows past the roots.

Medium culture (closed):

Rockwool and NFT: Plants are grown on rockwool slabs and transplanted into containers in channels containing nutrient solution that is recycled.

- Passive hydroponics: Plants are grown in a porous medium. Water is transported to the roots by high capillary action.
- Active hydroponics: Water is actively passed over the roots of plants. Many use water culture, ebb and flow, drip systems and NFT.

Media selection

Similar to soil-grown plants, the hydroponic medium must provide oxygen, water, nutrients and support for the plant. Medium moisture retention is determined by its particle size, shape and porosity. Popular choices for media are foam, gravel, perlite, rockwool, sand, hydroton, coco coir, and pumice. Each medium has advantages and limitations, and the choice will reflect availability, cost, quality and type of hydroponic system.

Nutrient solutions

Nutrients are provided to the plant by dissolving fertilizer salts in water. The two options for obtaining nutrient solutions are purchasing a commercial solution or making your own stock solution. An optimum formulation depends on several variables, such as the plant species, stage of plant growth, part of the plant representing the harvest, season during growing and the weather.

Managing the hydroponic system

Recharging the nutrient solution:

In an open system, the nutrient solution is used only once on crop plants. In a closed system, the nutrient solution is used once, then analyzed for pH and nutrients, and adjusted to the proper levels. It must also be sterilized to control the spread of pathogens and returned to the plants. Common methods for sterilization include heat, ultraviolet radiation or ozone.

Sterilizing hydroponic media:

Hydroponic systems are susceptible to pathogenic microorganisms accumulating in the medium with each successive crop. For best results, it is recommended to sterilize the system in between each crop.

Sterilization:

- Steam sterilization is effective at 180°F for at least a half hour and is effective at cleaning beds up to 8 inches in depth.
- Chemical sterilization is used when steam sterilization is not feasible. Bleach is commonly used and should be applied in a 10,000-ppm concentration. The solution should be allowed to sit on the medium for half an hour and then the medium rinsed thoroughly. Other options are formaldehyde (as a fungicide), chloropicrin (as an insecticide), Vapam (water-based fumigant) or basamid (granular soil fumigant). Many of these chemicals are toxic to humans; those

applying the chemicals should read the label carefully for use and safety information about the product.

Pest and disease management:
Integrated pest management (IPM) is the most effective and environmentally sensitive approach for both commercial and home hydroponic settings. IPM is not a single pest control method but one that is based on frequent monitoring and use of a variety of management techniques that depend on user tolerance to pests and severity of the outbreak. The grower should set action thresholds based on economic threat, monitor and identify pests, practice prevention and control for both effectiveness and risk. The grower must use the most appropriate IPM technique for the situation at hand.

Nutritional quality of hydroponics

No conclusive evidence is available regarding the nutritional quality of hydroponically grown produce as compared to soil-grown produce. Since hydroponics allows for control over all aspects of growing conditions, it is thought that hydroponically grown crops may eventually be superior to soil-grown crops in nutritional quality.

At University of Nevada, Reno, hydroponically grown strawberries and raspberries were compared to their soil-grown counterparts. Results indicated significantly higher levels of vitamin C, vitamin E and total polyphenolic compounds, but significantly less fructose and glucose, in hydroponically grown strawberries as compared to soil-grown plants. Hydroponic raspberries showed significantly lower levels of fructose and sucrose as compared to soil-grown raspberries. These findings may contribute to providing an environmentally sustainable food source in arid or urban growing conditions; however, more research is needed to determine best methods for hydroponic strawberry and raspberry crop production.

Hydroponics in the future

Hydroponics has adapted to many situations over a relatively short time period. In the future, areas suffering from drought may use desalinated seawater in hydroponic systems, and could therefore provide food in areas along coasts, in deserts and in developing countries. Astronauts are already enjoying lettuce grown hydroponically on the International Space Station. Research is currently being conducted to investigate other varieties of vegetables for growing hydroponically during space travel, which has the potential to feed astronauts on longer missions.

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Strawberries can be successfully grown in a hydroponic system. Here they are shown growing in a vertical system using ZipGrow towers.

Hydroton is a popular medium for hydroponic growing systems. It is made from expanded clay, has a neutral pH and is reusable.

Appendix 2

University of Nevada
Cooperative Extension

Special Publication

Nutritional and sensory analysis of raspberry varieties grown in northern Nevada during 2013-2014 growing seasons

Chenin Treftz, Heidi Kratsch, Jack Jacobs and Stanley Omaye

Introduction

Berry fruits have been promoted for many health benefits. They include antioxidant activity, lowered risk of heart disease and other obesity-related diseases, and prevention of certain types of cancers. Raspberries are high in vitamin C, vitamin E and other antioxidants.

Previous research on raspberry nutrition has focused on European raspberry varieties or on varieties from the Midwestern or southern United States. These studies show wide variations in vitamin and mineral contents. Little is known about antioxidant content of raspberries grown in dry regions. Raspberries grown in dry regions are thought to have less moisture but may be otherwise similar to berries grown in other regions of the world. A study conducted in Utah showed differences between several primocane raspberry species (Freeman et al., 2011).

In northern Nevada, the extreme temperatures limit food production in the summer and winter. Despite this limitation, consumers in Nevada and elsewhere are becoming interested in the health benefits of eating fruit and the farm-to-table benefits of locally grown produce. To our knowledge, no studies have looked at nutritional or sensory quality of raspberries grown in northern Nevada. The purpose of this study was to measure vitamin C, vitamin E, total polyphenolics (antioxidants) and sugars (glucose and fructose) in several raspberry varieties during two growing seasons and during different months of harvest. We believed these nutrients would vary across types, as well as at the month of harvest. We also measured taste preferences for three raspberry varieties. Our results can be used to inform potential berry farmers in dry climates about the nutritional qualities and consumer preferences for raspberries.

Methods

Raspberry growing conditions

Raspberries were planted in 2012 at Jacobs Family Berry Farm, Gardnerville, Nevada. All plants were drip irrigated every other day, three times per day. Berries were supported by a V-Trellis system. Berries were pruned according to variety as explained in Table 1.

Table 2. Pruning techniques for berries from Jacobs Family Berry Farm

Berry variety	Type	Prune-Early Spring	Tipping/Thinning-Summer	Pruning- After Harvest
Jewel	Floricane	Remove all previous year canes except 6-8 best and top to 4-	When new canes reach 4-5’, tip to encourage lateral growth. Thin by	Remove fruiting canes after harvest

		5’ high, cut laterals to 4-7”	removing laterals on the bottom 18” to “open” plant and remove new canes that emerge outside the row (12-18” width)	
Encore	Floricane	Same as Jewel	Same as Jewel	Same as Jewel
Nova	Floricane	Same as Jewel	Same as Jewel	Same as Jewel
Polana	Primocane	Cut to ground level (1-2”)	Same as Jewel	Same as Jewel
Jaclyn	Primocane	Cut to ground level (1-2”)	Same as Jewel	Same as Jewel
Joan J	Primocane	Cut to ground level (1-2”)	Same as Jewel	Same as Jewel
Mac Black	Floricane	Same as Jewel	Same as Jewel	Same as Jewel
Heritage	Primocane	Cut to ground level (1-2”)	Same as jewel	Same as Jewel

Nutrient analysis

Materials, equipment and procedures have been described previously (Treftz & Omaye, 2015). Raspberries were harvested in June, July and August during 2013 and 2014. At Jacobs Family Berry Farm, raspberries were harvested when they reached 100 percent visual red (or black, depending on variety) surface color between 7 AM and 8 AM. The berries were placed in tubes and then on dry ice in a cooler. The raspberries were transported to the University of Nevada, Reno and immediately stored in a freezer until ready for nutrient analysis. Raspberries were randomly selected for analysis by hand. Raspberries were rinsed with water to remove dirt and allowed to dry on a paper towel.

Sensory analysis

Participants were recruited through undergraduate Food Science classes at the University of Nevada, Reno (UNR) (N=76). This study was approved by the UNR Institutional Review Board (project number: 583149-1). Participants were not trained in sensory evaluation and were asked to give their taste preferences on locally grown berries. Sensory evaluation was conducted at the sensory laboratory at the UNR campus. The sensory laboratory was designed according to the American Society of Testing Materials standards and was built with an 11-inch sliding door. The raspberry samples were sampled within two days of harvest, and all data were collected during September 2013. Raspberries were rinsed with tap water, allowed to dry on a paper towels and served at room temperature in 2-ounce clear plastic cups. The students were asked to rank their preferences for three different berries on 13 taste attributes using a 5-point scale. The scale used smiley faces, ranging from 'very satisfied' to 'very unsatisfied' (Beckley, Moskowitz, & Resurrection, 2006).

Results

The results for the sensory analysis portion of the study are outlined in Table 2. Out of the 13 sensory attributes assessed, aroma intensity, sweetness, fruit juiciness, overall taste and overall flavor showed significant differences. Jaclyn aroma intensity ratings were higher than Polana. Jaclyn was rated higher for sweetness, fruit juiciness and overall taste and flavor, compared to Polana and Heritage.

Table 3. Sensory analysis results*

	Heritage	Polana	Jaclyn	P**
Overall Color	3.8 ± 1.0	3.9±1.0	3.5±1.1	0.11
Color Uniformity	3.7±0.8	3.8±1.0	3.7±1.1	0.82
Overall appearance	3.7±1.0	3.8±1.0	3.6±1.2	0.73
Overall aroma	3.2±0.9	3.2±0.9	3.4±1.0	0.71
Aroma	2.5±1.0	2.9±1.0[a]	3.5±1.1[b]	0.02

intensity				
Sweetness	3.6±0.1^{a}	3.2±1.2^{a}	4.1±1.2^{b}	<0.001
Amount of sourness	3.5±1.0	3.5±1.2	3.7±1.0	0.38
Fruit juiciness	3.1±0.9^{a}	3.6±1.0^{b}	4.0±1.0^{b}	<0.001
Overall taste	3.8±1.0^{a}	3.5±1.1^{ab}	4.3±0.83^{bc}	<0.001
Fruit firmness	3.9±0.9	3.6±1.0	3.7±1.2	0.26
Overall texture	4.0±0.8	3.9±0.9	4.0±1.0	0.58
Overall mouthfeel	4.0±0.9	3.8±1.0	3.9±1.0	0.13
Overall flavor	3.8±1.0	3.5±1.1^{a}	4.3±0.9^{b}	<0.001

*5= 'very satisfied', 4= 'satisfied' , 3='neutral', 2= 'unsatisfied', 1='very unsatisfied'
p-values < 0.05 are considered significant.

Nutrient analysis results for Encore variety are listed in Table 3. The results indicated significant differences for all nutrients except fructose. The highest vitamin E and total polyphenolic compounds were observed in July 2013. The highest amounts of fructose and glucose were observed in August 2013.

Results for Joan J are shown in Table 4. For all nutrients analyzed, the greatest variation in differences were seen during in August 2014, when the highest amounts of vitamin C, vitamin E, total polyphenolics and the lowest amounts of fructose and glucose were measured.

Table 3. Encore raspberry nutrient analysis

	July 2013	August 2013	August 2014	ANOVA
Vitamin C *	20.6 ± 4.0^{a}	16.9 ± 2.4^{b}	26.4 ±3.2^{c}	<0.001
Vitamin E *	2.01±0.09^{a}	1.15±0.02^{b}	1.37±0.2^{c}	<0.001
Total polyphenolics*	956±8.6^{a}	720±7.0^{ab}	717±12.3^{b}	<0.001
Brix (%)	11.43±0.07^{a}	10.32±0.2^{b}	10.24±0.2^{b}	<0.001
Fructose **	3.1±0.4	3.3±0.1	3.2±0.5	0.21
Glucose **	3.08±0.1^{ab}	3.41±0.3^{ac}	2.3±0.1^{bc}	<0.001

Superscripts with different letters indicate p<.05
*mg/100g berries
**g/100g berries

Table 4. Joan J raspberry nutrient analysis

	August 2013	September 2013	August 2014	September 2014	ANOVA
Vitamin C*	24.6 ±1.2^{a}	23.8 ±0.96^{a}	26.5 ±2.0^{b}	36.4 ±3.8^{c}	<0.001
Vitamin E*	1.50±0.12^{ab}	1.34±0.4^{ab}	1.59±0.19^{b}	1.17±.10^{a}	<0.001
Total polyphenolics*	589±64^{a}	884±15^{b}	1188±96^{c}	1074±92^{d}	<0.001
Brix (%)	10.3±.26^{a}	9.80±.0.3^{ab}	10.07±0.10^{ab}	8.6±0.26	<0.001
Fructose**	5.3±0.15^{a}	7.3±.02^{b}	4.7±0.06^{c}	6.4±.04^{d}	<0.001
Glucose**	2.4±.07^{a}	3.1±.15^{a}	2.3±.07^{b}	5.6±.07 ^{b}	<0.001

Superscripts with different letters indicate $p<.05$
*mg/100g berries
**g/100g berries

The results for Nova are outlined in Table 5. The highest levels of vitamin E, Brix and fructose were seen in August 2013. The highest levels of total polyphenolics were seen in July 2014. Jewel results are outlined in Table 6. Differences were observed between harvest dates for vitamin E, with higher results observed in July 2013. Table 7 outlines the result from Polana. Results varied between the harvest dates of September 2013 and September 2014 for all measurements except Brix. Also comparing September 2013 with September 2014, Heritage raspberries (Table 8) indicated significant differences among vitamin C, fructose and glucose levels. Table 9 outlines results from Jaclyn. The greatest differences were between the 2013 and 2014 harvest dates; however, differences were also seen between different months of the same year.

Table 5. Nova raspberry nutrient analysis

	July 2013	August 2013	July 2014	ANOVA
Vitamin C*	24.6^{a} ± 2.0	48^{b} ± 3.0	52^{c} ± 1.5	<0.001
Vitamin E*	1.26±0.10	1.43±0.16^{a}	1.25±.15^{b}	0.028
Total	829±16.20^{a}	965±10.4^{b}	1061±15.6^{c}	<0.001

polyphenolics*				
Brix (%)	8.9±.23^{a}	9.8±.0.10^{b}	9.6±0.10^{b}	<0.001
Fructose**	4.5±0.10^{a}	6.4±.08^{b}	5.3±0.08^{c}	<0.001
Glucose**	1.23±.15^{ab}	1.3±.07^{ac}	1.3±.07^{bc}	0.32

Letters that are different p<.05
*mg/100g berries
**g/100g berries

Table 6. Jewel raspberry nutrient analysis

	July 2013	August 2013	p*
Vitamin C*	32 ± 1.8	27 ± 0.6	0.001
Vitamin E*	4.56±0.08	3.94±0.82	0.04
Total polyphenolics*	963±18.4	987±169	0.90
Brix (%)	5.3±.07	5.3±.18	0.99
Fructose**	3.4±0.13	3.2±.13	0.29
Glucose**	3.1±.1.3	0.6±.17	0.07

p* value calculated using independent t-test

Table 7. Polana raspberry nutrient analysis

	September 2013	September 2014	p*
Vitamin C*	19±2.9	35±1.8	<0.001
Vitamin E*	1.2±0.13	1.8±0.13	<0.001
Total polyphenolics*	953±6.5	1365±17	<0.001
Brix (%)	9.9±.1	10.4±.18	0.55
Fructose**	8.7±0.17	5.3±.80	<0.001
Glucose**	3.3±.21	2.2±.08	<0.001

p* value calculated using independent t-test

Table 8. Heritage raspberry nutrient analysis

	September 2013	September 2014	p^{a}
Vitamin C*	22.4±.33	24.8±1.2	<0.001
Vitamin E*	1.4±0.08	1.3±0.1	0.08
Total polyphenolics*	738±8	732±6.3	0.11
Brix (%)	11.3±.52	10.2±1.7	0.14
Fructose**	8.3±0.24	5.6±.08	<0.001
Glucose**	3.4±.18	2.9±.07	<0.001

p^{a} value calculated using independent t-test
*mg/100g berries
**g/100g berries

Table 9. Jaclyn raspberry nutrient analysis

	August 2013	September 2013	August 2014	September 2014	ANOVA
Ascorbic acid*	40.2±4.1^{a}	43.9±4^{b}	22±0.8^{c}	19.9±.45^{c}	<0.001
α-tocopherol*	2.3±0.26^{a}	1.62±0.4^{b}	0.8±.10^{c}	1.20±.06^{d}	<0.001
Total polyphenolics*	754±6^{a}	778±19^{b}	574±15^{c}	900±11^{d}	<0.001
Brix (%)	10.9±.26^{a}	9.0±.0.1^{b}	8.6±0.10^{c}	9.0±0.19^{d}	<0.001
Fructose**	5.3±0.07^{a}	8.3±.08^{b}	4.3±0.09^{c}	6.5±.09^{d}	<0.001
Glucose**	4.0±.15^{a}	3.3±.12^{b}	1.5±.08^{c}	2.6±.02^{d}	<0.001

Letters that are different $p<.05$
*mg/100g berries
**g/100g berries

Discussion

This is the first time a nutritional analysis has been conducted on raspberries grown in northern Nevada. Similar to the previous study conducted with raspberries grown in high-desert growing conditions, variations were seen among varieties. Differences among vitamins, sugars and dates of harvest were dependent on times of harvest and variety of raspberry. Since not all raspberries were available at every harvest date, results cannot be easily compared among varieties. In general, it was observed that the greatest differences were among harvest years, and smaller differences among nutrients were observed between harvest months within the same years. This study did not control for environmental variation between harvest years, and such differences are likely the result of factors known to affect nutritional qualities of the fruit.

Sensory analysis data showed that untrained consumers preferred the Jaclyn variety compared to Heritage and Polana, with preferences for sweetness, overall taste and fruit juiciness. However, sugar analyses of these varieties were not different. Vitamin C content was the highest in the Jaclyn variety, and could potentially be contributing to the participants' observed taste differences.

Eating food grown locally has several benefits, from economic growth of the local economy to environmental and nutritional benefits. Growing raspberry fruits in high-desert climates has the potential to provide nutritionally dense and attractive fruits to the local population.

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