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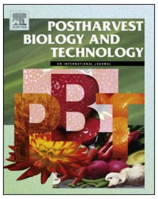

# Electronic tongue discrimination of four tomato cultivars harvested at six maturities and exposed to blanching and refrigeration treatments

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## ABSTRACT

The objective of this research was to evaluate whether an electronic tongue (e-tongue) could differentiate “taste” profiles of full ripe tomato fruit of different cultivars, harvest maturities, and exposure to refrigeration or blanching. The four cultivars included: two common commercial cultivars, ‘Tygress’ and ‘FL 47’, with round shape and firm texture; ‘Tasti-Lee’, a hybrid with high lycopene content due to the crimson gene for the premium tomato market; and ‘Cherokee Purple’, an heirloom cultivar that consistently ranked very high in taste tests. Commercially, tomatoes are often harvested at the mature green (MG) stage for the fresh fruit and food service markets, and traditional vine-ripe harvested tomatoes are generally sold directly at farmer’s markets. To assess the effect of harvest maturity on fruit flavor once the fruit are fully ripened, fruit were harvested at six maturities from MG to full red. ‘Tygress’, ‘FL 47’, and ‘Tasti-Lee’ fruit all had similar total soluble solids (TSS) and titratable acidity (TA) content regardless of harvest maturity. Nonetheless, ‘Cherokee Purple’ had much higher TSS and TA at all but the MG harvest stage. E-tongue tests not only confirmed the differences detected in TSS/TA data, but also differentiated between the three commercial cultivars, and six harvest maturities. Both refrigeration and blanching are common kitchen practices and they were tested on ‘Tasti-Lee’ fruit for which some changes in the taste profiles were found by e-tongue, especially for the refrigeration treatment. E-tongue sensors ZZ, JE, BB, HA, and JB data correlated to TSS and TA, with significantly high correlations with TSS. E-tongue profiles not only significantly related to TSS, but successfully predicted TSS.

## 1. Introduction

Tomatoes are one of the most cultivated and consumed vegetables in the world, however, fresh-market tomatoes sold in supermarkets have garnered much criticism concerning their lack of flavor or off-flavor (Baldwin et al., 2000, 2015; Tieman et al., 2017). Along with aromas from volatile components, taste contributed by sugars, acids, and other non-volatile compounds, plays a key role in the perception and acceptability of tomatoes by consumers (Baldwin et al., 2008; Tieman et al., 2012; Wang et al., 2016). Much research has been done on the flavor quality and associated changes in volatile and non-volatile chemicals in tomatoes and other fruits (Baldwin et al., 2008; Bucheli et al., 1999; Salles et al., 2003; Wang et al., 2016). It has been thirty-five years since Dodd and Persaud introduced the idea of an electronic nose (e-nose) as a device to mimic the discrimination of the mammalian olfactory system for smells (Persaud and Dodd, 1982; Röck et al., 2008). The technology has evolved and been adapted by many companies internationally, and used extensively for flavor research and quality control applications (Baldwin et al., 2011b; Wilson and Baietto, 2009). Our research group successfully used a FOX 4000 system (Alpha MOX, Toulouse, France) to discriminate various fruit sample aroma for apples (Bai et al., 2005), mangoes (Lebrun et al., 2008), strawberries (Du et al., 2010), oranges (Baldwin et al., 2012), and tomatoes (Wang et al., 2015b). The measurement technique is simple and fast, and the results correspond with volatile analysis and sensory panel results, for which such measurements are more time consuming, involve more training, sample preparation, and expense.

On the other hand, electronic tongue (e-tongue) technology was developed about twenty years later than the e-nose (Tahara and Toko, 2013). The mechanism for e-tongue is similar to e-nose, being an artificial intelligence system which detects taste profiles using electronic sensors meant to mimic taste perception in humans, and generate signal patterns using pattern recognition modules so as to simulate the transduction of taste signals by nerves in the brain into electric signals

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(Bouchikhi et al., 2016; Tahara and Toko, 2013). The e-tongue has a sensor array which is composed of several nonpolar semiconductors. These sensors are sensitive to various chemicals in solution, as are found in food products, so that it is possible to discriminate complex solutions containing many ions (Vlasov et al., 2002). While the e-tongue has been successfully applied for food quality (Baldwin et al., 2011b; Dias et al., 2016; Nery and Kubota, 2016), including for tomatoes (Beullens et al., 2008; Hong and Wang, 2014), our group evaluated the e-tongue for determining quality of orange juice (Raithore et al., 2013, 2015), and pomegranate juice (Bett-Garber et al., 2014) in comparison with sensory evaluation data, and demonstrated the potential to discriminate fruit/juice quality using e-tongue technology. For this experiment, there were hundreds of samples over multiple cultivars, treatments, and test dates which made a sensory evaluation impossible. One of the objectives of this research was to evaluate whether the e-tongue could differentiate "taste" profiles of tomato fruit including between different cultivars, harvest maturities, and refrigeration or blanching exposure in comparison with soluble solids and titratable acidity, which have been shown to effect sensory perception in tomatoes (Baldwin et al., 2008, 2015).

Large and uniform fruit with round shape, resistant to harvest and postharvest handling injuries, resistant or tolerant to major tomato diseases and insects, and capable of high yield have been the main consideration for the modern agricultural industry (Folta and Klee, 2016; Foolad, 2007). 'Tygress' and 'FL 47' are the representative commercial cultivars for that group. On the other hand, a significant drop in tomato flavor has been evident over the last 50 years (Klee, 2010). To improve the flavor quality, 'Tasti-Lee', a hybrid with high lycopene content due to the crimson gene, was bred for the premium tomato market and was well received by growers and consumers (Baldwin et al., 2015). 'Tasti-Lee' also possesses other advanced characteristics as a modern commercial cultivar such as uniform size and color, and resistance to *Fusarium wilt*, *Verticillium wilt* and gray leaf spot (Scott et al., 2013). In response to increasing demands for tasty fruits and vegetables, heirloom tomatoes have become increasingly popular and more readily available in recent years (Bai and Lindhout, 2007; Klosterman et al., 2014). 'Cherokee Purple', is a Florida heirloom cultivar, which consistently ranks very high in taste (Ozores-Hampton et al., 2015). This cultivar, however, has some disadvantages, such as low yield, soft texture and uneven shapes, which can lead to mechanical damage during harvest and postharvest handling. E-nose analysis showed differences in aroma volatiles between tomato cultivars (Berna et al., 2004), and this research was conducted to examine the ability of the e-tongue to discriminate the taste profiles of tomatoes.

To decrease harvest and postharvest handling injury and resulting decay, tomato fruits were harvested mature green (MG) to prolong storage/market life. There have been reports which showed that tomato fruit harvested before they are full ripe have impaired volatile production (Kader et al., 1977; Maul et al., 1998). Our previous research also found that in comparison to fruits harvested MG, the levels of *trans*-2-hexenal, *trans*-2-heptenal, 6-methyl-5-hepten-2-one, β-damascenone, methanol, *cis*-3-hexenol, and 2-isobutylthiazole were higher in 'FL 47' tomato fruits picked at breaker stage (Baldwin et al., 2011a). However, there is little information on the effect of early harvest on fruit taste, with the exception of sugars and acids (Beckles, 2012; Malundo et al., 1995).

The refrigeration (chilling) and blanching (heating) are two kitchen practices which are commonly used by consumers and food services. Regardless of many warnings from scientists over the years that such chilling temperature exposure could cause flavor loss (Maul et al., 2000), it remains a commonly used kitchen practice to extend storage time after purchase. The heat treatment is an efficient way to remove peel, and reduce microorganisms (Bai et al., 2004; Lurie, 1998; Plotto et al., 2003). However, little research has been done on the influence of blanching on flavor quality of tomatoes.

This research was conducted to answer the following questions: Do the premium market tomatoes show significantly better quality? Does delayed harvest improve fruit taste quality? Does refrigeration and blanching, the common kitchen practices, influence tomato taste? Finally, we wanted to determine the feasibility of e-tongue to discriminate fruit from different sources and compare the e-tongue profiles with sugar and acid contents.

## 2. Materials and methods

### 2.1. Materials and experimental design

Defect-free and uniformly sized tomatoes were harvested from a tomato research block at the USDA Picos Road Farm in Fort Pierce, Florida, USA. Four tomato (*Solanum lycopersicum*) cultivars were used, 'Tygress', 'FL 47', 'Tasti-Lee', and 'Cherokee Purple'. Tomatoes of each cultivar were harvested at six maturity stages: mature green (MG), breaker, turning, pink, light red, and red. All tomatoes were stored at 20 °C until ripened. Fruits were not ripened with exogenous ethylene. The ripened fruit were homogenized for chemical and e-tongue analysis for all cultivars. Each cultivar at each harvest maturity contained at least: 45 fruits at the beginning for the MG to turning stage tomatoes, 30 fruits for the pink and light red tomatoes, and 15 fruits for the red tomatoes; 15 uniformly ripened fruits (five fruits x three replicates) were used for homogenation. For the refrigeration and blanching experiment, 'Tasti-Lee' fruit alone was used. Additional fruit were harvested: 90 fruits each for the MG to turning stage tomatoes, 60 fruits each for the pink and light red tomatoes, and 30 for the red tomatoes; 15 uniformly ripened fruits (five fruits x three replicates) per treatment (refrigeration or blanching) were used for temperature exposure. Refrigeration treatment was applied by storing fruit in a 5 °C cold room for four days. Blanching treatment was applied by dipping tomatoes into boiling water (100 °C) for 60 s, then using iced water to cool the fruit to room temperature within 180 s. Non-treated tomatoes were used as a control.

### 2.2. Sample preparation

A composite sample per replicate was composed of five tomatoes, all treatments included three biological replicates, and each biological replicate was further divided into three chemical replicates. The tissues were homogenized by using a commercial food blender (Model VM0101, Vitamix, Cleveland, OH, USA) for 60 s. Homogenate samples of 540 mL per biological replicate were transferred into three 200 mL plastic containers, which would serve as the three chemical replicates and all stored at −20 °C. Four weeks after sample collection, frozen homogenates were thawed under tap water and passed through Whatman #1 filter papers by using vacuum funnel.

### 2.3. Titratable acidity (TA), total soluble solids (TSS), and e-tongue measurement

TA in fruit juice samples was quantified by titration using a titrator (808 Titrando, Metrohm, Wesbury, NY, USA) equipped with a 16-position automated sample changer (Model 730, Metrohm). Titrating solution was 0.1 mol $L^{-1}$ NaOH, endpoint was pH 8.1, and sample size was 6.0 g of tomato juice, which was diluted with 60 mL of ultra clean DI water.

TSS in fruit juice was measured with a digital refractometer (RX-5000α, Atago, Tokyo, Japan).

The e-tongue system used in this experiment was Alpha MOS Astree II Liquid Analyzer (Alpha MOS America, Hanover, MD, USA). This e-tongue system is composed of a 16 position auto-sampler, an array of sensors, a reference electrode (Ag/AgCl) and a chemometric software package. The experimental e-tongue sensors includes following 7 sensors: ZZ, JE, BB, CA, GA, HA and JB. The sensors were based on a chemically modified field effect transistor (CHEM-FET) technology and