ABSTRACT

DEKALB, COURTNEY DANIELLE. Value-Added Opportunities for Growers and Processors in North Carolina: Tomatoes and Watermelon. (Under the direction of Dr. Christopher C. Gunter and Penelope M. Perkins-Veazie).

Value-added products offer an opportunity for growers, diversifying their means of revenue. North Carolina has the potential to be a leader in the value-added food products, following the decline of bioprocessing industries. When considering crop or market diversification, tow broad categories exist. Growing new crops for further value added processing or using existing crops in new ways for value added processing. With this in mind, both processing tomatoes and watermelon have been suggested as potential value-added crops in North Carolina. Processing tomatoes would offer a new crop and opportunity for local processors. Value-added watermelon products provide a year-round supply of lycopene and citrulline, two value health compounds, and a means of utilization for watermelons left in the field. This work focused on processing tomato crop evaluation for post-harvest processing into a salsa product and development of a dehydrated watermelon product.

Ten processing tomato cultivars (HMX2905, HMX2906, HMX3881, HMX3882, HMX3888, HMX4909, HMX7883, N6402, N6404, and SPESSO6415) were analyzed on three commercial tomato grower's farms in 2015 and 2016. Cultivars were evaluated for marketable yield, total yield, soluble solid content (SSC), pH, and total lycopene content. Marketable yield ranged from 3.2 mt/ha to 82.4 mt/ha. HMX2906 was consistently highest in marketable yield among sites and years. In 2016, two cultivars (HMX2906 and HMX7883) had a total yield that exceeded the average yield for processing tomatoes (82,942.90 kg/ha). N6402 consistently had the highest SSC (4.8% to 7.1%), HMX4909 consistently fell within

the desirable range for pH (<4.4), and HMX2905 was the highest in total lycopene content (88.86 to 114.84). These results indicate that processing tomato production in North Carolina is feasible, but further research is needed to improve cultivar yield and post-harvest composition.

A preliminary ethephon trial was done to determine the ideal rate for uniform ripening in the hot and humid North Carolina environment. Five treatments were evaluated (0 L/ha, 0.24 L/ha, 0.47 L/ha, 0.94 L/ha, and 1.41 L/ha) in 2016 and evaluated for marketable yield, total yield, SSC, pH, and total lycopene content. Marketable yields ranged from 10,580.82 kg/ha to 45,730.00 kg/ha where 0.47 L/ha ethephon application had the highest. No treatment (0 L/ha) and 0.47 L/ha ethephon application had the highest SSC. No treatment had the lowest tomato fruit pH and 1.41 L/ha had the highest. Total lycopene content was lowest for 1.41 L/ha. The results from this preliminary study indicate that ethephon application rates could be reduced from the label rate 0.59 L/ha to 1.53 L/ha. This savings will help offset the higher costs for disease management in the hot and humid environment of North Carolina.

A study was conducted to assess the compositional analysis and determine the shelf-life for a dehydrated watermelon product. Watermelon strips were pretreated by application of the following: 1) no treatment (control), 2) addition of lime juice, 3) lime juice and cinnamon, 4) lime juice and cayenne pepper. Strips were dehydrated for 24hr at 55^{o}C and stored in vacuum-sealed bags. Water activity was measured at weeks 0, 2, 4, 6, and 8 and ranged from 0.291 to 0.479 a_w, which is below the water activity needed for microbial growth. Use of lime juice effectively lowered the pH of watermelon from 5.0 to 4.2, which is below the optimal range for microbial growth. Total lycopene content ranged from 146.05 to

273.81 µg/g fwt, a large increase compared to the 50 µg/g fwt in fresh watermelon. The watermelon jerky product appears to be shelf stable and the low pH and water activity should minimize food safety hazards. This product offers the possibility of a new year-round supply of lycopene.

Value-Added Opportunities for North Carolina Growers and Processors: Tomato and Watermelon

by
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DEDICATION

For Charlie.

BIOGRAPHY

Courtney D. DeKalb was born on March 4th, 1993 to Dan and Lori DeKalb in Oklahoma City, OK. Her father was a civil engineer and her mother was a Chapter 9 bankruptcy trustee. Courtney grew up in Norman, OK where her parents instilled keen sense of business and self-sufficiency. Growing up, she imagined herself pursuing careers in either marine biology or writing fiction novels. It was her freshman year of high school when she and her father started a vegetable garden. What started out as a small plot of radishes and lettuce led to six raised beds and a passion for horticulture. Throughout high school, Courtney worked for a retail nursery where she grew and sold bedding plants.

In 2011, Courtney began her undergraduate degree at Oklahoma State University in Horticulture Business with an emphasis in entrepreneurship. During her time at OSU, Courtney conducted research substituting soilless media with yard waste compost in transplant production. She worked her way through school, working as a waitress and assistant manager at a retail clothing store. She also expanded her experience in horticulture by working as the database and plant accession manager at the Oklahoma Botanic Garden and Arboretum, interning as a landscaper at Walt Disney World, and assisting with production and breeding operations at a small, direct to market vegetable farm. Courtney graduated from OSU in 2015.

After graduation, she moved to Raleigh, North Carolina to attend North Carolina State University for a Master of Science degree in Horticultural Science. During her time at NCSU, she developed an interest in food science and food safety. Her research focuses on assessing the feasibility of value-added crops and products through field and fruit compositional analysis. After completing her Master’s degree, Courtney hopes to work as a food safety regulator or procurement manager. She also plans to pursue her long-time dream of being a business owner.

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CHAPTER I

LITERATURE REVIEW

Abstract

Value-added products offer a means of diversification for growers, while also increasing the opportunities for local processors. After the decline of major bioprocessing industries in North Carolina, value-added food products offer a viable opportunity to decrease the unemployment rate while using the underutilized infrastructure in the eastern part of the state. Processing tomatoes have been suggested as potential crop to meet the demand for value-added food products. Research is needed to determine viable yielding cultivars with desirable post-harvest composition and adequate cultural practices for the hot and humid environment of North Carolina. Watermelon has also been suggested as an option for value-adding due to recent studies indicating a wealth of associated health benefits, primarily driven by lycopene and citrulline. Challenges associated with value-added watermelon products include maintaining lycopene and citrulline throughout processing and creating a product that is shelf-stable. Processing tomatoes and value-added watermelon products may offer new sources of revenue for growers and processors in North Carolina, but research is warranted to articulate the feasibility of these two crops.

The Benefits of “Value-Adding”

The term “value-added” is used to describe the additional activities within a company or institution that create new and valuable elements to products or services (Katz and Boland, 2000). In regards to vegetable production, this can be anything as simple as packaging fresh cut lettuce to more complex culinary activities, such as creating jams, relishes, and salsas.

Adding value to agriculture crops extends food availability and increases product variety for consumers (Alonso, 2011).

In a study conducted by Alsos et al. (2003), the authors describe three main theoretical perspectives that contribute to the decision-making process in business start-ups and specifically new business activities for farmers. First is the rural sociology perspective, which expands on the notion that farmers often generate income from more than one activity. This perspective allows growers to remain independent – if an anticipated form of income becomes less profitable, farmers can rely on another business activity. The second theoretical perspective describes the pursuit of opportunity by the grower. The third theoretical perspective refers to the synergistic aspect, implying that combining resources can create a competitive advantage.

Research has shown the benefits of value-added products. In Alabama, 66.7% of growers believe there is an existing market for value-added products. One grower stated "There is potential. [... Value added products] would just add a lot of value to the farmer" (Alonso, 2011). In South Carolina, fruit and vegetable preservation was found to employ the highest number of people per establishment (Bolotova, 2016).

North Carolina's economy has largely been dependent upon value-added products. In recent years, however, the major bioprocessing industries have declined (NCSU CALS and NCDA&CS, 2014). These industries include tobacco, textiles, and forestry. Tobacco farmers have shown interest in diversifying their income source. The transition has been difficult because few alternative opportunities have been identified and presented to growers (Beach et al., 2008). Textiles and lumber have also declined with international competition. As these income sources decline, growers must find supplemental sources of income. New innovations, such as products, programs, and alternative markets, are needed to expand the agri-food economy in North Carolina (Kline et al., 2015).

The North Carolina Food Processing and Manufacturing Initiative (NCFPMI) aims to do just that. The NCFPMI plans to stimulate the agri-food industry through the development of new food products and manufacturing technologies. The NCFPMI also plans to promote the entrepreneurial endeavors of start-ups, make the state more attractive for new companies, and provide training for members of the food manufacturing industry. The initiative projects that this stimulus would create around 38,000 jobs. Additionally, $10.3 billion in output are expected by 2020 (NCSU CALS and NCDA&CS, 2014).

In a decision-making diagram detailed by Morris and Brady (2004), the two ways growers can add value to the farming operation are either alternative crops or alternative marketing. Value-added products fall under the alternative marketing route. Based on the diagram, idea generation/screening and a feasibility evaluation must follow if a grower chooses to pursue value-added products as a means of alternative marketing (Morris and Brady, 2004). Recently, tomatoes (*Solanum lycopersicum*, L.) and watermelon (*Citrullus lanatus* (Thunb) Matsum & Nakai) have been identified as two value-added opportunities for growers in North Carolina.

Tomatoes for Processing

Tomatoes are the highest consumed processed vegetable in the United States (Gould, 1991). Processed tomato products include sauces, pastes, purees, and juice. The increased accessibility of foods containing processed tomato products, such as salsa, pizza, and pasta sauce, has caused a rise in consumption; the processing tomato accounts for 75% of the total tomato consumption in an American diet (USDA-ERS, 2016). California currently leads in products, with 94% market share (USDA-ERS, 2016). However, there are some indications that the market environment is changing. With willing processors, opportunity is available in new areas of production, such as North Carolina.

Differences Between Fresh Market and Processing Tomatoes

The vegetable produces in the state of North Carolina are already familiar with tomato production – the state ranks sixth in fresh market production, producing $47.1 million worth of tomatoes in 2014. (Statista, 2014). The production system for processing tomatoes differs from that of fresh market tomatoes. Processing tomatoes are grown on bare ground, not staked, machine harvested, and typically grown on contract with processors.

Economics is an additional difference between processing tomatoes and fresh market tomatoes. Fresh market tomatoes are largely more valuable than processing tomatoes. Fresh market tomato prices can vary based on many factors, including availability and shipping point-price (USDA ERS, 2016). For example, in 2016, the cost of a 25-pound carton of fresh market tomatoes ranged from $14.95-$18.95 (The Packer, 2016). This would amount to around $.27-$.34 for a kilogram. A metric ton of processing tomatoes, however, averaged at $46.76 between the years of 1997 and 2006. This would amount to approximately 0.047 for a kilogram of processing tomatoes (Miyao et al., 2008). This price difference has created a high volume/low input strategy for processing tomatoes in order to make money.

Another major difference that comes with processing tomato production is the post-harvest requirements set by processors. Three common parameters include soluble solids content (SSC), pH, and lycopene concentration. SSC and pH are the two main contributors to the taste of the tomato. A low pH (<4.4) is also required to prevent pathogen growth. Processors generally measure the product color to a hue angle of 20-26 (bright red) (Garcia and Barrett, 2006). Lycopene is the compound responsible for the red color of tomatoes. This can also be measured to determine the quality of processed products, but hue is more commonly used. These requirements are set so that processors can maintain product consistency when sourcing from multiple farms and across years.

Measuring SSC offers a means of approximating the soluble solids within the fruit. The primary solids are sugars, but this also includes citric acid, malic acid, amino acids, lipids, and minerals (Young et al., 1993). SSC has increased over time in tomato fruit and is generally desired to be around 7.0 - 7.5% (Rick, 1974). Water availability also has an impact on total soluble sugars within the fruit (Cahn et al., 2003), prompting processing tomato growers to cut irrigation four to six weeks prior to harvest. While this helps from a sensory and product quality perspective, it also helps growers mitigate fruits rots and reduce soil compaction during harvest (Hartz et al., 2008). SSC can be increased with cook time, but this is an unwanted cost on the processor level.

Fruit pH contributes to tomato taste, and a low pH is also needed in processed products to limit the growth of microbial pathogens. T.W. Garner Food Company, a salsa producer in North Carolina, requires their supplied tomato product have a pH range of 3.6-4.4 (Gann, 2016).

The red pigment in tomato, which is from the carotenoid lycopene, becomes the predominant fruit color when chlorophyll begins to degrade and the photosynthesis slows

(Prasanna et al., 2007, Riggi et al., 2008). The change in color is also associated with the conversion of the chloroplasts to the chromoplasts within the cells (Schouten et al., 2014). Consumers prefer a more intense color in processed product, as it is associated with quality and flavor (Barrett and Anthon, 2008, Papaioannou et al., 2016). Though not related to the perception of taste, it also important to consider that lycopene is the main antioxidant in tomatoes and has shown to lower the risk for cancer and cardiovascular disease (Clinton, 1998). Fruit should also have a uniform color at the time of harvest. Including fruit with less fully developed color can results in a visually unappealing product (Barrett and Anthon, 2008). This creates a priority for maintaining high lycopene contents in fruit.

History of Processing Tomatoes

The first indication of United States tomato presence was in 1710, but the fruit did not appear on the market until 1829. The tomato slowly gained familiarity in the market, but transition was long due to the plant's close relation to members of the poisonous nightshade family. As the tomato became more popular, so did tomato products. Harrison Woodhull Crosby, a gardener in Pennsylvania, became the first tomato canner in 1847 (Gould, 1991). The canning process increased in efficiency as advances in autonomy occurred in the late 19th century and the beginning of the 20th century. It was the 20th century when consumers first began to see diversification to the common tomato products of today. One author describes "from juice in 1920s to pizza sauce in 1960s, chili sauce in 1970s, and salsa in the 1990s, new tomato products have become food classics nearly every decade (Lucier, 1997).

Early production of the processing tomato spread throughout the Eastern and Midwestern part of the United States. Production was inefficient. Yields were very low; it took a large amount of acreage to fulfill the demand. Fields were also hand-harvested, increasing the amount of inputs it took to produce processing tomatoes. Before the 1960s, the industry was shared between Indiana, Ohio, New Jersey, Maryland, and California (Gould, 1991).

In the 1960s, the processing tomato industry in California began to expand. This was due to a number of reasons including an ideal growing environment, increased labor availability, breeding support from the University of California, Davis, and the development of the mechanical harvester (Gould, 1991). Production has increased from 2.4 million metric tons in 1960 to 12.7 in 2014. In addition, the yield per acre has increased from 38.78 metric tons in 1960 to 108.72 metric tons in 2012 (USDA, 2012, USDA, 2015). California now dominates the industry with 94% of the market share (USDA-ERS, 2012).

California has the ideal climactic and soil requirements for the tomato plant. Tomatoes are a warm-season plant, making them sensitive to frost. California’s season is long and threats of frost are minimal. Optimal production day time temperatures for tomato production are 20 to 24^{o}C, with cool night time temperatures between 15 to 17^{o}C. The plants thrive in a sandy loam soil (Hartz et al., 2008). In addition to the ideal growing conditions, California has traditionally had access to more filed labor, such as the Bracero program of the 1960s (Price, 1983).

California also had the resources to make the industry more efficient. The first major advancement was the machine harvester, introduced in the early 1960s by Jack Hanna, a professor at UC Davis (Allen, 2010). The machine cuts the plant at the base, shakes off the fruit, sorts the fruit, and moves it into bins to be transported to the processor. The mechanical harvester eliminates the need for a full crew, needing only five to eight workers to operate (Price, 1983). The mechanical harvester expanded production into a much larger scale in California, but had difficulty performing in the heavier Midwestern soils (Allen, 2010). Interestingly, social concerns arose over the introduction of the mechanical harvester. Previous employees rioted against losing their jobs to the machine and argued the expensive equipment would put smaller growers out of business. As not all types of tomatoes can be machine harvested, loss of consumer choice was another concern (Price, 1983).

The second advancement that led to the success of the California processing tomato industry was the breeding work done at UC Davis. The mechanical harvester necessitated cultivars to have specific fruit characteristics. These traits included a determinate growth pattern, uniform fruiting, uniform ripening timing habit, and firm fruit flesh (Grandillo et al., 1999). Coupled with these improvements, better plant and fruit quality were developed, including yield, high soluble solids content (SSC), low pH, and intense red color (Grandillo et al., 1999).

Opportunities in North Carolina

Given the advantages of California production, compelling reasons for a North Carolina processing tomato industry are needed. These include compromised water for agriculture in the western U.S., the price of oil and trucking costs to move tomatoes 3,000 miles, and the current and sustaining interest in locally grown products.

Water availability in California may become limited for agriculture. Predominantly, the recurrent droughts in California are worsening. Historically, California has had issues with drought conditions and it is projected that the current drought of 2007-2017 has permanently lowered water reserves. This is likely due to the addition of higher average temperatures (Hakan et al., 2015). Additionally, the surface reservoirs and ground water supply have declined and continue to decline (Hakan et al., 2015). The processing tomato industry didn’t see a decline in production during the drought (USDA, 2015), but there is a chance that future droughts may limit agricultural water for production.

Another advantage that North Carolina has is a local geographic location relative to east coast processors. California, located on the west coast of the United States, must ship processed product, like tomato paste, the entire country to supply east coast based end product processors, like tomato salsa producers. The U.S. average cost of on-highway diesel prices has decreased from $3.66 to $2.44 in the past year, after a 10-year rise in prices (USDA, 2015). Based on past oil price history, fluctuations in gas and diesel prices will continue. Long distance transportation also has an environmental impact, as it is considered to contribute to greenhouse gas emissions, an increasingly important factor to consumers (Martinez et al., 2010). North Carolina is positioned to supply eastern processors and their consumers with processing tomatoes at a more competitive distance.

There is also a current push for locally grown food. Consumers today care about who grew their food and how their food is grown (Martinez et al., 2010). Knowing this, North Carolina processors can use this as a marketing tool to increase the sales of their product to North Carolina and southeastern consumers.

In addition, it is recognized that there has been a recent decline in the state’s main biomass processing industries, specifically textiles, furniture, and tobacco. The decline in these industries has led to a decreased application of processing facilities and technologies.

The State of North Carolina currently has an initiative to capture this underutilized manufacturing capacity with value added food products. This is through the Food Processing and Manufacturing Initiative (NCSU CALS and NCDA&CS).

At the local level, a tomato processor, T.W. Garner Food Company, located in Winston-Salem, has well-established market for an existing a salsa product. The company is currently purchasing California grown processing tomatoes and have interest in a transition to North Carolina grown processing tomatoes. A supply of North Carolina grown processing tomatoes would allow the company to reduce their current shipping costs and allow them to diversify into other tomato-based products. The company is encouraging that research be conducted to determine how North Carolina growers can feasibly produce this crop.

Challenges in North Carolina

Though there is a basis of opportunity for a North Carolina processing tomato industry, there are challenges that must be overcome.

One of the most difficult challenges of production in North Carolina will be disease pressure. Before 1990, 20 disease resistant genes were prioritized in the development over new cultivars (Grandilllo et al., 1999) This disease management incorporation reflected predominately those diseases present in California production systems. While many of these diseases are present in North Carolina, regional differences in prevalence and severity exist between the two production environment. California diseases include *Verticillium* wilt, *Fusarium* wilt, *Alternaria* stem canker, gray leaf spot, bacterial speck, and nematodes. In North Carolina, additional and more serious pressure comes from bacterial wilt, early blight, late blight, septoria blight, southern blight, and anthracnose (Gould, 1991). These diseases are most prevalent in hot, humid environments, in contrast to the more arid areas of California production.

Another challenge that North Carolina processing tomato producers will face is the acquisition and utilization of the machine harvester. It is economically impossible for processing tomato production to occur without this mechanization (Price, 1983). The equipment is expensive and it is unclear how the machinery will perform on North Carolina soil types. Additionally, with smaller acreages per farm, spending the cost of this large capital equipment investment out may prove to be difficult.

The economic feasibility of processing tomato production is another challenge. This style of production is traditionally done on large-scale acreages. This may be impractical at first in North Carolina and adjustments will have to be made in budgeting and pricing to accommodate these differences in scale. It is also important to consider that the extra cost of fungicide applications and other inputs will need to be accounted for when budgeting. The smaller supply of tomatoes will make it more expensive for processors to purchase these local tomatoes. However, a consistent supply of high quality fruit with less inputs dedicated to shipping, may help alleviate these increases in cost.

Finally, there will be the challenge of the fruit quality. Tomato processors look for three things in their products – soluble solid content (SSC), pH, and lycopene. The balance of SSC and pH are the main contributors to the taste of a processed product. SSC is higher in processing tomatoes, so that they create a better quality finished product (Grandillo et al., 1999). Processing tomatoes are also required to be high in lycopene content as consumers have a preference for brightly colored products. SSC, pH, and lycopene content vary between environmental conditions and are heavily influenced by water availability and temperature. The difference in fruit composition may present a challenge to processors, who aim to maintain a consistent product.

Watermelon for Value-Adding

Watermelon is a warm season fruit, almost entirely consumed fresh in the United States. Watermelon production in North Carolina is well-established. The state planted 3,400 ha of watermelon in 2012, amounting to $34.9 million in sales (USDA ERS, 2013). Interest in watermelon has grown in recent years due to the associated health benefits of lycopene and citrulline. Value-added products would offer a year-round availability of watermelon's associated health benefits to consumers.

Like tomato, watermelon offers a bioavailable source of lycopene (Edwards et al., 2003). Lipophilic in nature, the long linear carbon chain has been shown to be an efficient antioxidant and mitigate the risk for diseases associated with oxidative stress (Clinton, 1998). One study showed that the consumption of lycopene-containing tomato juice lowered systemic inflammation in obese and overweight females (Ghavipour et al., 2013). Another study reported that when placed on a lycopene restricted diet, post-menopausal women had a higher potential for osteoporosis; a disease for which they are already at risk (MacKinnon et al., 2011). Lycopene has also been shown to limit the risk for cardiovascular disease, one of the highest causes of death in the United States (Clinton 1998, Jacques et al., 2013). Lycopene has also been correlated with a decreased risk for various cancers, specifically including prostrate, breast, gastric, color, skin, and bladder (Khachik et al., 2002, Viuda-Martos, 2011, Clinton, 1998). Maintaining the lycopene content of watermelon through processing may present a challenge for value-added products depending on the processing methods.

Watermelon is also the most abundant, natural source of citrulline (Rimando and Perkins-Veazie, 2005). High levels of citrulline form in watermelon as a combatant response to oxidative stress during drought (Akashi et al., 2001). Interest has increased in human consumption of citrulline, resulting in many epidemiological studies to determine its health benefits. One study determined that citrulline was an effective way to increase the recovery time for athletes, while also showing that watermelon is a more effective means of administration than supplements (Tarazona-Diaz et al., 2013). Figueroa et al. (2017) also showed that citrulline and watermelon supplementation offers an advantage to exercise performance. The study also indicated that that citrulline and watermelon supplementation lowers blood pressure at rest and may have implications for hypertension. Ventura et al. (2013) showed that citrulline supplements were an effective way to retain muscle function during a calorie-restricted diets in rats, implying that citrulline aids in maintaining muscle mass during weight-loss. Another study indicated that watermelon pomace juice increased arginine availability in obese rates with type II diabetes, resulting in improved glycemic control and a reduced risk for cardiovascular disease (Wu et al., 2007). Other studies have supported citrulline and watermelon’s beneficial impact on diabetes (Ahn et al., 2011). Maintaining the citrulline content of watermelon through value-added processing has not been extensively studied and is one of the focus areas of active research in this project.

A possible challenge for the future of value-added watermelon products is shelf-stability. As watermelon is a warm season crop, access to a natural source of lycopene and citrulline may be limited during off-season months. Maintaining a safe and high quality product during storage is a priority for value-added watermelon. A study conducted on freeze dried watermelon juice powder indicated that lycopene is stable in storage and the addition of sugar and citric acid may maintain the color (Arya et al., 1985). Arocho et al. (2012) found similar results, indicating that lycopene is stable in a dehydrated form up to a year. In regards to consumer acceptance, Chawla and Ranote (2009) determined that sensory perception of a dehydrated watermelon product decreased over six months, but remained acceptable for 'Sugarbaby' samples. Research to determine the water activity and pH of watermelon products over time is warranted, as these are the two main contributors to pathogenic microbial growth in products (FDA, 2001).

Conclusions

Value-added products offer an opportunity for growers to diversify, but can be met with challenges. Tomatoes for processing have been grown in California for the past 50 years, but opportunities exist in North Carolina. Challenges associated with processing tomato production include the high level of disease pressure associated with the hot and humid production environment of North Carolina and the potential effects on fruit composition. Research is warranted to determine viable cultivars and cultural practices to increase yields and meet the needs of processors. Watermelon has also been suggested as a value-added product, driven by the research on the associated health benefits of lycopene and citrulline. Challenges associated include how lycopene and citrulline translate into a processed product and the storage life of a watermelon products. Research is warranted to overcome these challenges so that they may offer an additional means of income for growers in North Carolina.

REFERENCES

Ahn, J., Choi, W., Kim, S., and Ha, T. Anti-diabetic effect of watermelon (*Citrullus vulgaris* Shrad) on Streptozotocin-induced diabetic mice. Food Science and Biotechnology 20 (1):251-254.

Akashi, K., Miyake, C., Yokota, A. 2001. Citrulline, a novel compatible solute in drought tolerant wild watermelon leaves, is an efficient hydroxyl radical scavenger. FEBS Letters 508 (3):438-442.

Allen, Arthur. 2010. Ripe: the search for the perfect tomato. Counterpoint Press. Berkeley, CA.

Alonso, A.D. 2011. Farmer's involvement in value-added produce: the case of Alabama growers. British Food Journal 113 (2):187-204.

Alsos, G.A., Ljunggren, E., Petterson, L.T. 2003. Farm-based entrepreneurs: what triggers the start-up of new business activities? Journal of Small Business and Enterprise Development 10 (4): 435-443.

Arocho, Y.D., Bellmer, D., Maness, N., McGlynn, W., and Rayas-Duarte, P. 2012 Watermelon pomace composition and the effect of drying and storage on lycopene content and color. Journal of Food Quality 35:331-340.

Arya, S.S. Premavalli, K.S., Siddiah, C.H., and Sharma, T.R. 1985. Storage behavior of freeze dried watermelon juice powder. Journal of Food Technology 20:351-357.

Barrett, D.M. and Anthon, G.E. 2008. Color quality of tomato products, p. 131-139. In: Culver, C et al. Color quality of fresh and processed foods. ACS Symposium Series, American Chemical Society, Washington, D.C.

Beach, R.H. Jones, A.S., Tooze, J.A. 2008. Tobacco farmer interest and success in income diversification. Journal of Agricultural and Applied Economics 40: 53-71.

Bergougnoux, Veronique. 2014. The history of tomato: From domestication to biopharming. Biotechnology Advances 32:170-189.

Bolotova, Y.V. 2016. Food manufacturing industry in South Carolina: an analysis of the size, structure, and performance. Journal of Food Distribution Research 47 (1):12-17.

Cahn, M.D., Herrero, E.V., Hanson, B.R., Snyder, R.L., Hartz, T.K., and Miyao, G. 2003. Effects of irrigation cut-off on processing tomato fruit quality. Acta Horticulturae 613: Proceedings of the Eighth International ISHS Symposium on the Processing Tomato. 75-80.

Clinton, S.K. 1998. Lycopene: chemistry, biology, and implications for human health and disease. Nutrition Review 56 (2):35-51.

Chawla R., and Ranote, P.S. 2009. Preparation and quality evaluation of dehydrated watermelon products. Journal of Food Science and Technology 46 (3):228-231.

Edwards, A.J., Vinyard, B.T., Wiley, E.R., Brown, E.D., Collins, J.K., Perkins-Veazie, P., Baker, R.A., Clevidence, B.A. 2003. Consumption of watermelon juice increases plasma concentrations of lycopene and beta-carotene in humans. Human Nutrition and Metabolism. 1043-1050.

Figueroa, A., Wong, A., Jaime, S.J., and Gonzales, J.U. 2017. Influence of L-citrulline and watermelon supplementation on vascular function and exercise performance. Curren Opinion in Clinical Nutrtion and Metabolic Care 20 (1):92-98.

Food and Drug Administration (FDA). 2001. Evaluation and definition of potential hazardous foods – Chapter 3. Factors that influence microbial growth. https://www.fda.gov/Food/FoodScienceResearch/SafePracticesforFoodProcesses/ucm094145.htm. Updated: 03/19/2015. Accessed: 03/10/2017.

Gann, J. 2016. Personal communication. T.W. Garner Food Company, Winston Salem, NC, USA

Garcia, E. and Barrett, D.M. 2006. Accessing lycopene content in California processing tomatoes. Journal of Food Processing and Preservation 30 (1):56-70.

Ghavipour, M., Saedisomeolia, A., Dialali, M., Sotoudeh, G., Eshraghyan, M.R., Moghadam, A.M., Wood, L.G. 2013 Tomato juice consumption reduces systemic inflammation in overweight and obese females. British Journal of Nutrition 109:2031-2035.

Gould, W.A. 1991. Tomato Production, Processing, and Technology. CTI Publications Inc. Baltimore, MD.

Grandillo, S., Zamir, D., Tanksley, S.D. 1999. Genetic improvement of processing tomato: a 20-years perspective. Euphytica 110:85-97.

Hakan, E., Mount, J., Chappelle, C., Lund, J., Medellin-Azuara, J., Moyle, P., Seavy, N. 2015. What if California's drought continues? Public Policy Institute of California. San Francisco, CA.

Hartz, T., Miyao, G., Mickler, J., Lestrange, M., Stoddard, S., Nunez, J., Aegerter, B. 2008. Processing tomato production in California. UC Vegetable Reseaerch & Information Center: Vegetable Production Series.

Jacques, P.F., Lyass, A., Massaro, J.M., Vasan, R.S., D'Agostino, R.B. 2013. Relationship of lycopene intake and consumption of tomato products to incident CVD. British Journal of Nutrition. 110:545-551.

Katz, J.P. and Boland, M. 2000. A new value-added strategy for the US beef industry: the case of US Premium Beef Ltd. Supply Chain Management: An International Journal. 5 (2):99-110.

Khachik, F., Carvalho, L., Bernstein, P.S., Muir, G.J., Zhao, D.Y., Katz, N.B. 2002. Chemistry, distribution, and metabolism of tomato carotenoids and their impact on human health. Experimental Biology and Medicine 227:845-851.

Kline, C.S., Joyner, L.E., Kirchoff, J.F., Crawford, A., Pitts, S.J., Wall-Bassett, E., Gurganus, C., Dunning, R., 2015 Gaps and barriers along the North Carolina agri-food chain. British Food Journal 118 (2):301-317.

Lucier, G. 1994. Tomatoes: a success story. Agricultural Outlook. July. Pgs. 15-17.

Mackinnon, E.S., Venket Rao, A., Rao, L.G. 2011. .Dietary restriction of lycopene for a period of one month results in significantly increased biomarkers in oxidative stress and bone resorption in postmenopausal women. The Journal of Nutrition 15 (2):133-138.

Martinez, S., Hand, M., Da Pra, M., Pollack, S., Ralston, K., Smith, T., Vogel, S. Charlk, S., Lohr, L. Low, S., Newman, C. 2010. Local food system: concepts, impacts, and issues. United State Department of Agricultural. Economic Research Service.

Miyao, G., Klonsky, K.M., Livingston, P. 2008. Sample costs to produce processing tomatoes transplanted in the Sacramento Valley. UC Cooperative Extension. https://coststudyfiles.ucdavis .edu/uploads/cs_public/5b/ee/5beec51c-f6e5-49cb-a358-8f748788c89a/tomatoessv1_2008.pdf. Accessed: 03/06/2017

Morris, J.R. and Brady, P.L. 2004. The Muscadine Experience: Adding Value to Enhance Profits, AAES Report 982, Arkansas Agricultural Experiment Station. http://arkansasagnews.uark.edu/Musc_Rev07_reduced4Web.pdf. Accessed: 01/25/2017.

North Carolina State University College of Agriculture and Life Sciences and North Carolina Department of Agriculture & Consumer Science (NCSU CALS and NCDA&CS). 2014. The North Carolina food processing and manufacturing initiative: an economic feasibility study.

The Packer. Tomato commodity pricing. http://www.thepacker.com/vegetables/tomatoes/ commodity-pricing. Accessed: 03/06/2017

Papaioannou, E.H., Liakopoulou-Kyriakides, M., Karabelas, A.J. 2016 Natural Origin Lycopene and “Green” Downstream Processing. Critical Reviews in Food Science and Nutrition 56:686-709.

Prasanna, V., Prabha, T.N., Tharanathan, R.N., Fruit ripening phenomena – an overview. Critical Reviews in Food Science and Nutrition.

Price, B.L. 1983. The political economy of mechanization in U.S. agriculture. Westview Press. Boulder, CO.

Rick, C.M. 1974. High soluble-solids content in large-fruited tomato lines derived from a wild green-fruited species. Hilgardia 42 (15):492-510.

Rimando, A.G. and Perkins-Veazie, P.M. 2005. Determination of citrulline in watermelon rind. Journal of Chromatograph A 1078:196-200.

Riggi, E., Patane, C., and Ruberto, G. 2008. Content of carotenoids at different ripening stages in processing tomato in relation to soil water availability. Australian Journal of Agricultural Research 59: 348-353.

Schouten, R.E., Farneti, B., Tijskins, L.M.M., Alarcon, A.A., and Woltering, E.J. 2014. Quantifying lycopene synthesis and chlorophll breakdown in tomato fruit using remittance VIS spectroscopy. Postharvest Biology and Technology 96:53-63.

Statista: The Statistics Portal. 2014. Top 10 fresh market tomato producing U.S. states in 2014.https://www.statista.com/statistics/193242/top-10- fresh-market- tomato-producing-states-in- the-us/ Accessed: 11/14/2016.

Tarazona-Diaz, M.P., Alacid, F., Carrasco, M., Martinez, I., and Aguayo, E. 2013. Watermelon juice: potential functional drink for sore muscle relief in athletes. Journal of Agricultural Food Chemistry 61:7522-7528.

United States Department of Agriculture, Economic Research Service (USDA-ERS). Tomatoes. http://www.ers.usda/.gov/topics/crops/vegetables-pulses/tomatoes.aspx. Accessed: 10/13/2016.

United States Department of Agriculture, Economic Research Service (USDA-ERS). U.S. Watermelon Industry. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do ?documentID=1399. Accessed: 2/28/17.

United States Department of Agriculture (USDA). 2015 California processing tomato report. 2015. NASS. Public Regional Field Office. Sacramento, CA.

United States Department of Agriculture (USDA). California processing tomatoes, 1920-2012. 2012. NASS. California Field Office. Sacramento, CA.

United State Department of Agriculture (USDA). Fruit and vegetable truck rate report. 2015. Agricultural Marketing Service. Fresno, CA.

Ventura, G., Noirez, P., Breuille, D., Godin, J.P., Pinaud, S., Cleroux, M., Choisy, C., Le Plenier, S., Bastic, V., Neveux, N., Cynober, L., and Moinard, C. 2013 Effect of citrulline on muscle function during moderate dietary restriction in healthy adult rats. Amino Acids 45:1123-1131.

Viuda-Martos, M., Sanchez-Zapata, E., Sayas-Barbera, E., Sendra, E., Perez-Alvarez, J.A., Fernandez-Lopez, J. 2011. Tomato and tomato byproducts. Human health benefits of lycopene and its application to meat products: a review. Critical Reviews in Food Science and Nutrition 54 (8):1032-1049.

Wu, G., Collins, J.K., Perkins-Vezie, P., Siddiq, M., Dolan, K.D., Kelly, K.A., Heaps, C.L., and Meininger, C.J. Dietary supplementation with watermelon pomace juice enhances arginine availability and ameliorates the metabolic syndrome in Zucker diabetic fatty rats. The Journal of Nutrition 137:2680-2685.

Young, T.E., Juvik, J.A., Sullivan, J.G. 1993. Accumulation of the components of total solids in ripening fruits of tomato. HortScience 118(2):286-292.

CHAPTER II

EVALUATION OF PROCESSING TOMATO CULTIVARS FOR A VALUE-ADDED NORTH CAROLINA PRODUCT

Abstract

The decline of North Carolina's manufacturing industry has left many unemployed and infrastructure underutilized in the rural parts of the state. North Carolina's Food Processing and Manufacturing Initiative aims to find new and diverse crops to supplement this decline. Processing tomatoes have been suggested, as North Carolina has a large tomato processor making a salsa product. Currently, the majority of processing tomatoes are grown in California where both the production and processing industry are well established. A study was designed to evaluate the feasibility of a processing tomato industry in North Carolina using cultivar evaluation for yield and post-harvest quality. Ten cultivars (HMX2905, HMX2906, HMX3881, HMX3882, MX3888, HMX4909, HMX7883, N6402, N6404, and SPESSO6415) were grown in 2015 and 2016 in a randomized complete block experimental design. The trials were grown on the farms of three commercial tomato growers with cultural practices managed by the grower. Among the three sites and two years, yield ranged from 3.21 mt/ha to 82.45 mt/ha. The tomato cultivar HMX2906 was consistently highest in marketable yield among sites and years. N6402 consistently had the highest soluble sugars content (4.8-7.1%), HMX4909 consistently fell within the desirable range for pH (<4.4), and HMX2905 was the highest in lycopene content (88.86 µg/g fwt to 114.84 µg/g fwt). These results indicate that processing tomato production in North Carolina is feasible, but further research will be needed to improve cultivar yield and post-harvest composition.

Introduction

Much of North Carolina’s economy is driven by agriculture and especially specialty crops. North Carolina’s major crops are unique compared to other agriculture-dominated states in that crops are for value-added products. Specifically, these major crops include tobacco for cigarettes, cotton for textiles, and forestry for furniture (NCSU CALS and NCDA&CS, 2014). These industries have declined in the last decade, as the result of increased regulations, changes in consumer trends, and increased foreign competition. This decline has had a major impact in the rural part of the state, where over 300,000 were left unemployed and infrastructure is underutilized (NCSU CALS and NCDA&CS, 2014).

In response to this decline, the North Carolina Food Processing and Manufacturing Initiative has focused on creative of value-added food products. The initiative’s objectives include finding new crops for growers for innovative products and aims to expand the agriculture and agribusiness economy by 22% by 2025, an estimated $100 billion impact for the state (NCSU CALS and NCDA&CS, 2014). This growth will be achieved through partnerships among universities, government organizations, and the entrepreneurial endeavors of start-ups and existing businesses. Consequently, this initiative will create new jobs through the state and diversify grower operations.

Processing tomatoes (*Solanum lycopersicum*, L.) have been suggested as a new crop for growers, as there is a pre-existing company with a well-established salsa product. Fresh market tomato production in North Carolina is well established; the state ranks fourth in production, producing 470,100 kg in 2013 (Statista, 2013). Processing tomatoes are not currently grown in the state. Though the same species as that used for fresh market production, the processing tomato growing system is vastly different. Processing tomatoes are a low input, high volume crop. The plants are grown on bare ground without staking and machine harvested.

California dominates the processing tomato industry with 95% of the industry share (USDA-ERS, 2016). In 2009, $1.1 billion processing tomatoes were sold (USDA-ERS, 2010). Processed tomato products include sauces, pastes, purees, juice, ketchup, and salsa. Consumption has steadily been on the rise since the 1960s, when production and processing technology became more efficient (Gould, 1992). Consumer awareness of tomatoes and processed tomato products for antioxidants also contributes to increased consumption (Clinton, 1998, MacKinon et al., 2011).

In the United States, processing tomatoes are bred for the dry, consistent California climate. In contrast, North Carolina has a wetter and humid environment, with regular 30^{o}C+ summer night temperatures. This presents a challenge of fruit set, which is optimal between night time temperatures of 15.5^{o}C – 21^{o}C (Maynard and Hochmuth, 2007). The high humidity in North Carolina is a challenge to growing processing tomatoes, creating high disease pressure from pathogens like early blight (*Alternaria solani*), late blight (*Phytophthora infestans*), southern blight (*Sclerotium rolfsii*), anthracnose (*Colletotrichum cereal*), and tomato spotted wilt virus (*Tospovirus* sp.) (Williamson, 2016).

Other expected challenges include the post-harvest quality of the fruit. Soluble solids content (SSC) is influenced by the amount of water applied during production and rainfall a few days before harvest can lower SSC. North Carolina can experience up to 50cm of precipitation in the production months, while California can experience as little as 2.5cm of precipitation during the production months (US Climate Data).

The objective of this study was to determine the feasibility of a processing tomato industry in North Carolina by evaluating processing tomato cultivars for yield and composition.

Materials and Methods

Ten processing tomato cultivars were selected for evaluation in 2015. These included HMX2905, HMX2906, HMX3881, HMX3882, HMX3888, HMX4909, and HMX7883 (HM Clause, Modesto, CA, USA). These cultivars were selected because of their strong disease resistance package. N6402, N6404, and SPESSO6415 (Nunhems, Bayer Seed Company, Leverkusen, Germany) were also selected. These cultivars were selected because of their current success in the established California processing tomato industry.

Transplants were grown on contract by a participating grower. Seeds were planted into a soilless media mix into polystyrene flats with inverted pyramid cells (cell size 25mm x 25mm x 75mm deep, Speedling, Ruskin, FL, USA). The transplants were misted throughout the day. No pesticides were applied during transplant production.

Field Design

Cultivars were tested in a complete randomized block design with three replications at three locations. Site locations were the same from 2015 to 2016.

Site 1 was located on the NC State Cunningham Research Station located in Kinston, North Carolina (longitude 35.304326, latitude -77.573349). The location’s soil type was a Norfolk loamy sand. In 2015, five rows were divided into ten 6.1m plots with 1.5m buffers between plots. The two outer rows acted as guard rows to prevent an edge effect. Tomatoes were transplanted at a 30cm x 30cm density into a black plastic mulch . In 2015, transplanting was done by hand on June 2 and the plants were harvested on August 28. In 2016, rows were divided into 3.5m plots with .75m buffers to separate plots. Planting density stayed at 30cm x 30cm, but were planted into a white plastic mulch (Triest Ag Goup, Inc, Greenville, NC) in 2016 to mitigate the high summer temperatures. Prior to planting, a 10-10-20 fertilizer was applied at a rate of 675 kg/ha lbs/ac and Telon II (Dow AgroScience, Indianapolis, IN, USA**)** was used for fumigation at a rate of 40 L/ha. In 2016, transplanting was done by hand on May 20 and plants were harvested on August 19.

Site 2 was a large scale, commercial vegetable farm located in Seven Springs, North Carolina (longitude 35.181733, latitude -77.783080). This farm was selected as an additional site because of grower interest. The location's soil type was a Pocalla loamy sand. In 2015, three rows were divided into 12.2m long plots with no space between plots. Plots spanned over two rows, with 1.5m in between rows. Tomatoes were transplanted every 61cm within rows into a white plastic mulch. In 2015, transplanting was done by hand on May 22 and plants were harvested on August 18. In 2016, the field design was similar but plot lengths were shortened to 10.4m and black plastic mulch was used by the grower. In 2016, transplanting was done by hand on May 23 and plants were harvested on August 15.

Site 3 was a hobby farm located in Mount Airy, North Carolina (longitude 36.429837, latitude -80.509471). This farm was selected as an additional site because of the proximity to the processor. In 2015, rows were divided into 8.6m plots with 1.5m buffers between plots. Tomatoes were transplanted at a 43cm x 30cm density into a black plastic mulch. In 2015, transplanting was done on May 20 and plants were harvested on August 4. The field design was the same for 2015 and 2016. In 2016, transplanting was done on May 25 and plants were harvested on August 29.

Tomatoes were grown in accordance with the southeastern manual for tomato production (UGA Extension). Fertility, irrigation, and pest control were managed at the discretion of the grower. This allowed growers the freedom to work in a system they were familiar with while not disrupting their other operations.

Harvest Data Collection

Harvest was done by hand in an "once-over" fashion to emulate a machine harvest. A minimum of three random plants were chosen within the plot for harvest. If yields were low, additional plants were selected until 20 marketable fruit were harvested for fruit compositional analysis. Plants were cut off at the soil level and all fruit were removed by hand. The fruit were hand graded into under-ripe, ripe and marketable, over-ripe, and culls. Culls were defined as fruit with less than 10% damage (Gould, 1992). Under-ripe was self-defined as anything with less than 50% color breakage and over-ripe was anything that appeared marketable, but was starting to soften or show other signs of age. Individual grades were weighed and marketable fruit were counted.

Post-Harvest Data Collection

After harvest, twenty marketable fruit were cut widthwise into approximately 2.5cm sections, frozen at -20^{o}C, and stored at -80^{o}C until fruit composition analysis could be done at the Plants for Human Health Institute in Kannapolis, NC. From each field plot, fruit were separated into four sub samples. Fruit were thawed and prepped for analyses through double blending. Fruit were first blended by a laboratory grade blender (Waring Commercial, Torrington, CT, USA) and then pureed by a homogenizer (Polytron, Kinematic Ag, Luzernerstrasse, Switzerland).

Data collected for post-harvest composition analysis included soluble solids content (SSC), pH, and lycopene. SSC was measured with a handheld digital refractometer (Atago USA, Bellevue, WA, USA). In 2015, 5mL of pureed sample were weighed and diluted with 60mL of deionized water. Afterwards, the samples were measured for pH using a compact titrosampler (Metrohm, Herisau, Switzerland). In 2016, a pH meter (Hach, Loveland, CO, USA) was used. For measurement of lycopene concentration, 2mL of the tomato puree were diluted in 18mL of deionized water. Sample absorbance at 560 and 700nm was measured using an UltraScan PRO colorimeter (Hunter Ultra Hunter Lab, Reston, VA, USA). Total lycopene content was calculated using the formula (Abs560-Abs700)*DF(wt/volume)* slope (28) and expressed as μg/g fresh weight (fwt).

Data Analysis

Harvest data was scaled to metric tons/hectare (mt/ha). Marketable yield and total yield for harvest were analyzed as the response variable for harvest data. Total yield was defined as the total output of the plant. This was defined as marketable fruit, under and over ripe fruit, and culls. For post-harvest quality data, SSC, pH, and lycopene content were analyzed as the response variables. Cultivars were analyzed within site and within year and as a one-way ANOVA using PROC GLIMMIX with SAS 9.3 (SAS Institute, Cary, NC, USA). Means were separated by Fischer’s least significance difference at $P \leq 0.05$.

Results

Harvest

Site 1. Marketable and total yields differed among most cultivars with yield (Table 1.1) Marketable and total yields in 2015 at site 1 were 21.05 to 49.16 mt/ha and 42.64 to 78.46 mt/ha respectively and did not differ statistically among cultivars (Table 1.1). Despite the lack of significant differences in yields, the cultivars HMX3882, HMX2906, and N6402 had the highest marketable yield and potential yields compared to HMX4909, HMX2905, and SPESSO6415. In 2016, marketable and total yields were 16.92 to 69.22 mt/ha and 21.05 to 82.02 mt/ha respectively (Table 1.1). HMX7883 and HMX3888 had statistically higher marketable and total yields than HMX2905, HMX3882, N6402, N6404, and SPESSO6415.

Site 2. Marketable and total yields were more similar across years than at site 1, but cultivars still differed in yield year by year (Table 1.2). In 2015, there were no statistical differences among cultivars in marketable or total yield, although N6404 and HMX7883 had higher marketable and total yield compared to HMX2906 and SPESSO6415. Marketable and total yield were 28.49 to 51.58 mt/ha and 45.42 to 69.99 mt/ha respectively (Table 1.2). In 2016, the cultivars HMX2906, HMX7883, and N6404 had high marketable yields and total yields compared to N6402, HMX2905, and SPESSO6415. Marketable and total yield were 36.14 to 82.45 mt/ha and 43.51 to 87.22 mt/ha respectively (Table 1.2).

Site 3. Yields were much lower at site 3 than at sites 1 or 2 in 2015 and 2016 (Table 1.3). In 2015, the cultivars N6402, HMX3882, N6404, and HKX2906 were higher in marketable yield compared to the other cultivars. The total yield of HMX7883, N6402, N6404, and SPESSO6415 were statistically higher than that of other cultivars. Marketable and total yield were 3.09 to 15.42 mt/ha and 13.56 to 28.74 mt/ha respectively (Table 1.3). Marketable yields and total yields, which ranged from 3.21 to 27.26 mt/ha and 9.50 and 39.05 mt/ha respectively, in 2016 did not differ statistically among cultivars. However, HMX7883 had an increase of 18 to 22 mt/ha compared to other cultivars.

Post-Harvest Compositional Differences

Site 1. The SSC of tomatoes from site 1 was slightly lower in 2015 than in 2016 and ranged from 4.7% to 5.9% (Table 1.4). The cultivars HMX4909, N6402, and N6404 were highest and HMX3882 and HMX7883 were lowest in SSC in 2015. In 2016, the cultivars HMX2906, HMX3881, HMX3882, HMX4909, N6402, and N6404 were higher and HMX3888, HMX7883, and SPESSO6415 lower in SSC.

Tomato pH ranged from 3.37 to 4.73 (Table 1.4). Fruit of HMX3881, HMX3888, and HMX4909 were lowest in pH, while HMX2905, HMX2906, and HMX7883 were highest in 2015. Fruit of HMX4909 was again lowest in pH for 2016, while HMX2905, HMX3882, HMX3888, and HMX7883 were highest in pH.

Total lycopene content was slightly higher in tomatoes from 2016 than those from 2015 and ranged from 68.87 to 114.84 ug/g fwt (Table 4). In 2015, fruit from HMX2905 was highest in total lycopene content, while HMX3881, HMX3882, HMX3888, and SPESSO6415 fruit were lowest. In 2016, fruit from HMX2905 and HMX3882 were highest in lycopene content and fruit from HMX7883was lowest in lycopene content.

Site 2. Tomato SSC was lower than in site 1 (Table 1.5) and ranged from 4.5 to 4.9. No significant differences were found among cultivars in 2015 or 2016.

Tomato pH was higher in 2016 than in 2015 and ranged from 4.17 to 4.59 (Table 1.5). In 2015, HMX2906, N6402, and SPESSO6415 were significantly lower in tomato fruit pH compared to HMX2905, HMX3881, HMX3888, HMX4909, HMX7883, and N6404. In 2016, fruit of HMX4909 and SPESSO6415 were lowest in pH and HMX7883 was highest.

Total lycopene content was inconsistent with year among cultivars and ranged from 61.48 to 96.04 ug/g fresh weight (Table 1.5). HMX3888 was highest and HMX2906 and HMX38881 were lowest in total lycopene content in 2015. In 2016, HMX2905 was highest and HMX7883 was lowest in total lycopene content.

Site 3. SSC was considerably higher than at the other sites for both years and ranged from 5.2 to 7.3 (Table 1.6). The cultivars HMX3881, HMX4909, N6402, and N6404 were highest and HMX2905, HMX3888, and SPESSO6415 were lower in SSC for 2015. In 2016, the cultivars HMX3881, HMX3882, and N6402 were highest for SSC compared to HMX2906, HMX7883, N6404, and SPESSO6415.

Tomato pH was generally lower than at sites 1 and 2 and ranged from 4.06 to 4.49 (Table 1.6). Tomatoes from HMX3881, HMX3882, HMX4909, N6402, N6404, and SPESSO6415 were lowest in pH compared to the other cultivars. In 2016, pH was lowest from fruit of HMX2906, HMX4909, and SPESSO6415 cultivars compared to HMX3882, HMX3888, and HMX7883.

Total lycopene content of fruit from HMX2905 and HMX3882 were highest in total lycopene content in both 2015 and 2016, respectively. HMX3881 was also highest in total lycopene at site 3, as well as at site 2, in 2015.

Discussion

The average yield for processing tomatoes is 33.6 mt/ha (Maynard and Hochmuth, 2007) and it not uncommon for California processing tomato yields to exceed 45.4 mt/ha (Aegerter et al., 2013). In this study, the cultivars HMX2906 and HMX7883 were the most consistent in yield response, with the most frequent highest marketable yields across the 3 site in both 2015 and 2016 (Tables 1.1, 1.2, 1.3). N6402 also had higher marketable yields across the three sites in 2015, but was low in marketable yield in 2016. The cultivars HMX3888 and HMX4909 had lower marketable yields when averaged across the three sites for both years. Disparity in yields across years, as seen with N6402, can be problematic as growers depend on the performance of a suggested cultivar.

Total yield was also considered for as an indicator of cultivar suitability. Total yield was defined as the marketable yield plus under ripe and over ripe tomatoes. Marketable yields across sites were 30 to 60% of the total yields. This large difference is likely due to the absence of a ripening hormone to maximize the once-over harvest. It is possible for some of the total yield to be captured as marketable yield through cultural practices that were no in place during this study, such as better insect and disease control, water management, harvest time, and applications of a ripening hormone. IN 2016, HMX2906 and HMX7883 had a greater total yield than the average yield for processing tomatoes of 82.9 mt/ha.

As part of processing tomato contracts with processors, compositional standards of SSC, red color, low pH, and low mold are required to ensure a consistent product across sites and years.

Soluble solids content is used as an approximate measurement of the sugar solution within the tomato fruit. Processors require tomatoes for processing to have a higher soluble solids content, generally 7.0-7.5%; this translates into the sweetness and viscosity of the processed product (Young et al., 1993, Rick, 1974). N6402 was highest in SSC at all three locations in both 2015 and 2016. HMX4909 and N6404 were also high in SSC across sites and years. In contrast, HMX7883 and SPESSO6415 were lowest in SSC across sites and years.

Tomatoes from site 3 were considerably higher in SSC compared to the other sites. The difference may be from the inverse relationship between SSC and yield in tomatoes as documented by Gould (1992). Site 3 was much lower in total and marketable yields compared to the other two sites. Another cause of higher SSC may be from water stress. It is a commercial practice in California to decrease irrigation rates prior to harvest to raise the SSC (Hartz et al., 2008). While this was not done intentionally during the experiment, environmental monitoring of site 3 showed a period of limited rainfall two weeks before harvest that may have impacted the soluble solids content of the fruit.

In processed tomatoes, pH is required to be below 4.4 (FDA, 2015). This is for perceived acidity to improve flavor of the processed product and to restrict the growth of microbial pathogens like *Clostridium botulinum* (FDA, 2015). The sterilization times and temperature of the processing line is influenced by product pH. Generally, a lower temperature is required for sterilization as pH decreases (Gould, 1992).

Of the cultivars, HMX4909 was the only cultivar whose fruit consistently fell within the required range of <4.4. HMX4909 was also consistently lowest at two sites in 2015 and all three sites in 2016 (Table 1.4, 1.5, 1.6), making it the best cultivar for the desired pH values. SPESSO6415 was also found to have a desirable pH, as it was the lowest at two sites in 2015 and 2016. Conversely, HMX7883 and HMX2905 were consistently highest in pH. In a study conducted by Renquist et al. (2001), it was found that production temperature can accelerate a rise in fruit pH. The authors suggested that earlier harvests are an appropriate to achieve desirable pH ranges in fruit, if other quality parameters are met. It is possible that plants were harvested too late in our study, decreasing the post-harvest compositional quality of fruit of some cultivars.

A high lycopene content is desired because consumers perceive a redder product as a healthier product (Barrett and Anthon, 2008, Papaioannou et al., 2016). Lycopene content, the main contributor to the red pigment of tomatoes, becomes predominant when chlorophyll begins to degrade and the photosynthesis mechanism slows and is associated with ripening (Prasana et al., 2007, Riggi et al., 2008). The change in color is also associated with the conversion of the chloroplast to the chromoplast within the cells (Schouten et al., 2014). Total lycopene content in California can range from 75.8 to 101.3 µg/g fwt depending on location and cultivar (Garcia and Barrett, 2006).

HMX2905 was consistently highest among cultivars for lycopene content across sites and years, with values ranging from 88.28 to 114.84 µg/g fwt (Table 1.4, 1.5, 1.6). SPESSO6415 was consistently lowest among cultivars for lycopene content across sites and years, at 61.48 to 86.20 µg/g fwt. One method used by growers to influence the ripening process and increase lycopene content is through application of a ripening agent, such as ethephon. This promotes an earlier harvest and more uniform color (Hartz et al., 2008).

Of the ten cultivars evaluated, none were consistent in all the measure yield and fruit quality parameters. Although HMX2906 was one of the highest yielding cultivars (Table 1.1, 1.2, 1.3), it had the fewest no desirable processing qualities, being high in pH, low in SSC, and low in total lycopene content (Table 1.4, 1.5, 1.6). In contrast, N6402 was consistently highest in SSC (Table 1.4, 1.5, 1.6), but was inconsistent in yield (Table 1.1, 1.2, 1.3). HMX4909 consistently fell within the desired pH range (<4.4) (Table 1.4, 1.5, 1.6), but had a lower yield in 2015 and an average yield in 2016 (Table 1.1, 1.2, 1.3). HMX2905 was consistently highest in lycopene content (Table 1.4, 1.5, 1.6), but was low in yield and SSC and high in pH (Table 1.1, 1.2, 1.3, 1.4, 1.5, 1.6). It is likely that more than one cultivar will need to be planted in production so that high yields and acceptable post-harvest qualities can be achieved.

HMX2905, HMX2906, HMX3881, HMX3882, HMX3888, HMX4909, and HMX7883 were originally bred for production in Argentina and selected for their disease resistance package (Hannah, 2016), primarily for resistance to tomato spotted wilt virus which can be nearly impossible to control once introduced in the field. Growing conditions in the humid southeast, as well as sporadic rainfall events during harvest will make cultivar selection for processing tomato challenging. A processing tomato cultivar for the more humid conditions in the eastern U.S. may be better than adapting cultivars bred for very different climatic conditions.

Conclusions

Processing tomato production in North Carolina remains a possibility despite the challenges. In this initial screening, none of the cultivars met all criteria, although some cultivars were acceptable for individual characteristics among yield and fruit composition. These results indicate a need to evaluate the effectiveness of cultural practices to maximize cultivar response of the most promising cultivars (HMX2906 and HMX7883), as well as a need to continue cultivar screening.

REFERENCES

Aegerter, B., Barrett, D., Hartz, T., Le Strange, M., Stoddard, S., Turini, T., Lundy, M. 2013. UCCE statewide processing tomato variety evaluation trials, 2013. UC Vegetable Reseaerch & Information Center: Vegetable Production Series.

Barrett, D.M. and Anthon, G.E. 2008. Color quality of tomato products, p. 131-139. In: Culver, C. et al. Color quality of fresh and processed foods. ACS Symposium Series, American Chemical Society, Washington, D.C.

Clinton, S.K. 1998. Lycopene: chemistry, biology, and implications for human health and disease. Nutrition Review 56 (2):35-51.

Food and Drug Administration (FDA). 2015. Evaluation and Definition of Potentially Hazardous Foods – Chapter 3. Factors that Influence Microbial Growth. https://www.fda.gov/Food/FoodScienceResearch/SafePracticesforFoodProcesses/ucm094145.htm. Accessed: 02/26/2017

Garcia, E. and Barrett, D.M. 2006. Accessing lycopene content in California processing tomatoes. Journal of Food Processing and Preservation 30 (1):56-70.

Gould, W.A. 1992. Tomato production, processing, and technology. CTI Publications Inc. Baltimore, MD.

Hannah, M. 2016. Personal communication. HM Clause, Modesto, CA, USA.

Hartz, T., Miyao, G., Mickler, J., Lestrange, M., Stoddard, S., Nunez, J., Aegerter, B. 2008. Processing tomato production in California. UC Vegetable Reseaerch & Information Center: Vegetable Production Series.

Mackinnon, E.S., Venket Rao, A., Rao, L.G. 2011. Dietary restriction of lycopene for a period of one month results in significantly increased biomarkers in oxidative stress and bone resorption in postmenopausal women. The Journal of Nutrition 15 (2):133-138.

Maynard, D.N. and Hochmuth, G.J. 2007. Knott's Handbook for Vegetable Growers. 5th edition. John Wiley & Sons, Inc. Hoboken, New Jersey.

North Carolina State University College of Agriculture and Life Sciences and North Carolina Department of Agriculture & Consumer Science (NCSU CALS and NCSDA&CS). 2014. The North Carolina food processing and manufacturing initiative: an economic feasibility study.

Papaioannou, E.H., Liakopoulou-Kyriakides, M., and Karabelas, A.J. 2016. Natural Origin Lycopene and “Green” Downstream Processing. Critical Reviews in Food Science and Nutrition 56:686-709.

Prasanna, V., Prabha, T.N., and Tharanathan, R.N. Fruit ripening phenomena - an overview. Critical Reviews in Food Science and Nutrition 47:1 1-19.

Renquist, A.R, English, J.M., and Reid J.B. 2001. Temperature, but not ethephon, influences fruit pH of processing tomato. HortScience 36(4):661-663.

Rick, C.M. 1974. High soluble-solids content in large-fruited tomato lines derived from a wild green-fruited species. Hilgardia 42 (15):492-510.

Riggi, E., Patane, C., and Ruberto, G. 2008. Content of carotenoids at different ripening stages in processing tomato in relation to soil water availability. Australian Journal of Agricultural Research 59: 348-353.

Schouten, R.E., Farneti, B., Tijskins, L.M.M., Alarcon, A.A., and Woltering, E.J. 2014. Quantifying lycopene synthesis and chlorophyll breakdown in tomato fruit using remittance VIS spectroscopy. Postharvest Biology and Technology 96:53-63.

Statista: The Statistics Portal. 2013. Top 10 fresh market tomato producing U.S. states in 2013. https://www.statista.com/statistics/193242/top-10- fresh-market- tomato-producing-states-in- the-us/ Accessed: 10/17/2016.

United States Department of Agriculture, Economic Research Service (USDA-ERS). Tomatoes. http://www.ers.usda/.gov/topics/crops/vegetables-pulses/tomatoes.aspx. Accessed: 10/13/2016.

United States Department of Agriculture, Economic Research Service (USDA-ERS). U.S. Tomato Statistics. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1210. Updated: 07/2010. Accessed: 10/13/2016.

University of Georgia (UGA) Extension. Commercial tomato production handbook.

US Climate Data. http://www.usclimatedata.com/climate/united-states/us Accessed: 04/08/2017.

Williamson, J. 2016. Tomato Diseases and Disorders. http://www.clemson.edu /extension /hgic/pests/plant_pests/veg_fruit/hgic2217.html. Accessed: 2/27/2017

Young, T.E., Juvik, J.A., Sullivan, J.G. 1993. Accumulation of the components of total solids in ripening fruits of tomato. HortScience 118(2):286-292.

Table 1.1. Effect of cultivar on marketable yield and total yield in field grown processing tomatoes at site 1 in the 2015 and 2016 growing seasons.

	2015		2016	
Cultivar	Marketable Yield[z] (mt/ha)	Total Yield[y] (mt/ha)	Marketable Yield (mt/ha)	Total Yield (mt/ha)
HMX2905	21.05	42.64	16.92c[x]	21.05c
HMX2906	49.16	74.31	42.75b	55.98ab
HMX3881	32.77	59.36	33.85bc	42.32bc
HMX3882	49.81	78.46	20.69bc	28.69bc
HMX3888	24.41	66.40	65.52a	79.85a
HMX4909	22.91	48.31	27.69bc	33.20bc
HMX7883	40.04	60.21	69.22a	82.02a
N6402	47.52	68.37	24.73bc	30.17bc
N6404	36.79	72.86	24.75bc	41.22bc
SPESSO6415	29.07	46.65	36.25bc	43.40bc
PR > F	0.0515	0.507	0.0008	0.0044

[z] Marketable yield was determined by collecting all red fruit with less than 10% damage from three plants per plot

[y] Total yield was determined by collecting all fruit, under ripe, marketable, over ripe, and culls, from three plants per plot

[x] Means separated by Fischer’s least significant difference, significance level of $P \leq 0.05$. Means within columns followed by the same letter are not significantly different.

Table 1.2. Effect of cultivar on marketable yield and total yield in field grown processing tomatoes at site 2 in the 2015 and 2016 growing seasons.

	2015		2016	
Cultivar	Marketable Yield[z] (mt/ha)	Total Yield[y] (mt/ha)	Marketable Yield (mt/ha)	Total Yield (mt/ha)
HMX2905	46.22	59.56	38.51de[x]	43.51d
HMX2906	38.89	50.93	82.45a	87.22a
HMX3881	43.29	54.85	56.20bcde	67.59abc
HMX3882	40.69	55.66	61.75bc	67.59abc
HMX3888	44.43	54.85	55.01bcde	71.64ab
HMX4909	45.57	66.09	57.31bcd	73.46ab
HMX7883	49.63	69.99	70.52ab	85.92a
N6402	45.24	64.61	36.14e	49.16cd
N6404	51.58	79.42	63.69abc	77.90ab
SPESSO6415	28.49	45.42	49.59cde	60.21abc
PR > F	0.8499	0.2341	0.0058	0.0050

[z] Marketable yield was determined by collecting all red fruit with less than 10% damage from three plants per plot

[y] Total yield was determined by collecting all fruit, under ripe, marketable, over ripe, and culls, from three plants per plot

[x] Means separated by Fischer's least significant difference, significance level of $P \leq 0.05$. Means within columns followed by the same letter are not significantly different.

Table 1.3. Effect of cultivar on marketable yield and total yield in field grown processing tomatoes at site 3 in the 2015 and 2016 growing seasons.

	2015		2016	
Cultivar	Marketable Yield[z] (mt/ha)	Total Yield[y] (mt/ha)	Marketable Yield (mt/ha)	Total Yield (mt/ha)
HMX2905	8.99bcd[x]	15.27de	4.89	9.50
HMX2906	10.09abc	21.63cde	5.36	11.25
HMX3881	9.62bcd	28.74a	5.60	10.11
HMX3882	15.42ab	25.35abc	9.35	15.62
HMX3888	3.09d	18.00bcde	7.80	29.55
HMX4909	4.57cd	13.56e	3.21	25.11
HMX7883	7.87cd	16.41bcde	27.26	39.05
N6402	16.99a	26.48ab	7.20	24.05
N6404	10.33abc	25.76ab	3.21	16.84
SPESSO6415	9.98bcd	21.59abcd	3.52	21.90
PR > F	0.0167	0.0129	0.0532	0.1346

[z] Marketable yield was determined by collecting all red fruit with less than 10% damage from three plants per plot

[y] Total yield was determined by collecting all fruit, under ripe, marketable, and over ripe, from three plants per plot

[x] Means separated by Fischer’s least significant difference, significance level of $P \leq 0.05$. Means within columns followed by the same letter are not significantly different.

Table 1.4. Effect of cultivar on fruit composition of processing tomatoes at site 1 in the 2015 and 2016 growing season.

	2015			2016		
Cultivar	Brix (°)	pH	Total Lycopene Content (µg/g fwt)	Brix (°)	pH	Total Lycopene Content (µg/g fwt)
HMX2905	5.2bc[z]	4.73a	109.02a	5.6abc	4.62ab	114.84a
HMX2906	4.9cde	4.64ab	86.08bcd	5.5bc	4.51bc	90.41cd
HMX3881	5.0cde	4.37d	79.64de	5.9a	4.45c	91.40cd
HMX3882	4.7e	4.57bc	81.54cde	5.8a	4.59ab	105.35ab
HMX3888	5.0bcde	4.40cd	68.87e	5.1d	4.66a	81.32d
HMX4909	5.4ab	4.40cd	89.36bc	5.8a	4.26d	85.72d
HMX7883	4.7de	4.62ab	87.81bcd	5.3cd	4.59ab	91.41cd
N6402	5.4ab	4.58bc	87.01bcd	5.9a	4.53bc	102.87b
N6404	5.5a	4.57bc	93.42b	5.6ab	4.51bc	96.58bc
SPESSO6415	5.1cde	4.56bc	81.20cde	5.1d	4.43c	86.20cd
PR > F	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[z] Means separated by Fischer's least significant difference, significance level of $P \leq 0.05$. Means followed by the same letter are not significantly different.

Table 1.5. Effect of cultivar on fruit composition of processing tomatoes at site 2 in the 2015 and 2016 growing season.

	2015			2016		
Cultivar	Brix (°)	pH	Total Lycopene Content (µg/g fwt)	Brix (°)	pH	Total Lycopene Content (µg/g fwt)
HMX2905	4.7	4.40ab[z]	88.28bc	4.5	4.45cd	93.14a
HMX2906	4.7	4.30bc	72.44f	4.2	4.42cd	78.94bc
HMX3881	4.5	4.54a	78.47ef	4.7	4.38ef	74.08bcd
HMX3882	4.6	4.36b	80.77de	4.7	4.51b	86.28ab
HMX3888	4.8	4.47ab	96.04a	4.7	4.50bc	72.43cd
HMX4909	4.6	4.41ab	87.44bcd	4.3	4.36f	73.82bcd
HMX7883	4.7	4.45ab	84.37bcde	4.4	4.59a	55.74e
N6402	4.8	4.17c	91.33ab	4.9	4.52b	74.49bcd
N6404	4.7	4.44ab	83.89cde	4.5	4.53b	84.84abc
SPESSO6415	4.9	4.31bc	83.64cde	4.4	4.37ef	61.48de
PR > F	0.6763	0.0049	<0.0001	0.3021	<0.0001	<0.0001

[z] Means separated by Fischer’s least significant difference, significance level of $P \leq 0.05$. Means followed by the same letter are not significantly different.

Table 1.6. Effect of cultivar on fruit composition of processing tomatoes at site 3 in the 2015 and 2016 growing season.

	2015			2016		
Cultivar	Brix (°)	pH	Total Lycopene Content (µg/g fwt)	Brix (°)	pH	Total Lycopene Content (µg/g fwt)
HMX2905	6.5d[z]	4.41ab	95.03a	6.1bc	4.36bc	112.82a
HMX2906	6.5cd	4.41ab	66.60de	5.4cd	4.06d	86.47bc
HMX3881	7.27a	4.20cd	96.69a	6.4ab	4.27c	93.44b
HMX3882	6.5cd	4.27bcd	95.85a	7.0a	4.45ab	110.82a
HMX3888	6.4d	4.35abc	78.02bcd	5.2d	4.41ab	85.28bc
HMX4909	7.3a	4.29abcd	78.02bcd	6.4ab	4.12d	82.61bc
HMX7883	6.6bcd	4.49a	62.43e	5.7bcd	4.48a	94.47b
N6402	7.1ab	4.26bcd	90.17ab	6.3ab	4.28c	95.03b
N6404	7.0abc	4.16d	85.82abc	5.8bcd	2.25c	95.59b
SPESSO6415	6.2d	4.16cd	71.43cde	5.8bcd	4.13d	78.74c
PR > F	<0.0001	0.0123	<0.0001	0.0001	<0.0001	<0.0001

[z] Means separated by Fischer’s least significant difference, significance level of $P \leq 0.05$. Means followed by the same letter are not significantly different.

CHAPTER III

PROCESSING TOMATO RESPONSE TO ETHPHON APPLICATION IN NORTH CAROLINA

Abstract

Best cultural practices relative to processing tomato cultivars are needed for successful adaptation in the hot and humid production environment of North Carolina. One cultural practice traditionally used in processing tomato production is ethephon application, commonly use to promote earlier and more uniform tomato ripeness and color. A study was done to determine best ethephon application rates for processing tomatoes grown in North Carolina relative to yield and post-harvest composition. Five treatments were evaluated (0 L/ha, 0.24 L/ha, 0.47 L/ha, 0.94 L/ha, and 1.41 L/ha) in 2016 using a randomized complete block design. Marketable yields ranged from 10.58 to 45.73 mt/ha. A rate of 0.47 L/ha ethephon application gave the highest marketable yield. Application rate had no effect on total yield. Tomato composition was highest in SSC for 0 and 0.47 L/ha application rate. Tomato pH was highest at the 1.41 L/ha rate and lowest for 0 L/ha (control). Total lycopene content was lowest from fruit with the 1.41 L/ha ethephon rate. This preliminary data indicates that ethephon application rate could be reduced from the label rate of 0.59 to 1.53 L/ha, given the warm growing environment in North Carolina.

Introduction

Processing tomato represents to 89% of the total tomato production in the United States, and 95% of production is in California (USDA ERS, 2016). Processing tomatoes are used for tomato sauces, pastes, purees, juice, soup, ketchup, and salsa, with a value of over $1.2 billion in 2009 (USDA ERS, 2010).

Interest in processing tomato production in North Carolina has been stimulated by the presence of a large salsa processor. North Carolina growers are familiar with fresh market tomato production, which is generally a high input crop, requiring plastic mulch, staking, hand labor harvesting, and cultivars selected for large size in good firmness (Ivors, 2010). In contrast, processing tomatoes are a low input, high-volume crop, grown on bare ground without staking, once-over machine harvested, and cultivars are selected for high SSC, lycopene, and uniform size. In contrast to fresh market tomatoes, a ripening hormone (ethephon) is sprayed on processing tomatoes two weeks prior to harvest.

Ethephon, used to maximize red color uniformity in tomato in once-over machine harvest, was discovered in 1965 and registered in 1973 (US EPA/NCEPI, 1995). Ethephon acts by liberating ethylene, thus promoting fruit ripening (Extoxnet, 1995) and absorption of ethephon increases with high temperatures (Kretchman et al., 1974). Suggested rates of Ethrel brand ethephon plant regulator (Bayer CropScience, Leverkusen, Germany) recommends 0.58 L/ha to 1.53 L/ha, depending on the temperature of production location (CALS NCSU, 2017).

Processors generally measure the product color to a hue angle of 20-26 (bright red) (Garcia and Barrett, 2006). Lycopene, the main contributor to the red color of tomatoes, increases with ripening and is an antioxidant that has been shown to lower the risk of cancer and cardiovascular diseases (Clinton, 1998, MacKinnon et al., 2011). A high lycopene content is required by processors, as consumers perceive redder products as healthier and higher quality and it creates a uniformly colored product (Barrett and Anthon, 2008, Papaioannou et al., 2016).

The objective of this study was to evaluate the performance of processing tomato cultivars following an ethephon application when grown under the warm and humid North Carolina production environment and measure the impact on yield and compositional fruit quality.

Materials and Methods

The tomato cultivar N6404 (HM Clause, Modesto, CA, USA) was used for the experiment. Seeds were planted into a soilless media mix into polystyrene flats with inverted pyramid cells (cell size 25mm x 25mm x 75mm deep, Speedling, Ruskin, FL, USA) for transplant production. The transplants were grown in a greenhouse on mist benches. No pesticides were applied during transplant production.

The experiment was conducted in 2016 at Cunningham Research Station in Kinston, North Carolina (longitude 35.304326, latitude -77.573349), on a Norfolk loamy sand. The location's soil type was a Norfolk loamy sand. Before transplanting, a 10-10-20 fertilizer was applied at a rate of 672.511and Telone II (Dow AgroSciences, Indianapolis, IN, USA**)** was used for fumigation at a rate of 60.80 L/ha. Experiment 1 was planted on May 23. Rows were divided into 3.5m plots with .75m buffers. Tomatoes were transplanted a density of 30cm x 30cm. Plants were grown on a white plastic (Triest Ag Group, Inc., Greenville, NC, USA) mulch and drip irrigated. Irrigation rates were adjusted accordingly as rainfall was inconsistent throughout production.

Ethephon (Boll Buster Cotton Defoliant, Loveland Products, Loveland, CO, USA) treatments were arranged in a randomized complete block design with four replications. Ethephon was applied at rates of 0 L/ha, 0.24 L/ha, 0.47 L/ha, 0.94 L/ha, and 1.41 L/ha. Applications were made with a backpack sprayer on August 5, which had a max/min temperature of 32/27^{o}C and 1.27cm of precipitation prior to spray application.

Harvest Data Collection

A once-over hand harvest was done to mimic a commercial machine harvest. A minimum of three plants per plot were randomly chosen for yield data. If necessary, additional plants were harvested until a total of at least 20 marketable fruit were collected for tomato compositional analysis. Plants were cut off at the base and all fruit were hand-picked from the vine. The fruit were hand graded into under-ripe, marketable, over-ripe, and culls. Under-ripe tomatoes were defined as fruit that were less than 50% color. Marketable fruits were defined as those with less than 10% damage and more than 50% color. Over-ripe was defined as those that were marketable, but starting to show signs of being on the vine too long, such as wrinkling or loss of texture. Culls were defined as any tomatoes that had more than 10% damage from abiotic stress, disease pressure, or insect damage. Individual grades were weighed.

Post-Harvest Data Collection

After harvest, twenty marketable fruit from each plot were cut into 2.5cm diameter intersections and frozen at -20^{o}C and held at -80^{o}C until compositional analysis was done in January 2017 at the Plants for Human Health Institute, Kannapolis, North Carolina. The marketable fruit were divided into four subsamples. Fruit were thawed, blended by a laboratory blender (Waring Commercial, Torrington, CT, USA), then pureed using a homogenizer (Polyton, Kinematic Ag, Luzernerstrasse, Switzerland).

Samples were tested for SSC, pH, and lycopene content. SSC was determined by placing a 0.5 ml puree on a digital refractometer (Atago PR-1, Bellevue, WA, USA). For pH, 5g of pureed sample were diluted with 60ml of deionized water and measured using a compact titrosampler (Metrohm, Herisau, Switzerland). Total lycopene content was done using colorimeter equipped with a xenon lights (UltraScan PRO Colorimeter, Hunter Lab, Reston, VA, USA). Absorbance of 2 g of tomato puree and 18 ml of deionized water was made at 560 and 700 nm using an UltraScan PRO (Hunger Lab, Reston, VA, USA) 2ml of pureed sample were weighed out and diluted with 18ml of deionized water. Samples absorbance at 560 and 700nm was measured using an UltraScan PRO (Hunter Lab, Reston, VA, USA). Total lycopene content was calculated using the formula (Abs560-Abs700)*DF(wt/volume)*slope (28) and expressed as μg/g fresh weight (fwt).

Data Analysis

The experimental design was a randomized complete block. Marketable yield and total yield for harvest were analyzed as the response variable for harvest data. Total yield included marketable, under ripe, and over ripe, and was meant to capture the entire output of the plant. SSC, pH, and lycopene content were analyzed as the response variables for fruit composition. Application rates were analyzed separately and as a one-way ANOVA using PROC GLIMMIX with SAS 9.3 (SAS Institute, Cary, NC, USA). Means were separated by Fischer’s least significant difference at $P \leq 0.05$.

Results

Ethephon application at 0.47 L/ha resulted in the highest marketable yield (45.73 mt/ha) (Table 2.1). Ethephon rate had no significant effect on total yield, although the 0.47 L/ha rate resulted in a total yield 50 to 120% higher than all other rates. Marketable yield was lowest at the 1.41 L/ha rate.

Compositional quality of tomatoes differed in with rate of ethephon application (Table 2.2). SSC was highest and pH lowest in tomatoes from the 0.47 L/ha ethephon application. In contrast, tomatoes from the 1.41 L/ha treatment were lowest in total lycopene (75.9 μg/g fwt) compared to other rates (88.54 to 95.2 μg/g fwt).

Discussion

Results from this preliminary study indicate that 0.47 L/ha gave best effects on yields while 1.41 L/ha was detrimental to both total and marketable yield. This suggests that rates above 0.47 L/ha may be detrimental, while rates below 0.47 are not adequate to promote uniform ripening under these test conditions.

Absorption of ethephon increases with high temperatures, and application of ethephon at higher rates at temperatures above 32°C can increase premature fruit drop and plant senescence, leading to fruit exposure and sun scale (Kretchman et al., 1974). The label for Ethrel brand ethephon plant regulator (Bayer CropScience, Leverkusen, Germany), the most commonly used ethephon product on processing tomatoes, recommends 0.58 L/ha (1.25 pints/acre) to 1.53 L/ha (3.25 pints/acre) in warm conditions (CALS NCSU, 2017). Plants were exposed to an average maximum air temperature of 33°C during the week prior to spray applications, and high rates of ethephon combined with the high temperature may have caused enough damage to decrease marketable yields.

Processing tomato quality is defined as high soluble solids (7.0-7.5%), a pH of less than 4.4, and a high lycopene content. Soluble solids content is used as an estimation of the sugar concentration of liquids and translates into the sweet taste and texture of the processed product. In California production systems, this is typically controlled by reducing irrigation water availability 4 to 6 weeks prior to harvest (Hartz et al., 2008, Cahn et al., 2003). In North Carolina's production environment, due to variability in rainfall during the late season, the efficacy of this method is less predictable. SSC was higher in tomatoes from 0 L/ha and 0.47 L/ha ethephon treatments. Previous studies have shown that there is no relationship between ethephon applications and soluble solids content (Fonseca et al., 1980).

To eliminate pathogenic risks that are associated with canned products, like *Clostridium botulinum* (FDA, 2015), processors require a pH of below 4.4 for tomatoes. Tomato pH also has an effect on the taste of processed products and the sterilizations times and temperatures of the processing line (Gould, 1992). All tomato pH values in this study were higher than 4.4 and increased with as the rate of applied ethephon increased. The high tomato pH values may have resulted from the high night temperatures and have been further increased by ethephon triggered ripening. The interval between ethephon application and harvest may need to be reduced to 5-7 days or carefully tailored based on the number of hours at night temperatures above 20^{o}C. Renquist et al. (2001) reported that earlier harvests on ethephon-applied processing tomatoes are required.

Total lycopene content was highest in fruit from 0 L/ha, 0.24 L/ha, 0.47 L/ha, and 0.94 L/ha and lowest for 1.41 L/ha. The lack of difference in lycopene content for no and low rates of ethephon application, and lower lycopene content at high ethephon rates, indicate that the interval between application and harvest may have been too long. Gaweda et al. (2016) reported no increase in lycopene content in processing tomato produced in Poland. While more trials are needed to better define ethephon application and harvest intervals, the high temperature production environment of North Carolina indicates that ethephon application would be more effective at lower rates.

Conclusion

Feasibility of North Carolina processing tomato production will require both cultivar selection and tailored cultural practices. Application of ethephon at 0.47 L/ha may be effective at increasing marketable yields of processing tomato. There is a possibility that low to no ethephon applications would be sufficient for North Carolina growers, which would slightly decrease cost per hectare and may offset the higher costs for disease management needed in the hot and humid production environment. Growers should test small portions of their field with ethephon to test best rates before deciding on large scale application.

REFERENCES

Barrett, D.M. and Anthon, G.E. 2008. Color quality of tomato products, p. 131-139. In: Culver, C. et al. Color quality of fresh and processed foods. ACS Symposium Series, American Chemical Society, Washington, D.C.

Cahn, M.D., Herrero, E.V., Hanson, B.R., Snyder, R.L., Hartz, T.K., and Miyao, G. 2003. Effects of irrigation cut-off on processing tomato fruit quality. Proceedings of the Eighth International ISHS Symposium on the Processing Tomato. 613: 75-80.

Clinton, S.K. 1998. Lycopene: chemistry, biology, and implications for human health and disease. Nutrition Review 56 (2):35-51.

College of Life Science, North Carolina State University (CALS NCSU). 2017. 2017 Agricultural Chemical Manual. https://content.ces.ncsu.edu/north-carolina-agricultural-chemicals-manual Updated: 03/07/2017. Accessed: 04/08/2017.

Extension Toxicology Network (Extoxnet). 1995. Pesticide Information Profile – Ethephon. http://pmep.cce.cornell.edu/profiles/extoxnet/dienochlor-glyphosate/ethephon-ext.html#1. Accessed: 03/07/2017.

Fonseca, H., Noquera, J.N., Graner, M., Annicchino, A.V.K.O., Castro, P.R.C., Minami, K., Vello, N.A. 1980. Effect of Growth Regulators on the Technological and Sensory Characteristics of Tomatoes (Lycopersicon esculentum Mill., c.v. Gigante Piedade). Acta Horticulturae 100: Symposium on Production of Tomatoes for Processing. 105-112.

Food and Drug Administration (FDA). 2015. Evaluation and Definition of Potentially Hazardous Foods – Chapter 3. Factors that Influence Microbial Growth. https://www.fda.gov/Food/FoodScienceResearch/SafePracticesforFoodProcesses/ucm094145.htm. Accessed: 02/26/2017

Garcia, E. and Barrett, D.M. 2006. Accessing lycopene content in California processing tomatoes. Journal of Food Processing and Preservation 30 (1):56-70.

Gaweda, M., Jedrszcyk, E., Skowera, B., Jedrzejczak, R., and Szymczyk, K. 2016 The effect of application of ethephon to processing tomato plants on the chemical composition of fruits. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 44(2):484-490.

Gould, W.A. 1992. Tomato production, processing, and technology. CTI Publications Inc. Baltimore, MD.

Hartz, T., Miyao, G., Mickler, J., Lestrange, M., Stoddard, S., Nunez, J., Aegerter, B. 2008. Processing tomato production in California. UC Vegetable Reseaerch & Information Center: Vegetable Production Series.

Ivors, K. 2010. Commercial production of staked tomatoes in the Southeast. North Carolina State University Extension.

Kretchman, D.W. and Wittmeyer, E.C. 1974. Considerations for using ethephon on tomatoes for processing in 1974. Ohio Agricultural Research and Development Center, Department of Horticulture Series No. 408.

Mackinnon, E.S., Venket Rao, A., Rao, L.G. 2011. Dietary restriction of lycopene for a period of one month results in significantly increased biomarkers in oxidative stress and bone resorption in postmenopausal women. The Journal of Nutrition 15 (2):133-138.

Papaioannou, E.H., Liakopoulou-Kyriakides, M., and Karabelas, A.J. 2016. Natural origin lycopene and “green” downstream processing. Critical Reviews in Food Science and Nutrition 56:686-709.

Renquist, A.R, English, J.M., and Reid J.B. 2001. Temperature, but not ethephon, influences fruit pH of processing tomato. HortScience 36(4):661-663.

United States Environmental Protection Agency, National Center for Environmental Publications and Information. R.E.D. Facts: Ethephon. Cincinnati, Ohio. April 1995.

United States Department of Agriculture, Economic Research Service (USDA-ERS). Tomatoes. http://www.ers.usda/.gov/topics/crops/vegetables-pulses/tomatoes.aspx. Accessed: 10/13/2016.

United States Department of Agriculture, Economic Research Service (USDA-ERS). U.S. Tomato Statistics. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1210. Updated: 07/2010. Accessed: 10/13/2016.

Table 2.1. Effect of ethephon application rates on marketable yield and total yield in field grown processing tomatoes in 2016.

Application Rate	Marketable Yield[z] (mt/ha)	Total Yield[y] (mt/ha)
0 L/ha	14.97b[x]	19.09
0.24 L/ha	24.05b	27.29
0.47 L/ha	45.73a	52.53
0.94 L/ha	19.68b	24.47
1.41 L/ha	10.58b	13.38
PR > F	0.0038	0.0542

[z] Marketable yield was determined by collecting all red fruit with less than 10% damage from three plants per plot

[y] Total yield was determined by collecting all fruit, under ripe, marketable, and over ripe, from three plants per plot

[x] Means separated by Fischer's least significant difference, significance level of $P \leq 0.05$. Means followed by the same letter are not significantly different.

Table 2.2. Effect of ethephon application on compositional quality of processing tomatoes in the 2016 growing season.

Application Rate	SSC	pH	Total Lycopene Content (µg/g fwt)
0 L/ha	5.3ab[z]	4.63c	95.22a
0.24 L/ha	5.1bc	4.70b	88.54a
0.47 L/ha	5.6a	4.66bc	92.01a
0.94 L/ha	5.2bc	4.71ab	94.13a
1.41 L/ha	5.0c	4.78a	75.92b
PR > F	0.0014	0.0016	0.0003

[z] Means separated by Fischer’s least significant difference, significance level of P ≤ 0.05. Means followed by the same letter are not significantly different.

CHAPTER IV

COMPOSITIONAL QUALITY AND SHELF-LIFE EVALUATION OF A WATERMELON JERKY PRODUCT

Abstract

Interest in value-added watermelon products has grown due to the increased information on its health benefits, including lycopene and citrulline. A dehydrated watermelon product, “watermelon jerky”, is a possible opportunity. This study was designed to evaluate the compositional quality of watermelon jerky and determine the shelf-stability. Watermelon strips were pretreated by application of the following: 1) no treatment (control), 2) addition of lime juice, 3) lime juice and cinnamon, 4) lime juice and cayenne pepper. Strips were dehydrated for 24hr at 55^oC and stored in vacuum-sealed bags. Water activity was measured at weeks 0, 2, 4, 6, and 8 and ranged from 0.291 to 0.479 a_W, which is below water activity needed for microbial growth. SSC of the watermelon jerky was 64.5 to 104.7, much higher than the 9 to 12 SSC of fresh watermelon and of other dehydrated fruit products. Use of lime juice was effectively lowered pH from 5.0 to 4.2, a range where microbial growth would be limited. Total lycopene content ranged from 146.05 µg/g fwt to 273.81 µg/100g fwt, a 4 to 5-fold increase compared to fresh watermelon (50 µg/g). The watermelon jerky product appears to be shelf-stable with low pH and water activity and offers the possibility of a new year-round supply of food based lycopene.

Introduction

In 2014, the United States produced 1,904,700 metric tons of watermelon, most of which is consumed fresh. Shelf-stable, value-added watermelon products would offer growers another niche market and possibly utilization of fruit now left in the field (Arocho et al., 2012). Developing watermelon value-added products has been challenging due to its high water content and difficulty in controlling off flavor development. Use of high pressure pasteurization is now being used to create commercial watermelon juice products and there is interest in creating new value added products. Dehydrated watermelon, or “watermelon jerky”, is a possible opportunity for a value-added product.

Watermelon is a bioavailable source of the antioxidant lycopene (Edwards et al., 2003). Lycopene differs from other antioxidants as it is lipophilic and can quench free radicals in fat-soluble parts of the cell. Consumption of lycopene containing foods can lower oxidative stress in the body (Khachik et al., 2002). Lycopene has been shown to reduce the risk of cardiovascular disease and many cancers, including gastric, colon, skin, bladder, breast, and prostate (Jacques et al., 2013 Clinton, 1998, Viuda-Martos et al., 2011).

Among domestic crops, watermelon is the most abundant, natural source of citrulline (Rimando and Perkins-Veazie, 2005). Interest in health benefits of citrulline, a precursor of arginine in the animal nitric oxide system, has been growing in recent years. Studies have shown citrulline and watermelon supplements to be an effective way to relieve muscle soreness in athletes (Tarazona-Diaz et al., 2013). Another study showed that citrulline supplements were an effective way to retain muscle function during weight-loss in rats (Ventura et al., 2013). Wu et al. (2007) showed watermelon pomace to be an effective way to increase arginine availability in obese rats with type II diabetes, resulting in improved glycemic control and a reduced risk for cardiovascular disease.

Two factors that contribute to microbial growth in food products are water activity (a_w) and pH (FDA, 2001). An adequate combination of these two factors can lead to a shelf-stable product that does not need to be refrigerated and low food safety risk. The pH and water activity of a dehydrated watermelon product is unknown.

This study was designed to determine the compositional quality and shelf-life of a watermelon jerky product. By evaluating the compositional quality and shelf-life, the feasibility of a value-added, dehydrated watermelon product can be determined.

Materials and Methods

Watermelon Jerky Preparation

Two mini-sized watermelon (about 3kg each) were selected from a commercial grocery store. Fruits were washed before cutting. The fruit were cut in half and the rind was removed. The flesh was then cut into 6mm strips. Watermelon strips were subjected to four treatments consisting of 1) no addition (control), 2) addition of lime juice, 3) lime juice plus cinnamon powder, and 4) lime juice plus cayenne powder. Lime juice (Italia Garden Italian Lime Juice, Concord Foods, Brockton, MA, USA) was applied at a rate of 4.92 ml per gram of watermelon on a fresh weight basis. Cinnamon (McCormick, Sparks, MD, USA) was sprinkled over the lime and cinnamon samples after the lime application at a rate of 0.22 g per 100 g of strips. Cayenne (Morton and Bassett, San Francisco, CA, USA) was sprinkled over the lime and cayenne samples after the lime application at a rate of 0.22 g per 100 g of strips.

Samples were dried on a food grade home dehydrator (Presto Services Inc., Menlo Park, CA, USA) for 24 hours with a hot air output at 55°C. Lime and cayenne treated strips were placed on the bottom rack, lime and cinnamon on the second rack, lime on the third rack, and control strips on the top rack. This was done to prevent cross contamination of spices with controls or lime juice treated strips. Samples were occasionally flipped throughout the 24 hours to prevent potential sticking to the racks and to promote even dehydration. After dehydration strips to a crisp texture, strips were stored in vacuum-sealed bags (FoodSaver Brand, Tilia International, San Francisco, CA).

Water Activity

Water activity of jerky samples was taken at 0, 2, 4, 6, and 8 weeks with a water activity meter (Aqua Lab, Pullman, WA, USA). Jerky was cut into 2.5 cm pieces before readings to facilitate measurement. Three subsamples were taken for each for treatment. In between readings, samples were kept in vacuum sealed bags (FoodSaver Brand, Tilia International, San Francisco, CA) at room temperature to mimic a consumer's pantry.

Quality Data Collection

For the second experiment, watermelon jerky samples were frozen at 0, 2, and 4 weeks at -80°C following storage at ambient temperature. For the third experiment, samples were frozen at 0, 4, and 8 weeks at -80°C. Samples were processed for quality at the Plants for Human Health Institute in Kannapolis, NC. Quality data included SSC, pH, lycopene, and citrulline.

Three subsamples were used for each treatment at each week. A ratio of one part jerky to two parts water was used to rehydrate the samples for analyses in 10 ml plastic vials. Stainless steel balls (9mm) were added to samples and homogenized for 60 sec using a Genogrinder (SPEX Model 2000, Spex Sample Prep, Metuchen, NJ, USA).

A 0.5 g of the homogenized sample was place on a digital refractometer (Atago USA, Bellevue, WA, USA). SSC values were multiplied by a dilution factor of 3. A pH meter (Hach, Loveland, CO, USA) was used to determine the pH of samples. To quantify the lycopene content of the watermelon jerky samples, 0.5mL of the hydrated jerky was weighed into a 50mL test tube and diluted with 15mL of deionized water. Sample absorbance at 560 and 700 nm was measured using an UltraScan PRO colorimeter (Hunter Lab, Reston, VA, USA). Total lycopene was calculated using the formula (Abs560-Abs700)*DF (wt/volume)*slope (28) and expressed as µg/g fwt.

Citrulline content of the watermelon jerky samples was determined by extracting 0.2g of pureed sample with 1.2mL of 0.03M H_3PO_4. The samples were vortexed (Vortex Genie Pulse, Scientific Industries Inc., Bohemia, NY, USA) for 60 sec, sonicated (Branson 1310 ultrasonicator) for 30 min and then left at room temperature for 10 min. Extractions were centrifuged for 20,817 x g at 4°C for 20 min (Eppendorf 5417R). A 1 mL sample was syringe filtered through 0.2 um nylon filters into HPLC vials (Agilent, Santa Clara, CA, USA). Samples were injected on the HPLC (Elite LaChrom, Hitachi, Chiyoda, Tokyo, Japan) for citrulline content following a modified method used by Jayaprakasha et al. (2010). Citrulline values were multiplied by a dilution factor of 3.

Data Analysis

Experiment 1 was analyzed as a two-way ANOVA with water activity as the response variables and time and treatment as the main effects. Experiment 2 and 3 were analyzed as a two-way ANOVA with time and treatment as the main effects. SSC, pH, lycopene content, arginine content, and citrulline content were analyzed as the response variables. All data were analyzed in PROC GLIMMIX using SAS 9.3 (SAS Institute, Cary, NC, USA). Means were separated by Fischer's least significant difference at $P \leq 0.05$.

Results

Experiment 1

There were no significant differences among treatments for water activity, although water activity changed over storage time (Table 1). There was no significant interaction between time and treatment. During the eight weeks of storage, water activity ranged from 0.291 to 0.479. Week 2 was highest for water activity and decreased sharply between weeks 4 and 6.

Experiment 2

Treatments differed in pH and was highest for the control (5.47) and lowest in the lime + cinnamon treatment (3.79) (Table 3.2). Storage time did not differ in pH. No significant interactions between time and treatment were found.

There was a significant interaction between time and temperature for total lycopene content (Table 4). Values were lowest for the control at week 0, lime at week 0 and 4, lime + cinnamon at week 4. Total lycopene content was highest for lime + cinnamon at week 2 and lime + cayenne at week 0. Total lycopene content ranged from 170 µg/g fwt to 267.9 µg/g fwt among treatments.

A significant difference was not seen among weeks, but was seen among treatments for citrulline content (Table 5). Citrulline ranged from 34.2 mg/100g fwt to 49.2 mg/100g fwt, with the control as the highest and lime + cinnamon as the lowest.

Experiment 3

Treatments and storage time affected pH with a significant interaction between time and treatment. Application of lime juice significantly lowered pH to 3.38 compared to the 5.04 pH of the control (Table 3.5). Weeks 0 and 4 were higher in pH (3.96) and lowest for week 8 (3.85) (Table 3.6).

Total lycopene content ranged from 146.05 to 273.91 ug/100mg fresh weight (Table 3.7). Lime + cinnamon at all weeks was significantly highest in total lycopene to control or lime juice at all weeks.

Citrulline content was not significantly different among treatments, storage time, or the interaction of these. Citrulline content ranged from 22.3 to 1013.3 mg/100mg dry weight (Table 3.8).

Discussion

Water activity is a measurement of the unbound water molecules within a food product and is one of the most important contributors to food spoilage (Syamaladevi et al., 2016). Historically, lowering the water activity of a food product is an effective way to mitigate microbial growth, as it limits the available water pathogens need to reproduce. Low water activity foods are defined as products with <0.85 a_w (Beuchat et al., 2012). However, low water activity foods have been the subject of recent recalls, including products like peanut butter, pistachio nuts, and dry milk (Farakos and Frank, 2014). The majority of these recalls were caused by *Salmonella*; the pathogen needs 0.94 a_w for growth (Beuchat et al., 2012). *Staphylococcus aureus* is also a concern in low water activity foods, needing 0.83-0.85 a_w for growth (Beuchat et al., 2012). Dried fruit averages 0.55-0.80 a_w (FDA, 2001).

Our results indicate that a dehydrated watermelon product would have 0.29-0.48 a_w. This categorizes watermelon jerky as a low-water activity product and below the reproductive range of *Salmonella* and *Staphylococcus aureus*. However, in a study done by Beuchat and Mann (2014), it was found that *Salmonella* could survive on dried fruit products past 252 days. The authors suggest a lethality treatment to eliminate pathogens on dried fruit. If the product were to not undergo a lethality treatment, sanitary and control measures could be implemented to prevent a base pathogen population.

The cause of the decreased a_w between week 4 and 6 is unknown. Water activity decreases with temperature (FDA, 2015). Experiment 1 was conducted between October 2016 and December 2016. There is the possibility that decreasing outside temperatures had an effected on the water activity of the samples during storage.

Fresh watermelon pH ranges from 5.2-5.6 (FDA, 2001). This is consistent with our results for the control samples, indicating the pH does not change with dehydration. The addition of lime juice decreased the pH to <4.2 in both experiments. Reducing the pH is an effective way to control the microbial growth within a product. The minimum pH for survival of *Staphylococcus aureus* and *Salmonella* spp. is 4.0 and 4.2 respectively (FDA, 2001). The addition of lime juice was an effective way to reach a desirable pH range. In experiment 2, there was no change of pH over time. In experiment 3, there was a decline of pH from week 4 to 8. These results indicate that watermelon jerk treated with lime juice is in the optimal pH range to limit microbial growth and is shelf stable.

Lycopene is a valuable, lipophilic antioxidant which has shown to decrease oxidative stress, cardiovascular disease risk, and cancer risk (Clinton, 1998, Jacques et al. 2013, MacKinnon et al., 2011, Viuda-Martos et al., 2011) and is being extracted from tomato and used as a natural colorant. Total lycopene content in fresh watermelon can range from 38.6 to 69.2 ug/g fwt depending on the cultivar, location, and harvest date (Perkins-Veazie et al., 2001). Watermelon jerky samples showed a 600% increase in total lycopene content compared to fresh watermelon. Total lycopene values collected for lime + cinnamon and lime + cayenne may be erroneously high and influenced by the color of the spices. Samples treated with cinnamon appeared reddish brown, while those treated with cayenne appeared redder than the control and lime. These results indicate that a watermelon jerky product may be an effective and novel way to increase lycopene intake by consumers. Total lycopene appears to be relatively stable over time in the dehydrated watermelon. This is consistent with the results from Arya et al. (1985), where freeze dried watermelon juice powder with a citric acid and sugar was reported to have a 324.8 μg/g at month 0 and 22.3 μg/g at month 6.

Citrulline is a metabolic intermediate in the animal nitric oxide cycle that has shown to reduce oxidative stress and improve athletic ability and recovery (Tarazona-Diaz et al., 2013). Watermelon is the most abundant source of citrulline and a shelf-stable, dehydrated product would offer a natural year-round alternative to supplements. The citrulline content of different seedless watermelon cultivars ranged from 5.7 mg/100g dry weight - 28.6 mg/100g dry weight (Rimando and Perkins-Veazie, 2005). Citrulline values obtained from our results are much higher compared to these values, indicating that a watermelon jerky product would be an effective functional food for delivery of citrulline. Citrulline appeared to be stable in jerky samples over storage time.

Chawla and Ranote (2009) found that sensory quality scores for a dehydrated watermelon product made with the cultivar ‘Sugarbaby’ remained acceptable for up to six months. It was also found that treatment with 0.3% salt and 0.3% citric acid scored highest for taste, flavor, and overall acceptance. Further research is warranted to determine the consumer acceptance and sensory quality of the treatments used during our study.

Conclusions

A dehydrated watermelon jerky product would be a viable value-added option for growers. The low water activity and low pH of lime treated samples indicate that the product is not a conducive environment for pathogenic microbial growth. This also indicates that the product is shelf-stable and not subjected to the same seasonality of fresh watermelon. The exceptionally high values for lycopene and citrulline content give the product a marketing advantage as a functional food. Sensory quality and consumer acceptance studies of treatments over time are warranted. This value-added opportunity would allow growers to diversify their operation.

REFERENCES

Arocho, Y.D., Bellmer, D., Maness, N., McGlynn, W., and Rayas-Duarte, P. 2012 Watermelon pomace composition and the effect of drying and storage on lycopene content and color. Journal of Food Quality 35:331-340.

Arya, S.S. Premavalli, K.S., Siddiah, C.H., and Sharma, T.R. 1985. Storage behavior of freeze dried watermelon juice powder. Journal of Food Technology 20:351-357.

Beuchat, L.R., Komitopoulou, E., Beckers, H., Betts, R.P., Bourdichon, F., Fanning, S., Joosten, H.M., and Ter Kuile, B.H. 2012. Low-water activity foods: increased concern as vehicles of food borne pathogens. Journal of Food Protection 76 (1):150-172.

Beuchat, L.R. and Mann, D.A. 2014. Survival of *Salmonella* on dried fruits and in aqueous dried fruit homogenates as affected by temperature. Journal of Food Protection 77 (7):1102-1109.

Clinton, S.K. 1998. Lycopene: chemistry, biology, and implications for human health and disease. Nutrition Reviews 56 (5):449-457.

Chawla R., and Ranote, P.S. 2009. Preparation and quality evaluation of dehydrated watermelon products. Journal of Food Science and Technology 46 (3):228-231.

Diamante, L.M., Bai, X., and Busch, J. 2014. Fruit Leathers: Method of Preparation and Effect of Different Conditions on Qualities. International Journal of Food Science 2014 (2014):1-12.

Edwards, A.J., Vinyard, B.T., Wiley, E.R., Brown, E.D., Collins, J.K., Perkins-Veazie, P., Baker, R.A., Clevidence, B.A. 2003. Consumption of watermelon juice increases plasma concentrations of lycopene and beta-carotene in humans. Human Nutrition and Metabolism. 1043-1050.

Farakos, S.M.S and Frank, J.F. 2014. Challenges in the control of foodborne pathogens in low-water activity foods and spices, p. 15-35. In: Gurtler, J.B., Doyle, M.P., Kornacki, J.L. (eds.). The Microbiological Safety of Low Water Activity Foods and Spices.

Food and Drug Administration (FDA). 2001. Evaluation and definition of potential hazardous foods – Chapter 3. Factors that influence microbial growth. https://www.fda.gov/Food/Food ScienceResearch/SafePracticesforFoodProcesses/ucm094145.htm. Updated: 03/19/2015. Accessed: 03/10/2017.

Food and Drug Administration (FDA). Water activity (aw) in foods.
https://www.fda.gov/ICECI
/Inspections/InspectionGuides/InspectionTechnicalGuides/ucm072916.htm. Updated: 01/27/2015. Accessed: 03/10/2017

Jacques, P.F., Lyass, A., Massaro, J.M., Vasan, R.S., D'Agostino, R.B. 2013. Relationship of lycopene intake and consumption of tomato products to incident CVD. British Journal of Nutrition 110: 545-551.

Jayaprakasha, G.K. Chidambara Murthy, K.N., and Patil, B.S. 2010. Rapid HPLC-UV method for quantification of L-citrulline in watermelon and its potential role on smooth muscle relaxation markers. Food Chemistry 127:240-248.

Khachik, F., Carvalho, L., Bernstein, P.S., Muir, G.J., Zhao, D.Y., Katz, N.B. 2002. Chemistry, distribution, and metabolism of tomato carotenoids and their impact on human health. Experimental Biology and Medicine 227:845-851.

MacKinnon, E.S., Venket Rao, A., Rao, L.G. 2011. Dietary restriction of lycopene for a period of one month resulted in significantly increased biomarkers in oxidative stress and bone resorption in postmenopausal women. The Journal of Nutrion 15 (2):133-138.

Perkins-Veazie, P., Collins, J.K., Pair, S.D., and Roberts, W. 2001. Lycopene content differs among red-fleshed watermelon cultivars. Journal of the Science of Food and Agriculture 81: 983-987.

Rimando, A.G. and Perkins-Veazie, P.M. 2005. Determination of citrulline in watermelon rind. Journal of Chromatograph A 1078:196-200.

Syamaladevi, R.M., Tang, J., Villa-Rojas, R., Sablani, S., Carter, B., and Campbell, G. 2016. Influence of water activity on thermal resistance of microorganisms in low-moisture foods: a review. Comprehensive Reviews in Food Science and Food Safety 15 (2):353-370.

Tarazona-Diaz, M.P., Alacid, F., Carrasco, M., Martinez, I., and Aguayo, E. 2013. Watermelon juice: potential functional drink for sore muscle relief in athletes. Journal of Agricultural and Food Chemistry 61:7522-7528.

Ventura, G. Noirez, P., Breuille, D., Godin, J.P., Pinaud, S., Cleroux, M., Choisy, C., Le Plenier, S., Bastic, V., Neveux, N., Cynober, L., and Moinard, C. 2013. Effect of citrulline on muscle functions during moderate dietary restriction in healthy adult rats. Amino Acids 45:1123-1131.

Viuda-Martos, M., Sanchez-Zapata, E., Sayas-Barbera, E., Sendra, E., Perez-Alvarez, J.A., Fernandez-Lopez, J. 2011. Tomato and tomato byproducts. Human health benefits of lycopene and its application to meat products: a review. Critical Reviews in Food Science and Nutrition 54 (8):1032-1049.

Wu, G., Collins, J.K., Perkins-Veazie, P., Siddiq, M., Dolan, K.D., Kelly, K.A., Heaps, C.L., and Meininger, C.J. 2007. Dietary supplementation with watermelon pomace juice enhances arginine availability and ameliorates the metabolic syndrome in zucker diabetic fatty rats. The Journal of Nutrtion 137:2680-2685.

Table 3.1. Effect of time on water activity in watermelon jerky samples from experiment 1.

Week	Water Activity (a_w)
0	0.399c^z
2	0.479a
4	0.445b
6	0.291e
8	0.323d
PR > F	<0.0001

^{z}Means separated by Fischer's least significant difference, significance level $P \leq 0.05$. Means followed by the same letter are not significantly different.

Table 3.2. Effect of treatment on pH in watermelon jerky samples from experiment 2.

Treatment	pH
Control	5.47a[z]
Lime	4.19b
Lime + Cinnamon	3.79d
Lime + Cayenne	4.08c
PR > F	<0.0001

[z] Means separated by Fischer's least significant difference, significance level of $P \leq 0.05$. Means followed by the same letter are not significantly different.

Table 3.3. Effect of treatment and time on total lycopene content in watermelon jerky samples from experiment 2.

Treatment	Week	Total Lycopene Content (μg/g fwt)
Control	0	203.03cde[z]
Control	2	227.36bc
Control	4	207.00cd
Lime	0	178.50de
Lime	2	214.28cd
Lime	4	170.18e
Lime + Cinnamon	0	230.13bc
Lime + Cinnamon	2	267.88a
Lime + Cinnamon	4	202.16cde
Lime + Cayenne	0	259.39ab
Lime + Cayenne	2	217.78cd
Lime + Cayenne	4	233.33bc
PR > F		0.0147

[z] Means separated by Fischer's least significant difference, significance level of $P \leq 0.05$. Means followed by the same letter are not significantly different.

Table 3.4. Effect of treatment on citrulline content in watermelon jerky samples from experiment 2.

Treatment	Citruline Content (mg/100g fwt)
Control	49.2a^{z}
Lime	37.8b
Lime + Cinnamon	34.2d
Lime + Cayenne	36.6c
PR > F	<0.0001

^{z}Means separated by Fischer's least significant difference, significance level of $P \leq 0.05$. Means followed by the same letter are not significantly different.

Table 3.5. Effect of treatment on pH in watermelon jerky samples from experiment 3.

Treatment	pH
Control	5.04a[z]
Lime	3.38d
Lime + Cinnamon	3.52c
Lime + Cayenne	3.75b
PR > F	<0.0001

[z] Means separated by Fischer's least significant difference, significance level of P ≤ 0.05. Means followed by the same letter are not significantly different.

Table 3.6. Effect of time on pH in watermelon jerky samples from experiment 3.

Week	pH
0	3.96a
4	3.96a
8	3.85b
PR > F	0.0478

[z] Means separated by Fischer's least significant difference, significance level of $P \leq 0.05$. Means followed by the same letter are not significantly different.

Table 3.7. Effect of time and treatment of total lycopene content in watermelon jerky samples from experiment 3.

Treatment	Week	Total Lycopene Content (µg/g fwt)
Control	0	146.05d[z]
Control	4	175.08cd
Control	8	154.53cd
Lime	0	162.71cd
Lime	4	155.23cd
Lime	8	171.56cd
Lime + Cinnamon	0	263.34ab
Lime + Cinnamon	4	273.81a
Lime + Cinnamon	8	268.44ab
Lime + Cayenne	0	241.39b
Lime + Cayenne	4	185.33c
Lime + Cayenne	8	185.98c
PR > F		0.0120

[z] Means separated by Fischer's least significant difference, significance level of $P \leq 0.05$. Means followed by the same letter are not significantly different.

Table 3.8. Effect of treatment and time on citrulline content in watermelon jerky samples from experiment 3.

Treatment	Week	Citrulline Content (mg/100 mg fwt)
Control	0	267.7
Control	4	268.2
Control	8	451.8
Lime	0	362.6
Lime	4	1013.3
Lime	8	391.9
Lime + Cinnamon	0	472.0
Lime + Cinnamon	4	371.5
Lime + Cinnamon	8	405.9
Lime + Cayenne	0	399.1
Lime + Cayenne	4	489.3
Lime + Cayenne	8	226.3
PR > F		0.2176

APPENDICES

Appendix A: Chapter II

This table represents informal sensory evaluation of processing tomatoes, based on screening by three tomato processors.

Fruit were cut into 2.5cm sections and tasted fresh. Cultivars were ranked based on overall acceptance.

Table A – 1.1 Batch test sensory analysis of processing tomato grown at Site 1

		HMX2905	HMX2906	HMX3881	HMX3882	HMX4909	HMX7883	N6402	N6404	SPESSO6415
Panelist 1	Ranking	1	2	5	3	4	6	8	9	7
	Comments	Good color, flavor okay	Okay flavor, light color	Slight tomato flavor, light color	Bland, light color	No flavor, bland, light color	Too soft	No flavor, crunchy	Mushy, light color	No flavor, too light
Panelist 2	Ranking	2	1	8	6	5	4	7	9	3
	Comments	Sweet	Good taste	Odd	Bland	Not much flavor	No comment	Bland	Odd	Sweet/tart
Panelist 3	Ranking	1	4	6	9	5	2	8	3	7
	Comments	Good in all areas	Fair to poor in all areas	Fair to poor in all areas	Fair to poor in all areas	Fair to poor color, texture and taste	Good taste, sweet, good color, good texture	Poor to fair taste, bland, poor color and texture	Good taste, poor color, fair texture	Fair to poor taste, poor color, poor texture