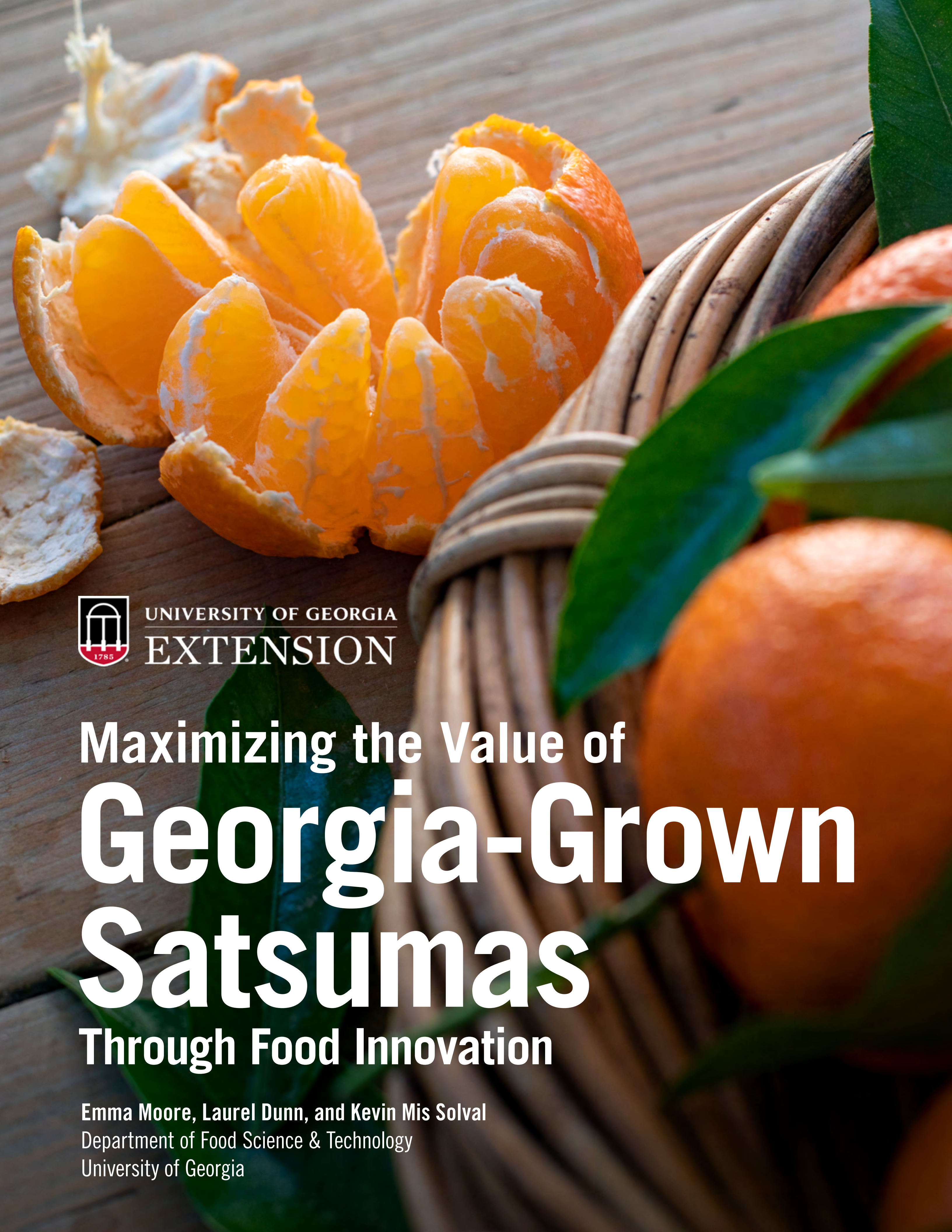

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Maximizing the Value of Georgia-Grown Satsumas Through Food Innovation

Emma Moore, Laurel Dunn, and Kevin Mis Solval
Department of Food Science & Technology
University of Georgia

History and Introduction to the United States

Citrus are some of the most well-known, healthy, and popular fruits in the world; they include oranges (*Citrus sinensis*), lemons (*Citrus limon*), grapefruit (*Citrus paradisi*), limes (*Citrus aurantiifolia*), and satsuma mandarins (*Citrus unshiu* Marcovitch). Traditionally, citrus plants are grown in warm climates, including the "citrus belt" that covers parts of the Mediterranean, China, Japan, and North, Central, and South America.

Satsuma mandarins were first identified over 700 years ago in Kagoshima Prefecture in Japan. In 1876, satsumas were introduced to North America. By the beginning of the 1900s, more than a million 'Owari' satsuma trees were planted from the Florida Gulf Coast to Texas. Satsuma mandarin plants grow well in warm climates and can withstand cold temperatures during winter months. In addition, they can produce high-quality fruits that are sweet and easy to peel compared to other citrus fruits. To meet market demand, satsuma mandarins must have an appealing appearance with the right color, size, texture, and flavor profile.

Satsuma mandarins are rapidly becoming a popular citrus crop in the southern U.S. Jacob Price played a key role in bringing the first satsuma trees to southern Georgia in 2013, and since then, the number of commercial trees in the state has risen from 4,500 to over 390,000. As a result, southern Georgia is becoming an important region for satsuma mandarins because of its warm climate and ideal growing conditions.

Anatomical and Nutritional Composition of the Satsuma Fruit

To fully appreciate the benefits of satsuma mandarins, it is essential to understand their nutritional composition. The fruit can be divided into two main parts: the *pericarp* (peel) and the *endocarp*. The peel is made up of the outermost layer (the *epicarp* or *flavedo*), and the middle layer (the *mesocarp* or *albedo*). The epicarp has essential oils and carotenoids, while the mesocarp contains high amounts of pectin. The endocarp is the spongy tissue surrounding the seeds (if present). It makes up the edible portion of the fruit, representing about 74% of its weight, and consists of pulp and juice vesicles. Figure 1 shows the anatomy of the satsuma fruit.

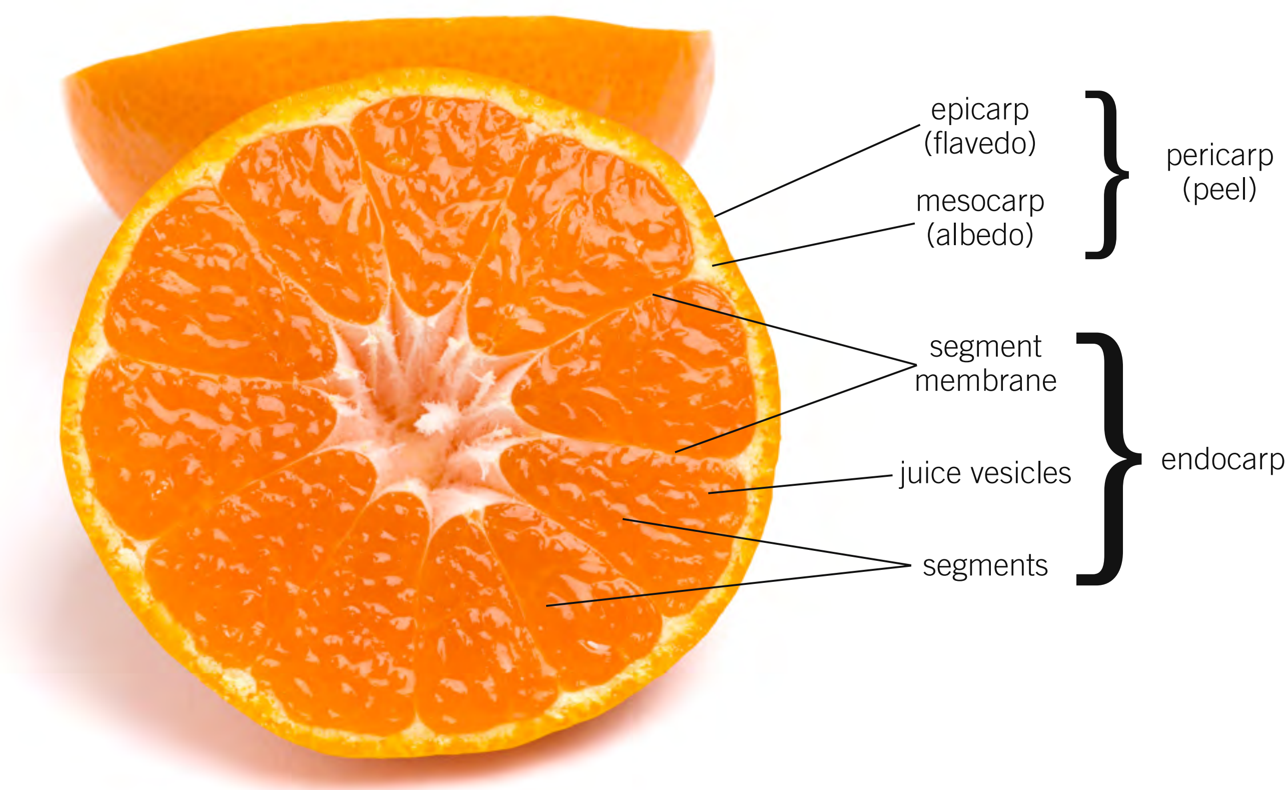

Figure 1. Anatomy of the satsuma mandarin (*Citrus unshiu*).

Note. Adapted from "An integrated approach to mandarin processing: Food safety, and nutritional quality, consumer preference, and nutrient bioaccessibility," by P. Putnik, F. J. Barba, J. M. Lorenzo, D. Gabric, A. Shpigelman, G. Cravotto, & D. Bursac Kovacevic, 2017, *Comprehensive Reviews in Food Science & Food Safety*, *16*(6), p. 1346 (https://doi.org/10.1111/1541-4337.12310). Copyright 2017 by the Institute of Food Technologists.

A satsuma mandarin provides about 35 calories, 1 g of protein, and 12 g of carbohydrates (2 g of fiber and 10 g of natural sugars). These fruits are also rich in *phytonutrients* (antioxidants) such as vitamins (A, C, and E), carotenoids, phenolics, minerals, sugars, organic acids, amino acids, and pectin. In particular, satsuma mandarins are an excellent source of natural antioxidants (because of their vitamin C content) and carotenoids.

Phytonutrients such as phenolic compounds are found in satsuma juice and include flavonoids and phenolic acids. Flavones, a subclass of flavonoids, make up 87% to 97% of the total polyphenols in satsuma juice, with hesperidin and narirutin being the most abundant flavones. The presence of hesperidin affects the appearance, taste, and nutritional quality of citrus juices. It can lead to undesirable cloudiness from the development of crystals after juice extraction. However, the bitterness produced in citrus juices by hesperidin can be reduced with the help of an enzyme called *Aspergillus sojae* naringinase.

Limonoids and synephrine (plant alkaloids) can be found in satsuma juice and seeds. Limonin is a limonoid that adds bitterness to satsuma juice. However, this effect can be reduced with debittering techniques.

Satsuma juice also is a good source of potassium, phosphorus, and magnesium, as well as sugars such as sucrose, fructose, and glucose, and organic acids (citric, malic, and succinic acids). Interestingly, satsuma juice flavor is influenced mainly by the balance between sugars and organic acids. While satsuma juice is not a high-protein food, it provides eight essential amino acids, including asparagine, arginine, aspartic acid, proline, and glutamine.

Satsuma peels, which often are discarded, contain vitamin C, carotenoids, flavonoids, essential oils, minerals, and pectin. The main essential oil in satsuma peels, limonene, has anti-inflammatory and antitumor properties. Meanwhile, pectin is a soluble fiber with strong prebiotic properties. The proximate and nutritional composition of satsuma fruits are shown in Tables 1 through 3. Overall, the satsuma mandarin is a tasty and nutritious fruit with interesting phytonutrients.

Table 1. Nutritional Composition of the Satsuma Mandarin Fruit.

Nutrient	Per 100 g
Energy	35 kcal
Protein	1 g
Total lipid (fat)	0 g
Total carbohydrates	12 g
Dietary fiber	2 g
Total sugars	10 g

Note. Data for this table was condensed from Putnik et al. (2017) and the Florida Department of Agriculture and Consumer Services (2021).

Table 2. Nutrients Found in the Endocarp of the Satsuma Mandarin.

Nutrient	Quantity (range)
Soluble sugars	
Sucrose	28.1–66.2 g/L
Fructose	9.2–18.1 g/L
Glucose	6.9–19.8 g/L
Organic acids	
Citric	12.2–16.9 g/L
Malic	3.8–8.2 g/L
Succinic	0.8–3.7 g/L
Carotenoids†	10–40 µg/g
Beta-criptoxanthin	55%
Zeaxanthin	13%
Phenolic compounds†	47.1–78.7 mg GAE/g
Flavonoids	10–93.2 mg/L
Limonoids†	105–1128 µg/g
Synephrine	7.6–22.5 mg/L

Note. † indicates phytonutrients.
The endocarp contains the pulp, juice, etc.
The data in this table was derived from Putnik et al. (2017), Akyildiz and Agcam (2014); Alquezar et al. (2008); Kelebek and Selli (2014); Lado et al. (2016); Sdiri et al. (2012); and Ye et al. (2011).

Food Applications of Satsumas

Satsuma mandarins are tasty, nutritious, and versatile fruits with a wide range of applications in the food industry. In addition, they are easy to peel, seedless, and sweeter than most other citrus fruits. Besides being consumed fresh or in salads, they can be used as raw materials for essential oils, juices, jellies, confectioneries, and sweet applications. The essential oils extracted from the satsuma peels often are used as a natural flavoring for various food items such as candies, soft drinks, ice cream, chewing gum, and bakery products. Commercial satsuma juices are heat-treated to inactivate microorganisms and enzymes. Unfortunately, treating fruit juices with heat often results in burned off-flavors and potential loss of nutritional quality. This effect often is undesirable to modern consumers who prefer safe, high-quality juices with a homemade appeal.

To overcome these issues, researchers have investigated nonthermal pasteurization methods such as pulsed electric fields (PEF) and high-pressure processing (HPP). PEF technology uses electrical pulses to inactivate microorganisms and enzymes. As a result, PEF-treated juices often exhibit better sensory and nutritional qualities than heat-treated products. However, PEF is a relatively new technology with limitations, including the high initial cost of PEF equipment and the need for process optimization. Alternatively, HPP is a popular nonthermal technology that uses high hydrostatic pressure (> 600 MPa, or > 87,000 psi) to inactivate microorganisms and enzymes in fruit juices. Often, products treated with HPP maintain better sensory and nutritional qualities than heat-treated products.

Satsuma mandarins are a popular fruit with a wide range of potential applications in the food industry. Satsuma mandarins are known for their sweet and tangy flavor—which has the potential to be used in a variety of plant-based foods as a natural sweetener and flavor enhancer. For example, the fruit can be pureed and added to smoothies, used as a topping for vegan desserts, or incorporated into sauces or dressings to add a fresh citrus flavor. Satsuma juice can substitute lemon or lime juice in some plant-based foods, adding a tangy kick to plant-based marinades, soups, and stews. Dried food ingredients derived from satsuma mandarins can be used as seasonings, natural antioxidants, and flavoring agents with a strong potential for creating exciting and new foods.

Food Safety Considerations

Citrus fruits are naturally acidic, which prevents the growth of spoilage and pathogenic microorganisms and thus reduces the risk of foodborne illnesses. However, foodborne pathogens including *Salmonella enterica* and *Escherichia coli* O157:H7 can contaminate fresh fruit and pose a public health risk.

Table 3. Nutrients Found in the Pericarp of the Satsuma Mandarin.

Hesperidin	55.82 mg/g
Didymin	1.23 mg/g
Tangeretin	0.86 mg/g
Sinensetin	0.12 mg/g
Beta-crytoxanthin	1278.33 µg/100 g
Beta-carotene	66.67 µg/100 g
Limonene	94.03%
Alpha-pinene	0.40%
Alpha-terpineol	0.09%
Citronellal	0.04%
Total ascorbic acid	129.39 mg/100 g
Boron (B)	19.57 mg/L
Manganese (Mn)	3.41 mg/L
Potassium (K)	0.54%
Sulfur (S)	0.08%
Sodium (Na)	0.02%

Note. † indicates phytonutrients.
The pericarp is the peel of the fruit.
The data in this table was derived from Bermejo et al. (2011) using the mandarin cultivar 'Owari'.

Therefore, following hygienic practices is essential for those handling fresh or processed satsuma mandarins. In addition, following good agricultural practices established by the USDA, or the requirements within the rule Standards for the Growing, Harvesting, Packing, and Holding of Produce for Human Consumption (2015; i.e., the produce safety rule), is critical to ensure pathogens are not introduced during the packing or production of satsuma-based products. For example, sanitizing the whole citrus fruit with chlorinated water (i.e., 15–20 ppm of chlorine) before transporting or processing can help reduce the chances of microbial contamination. Harvest crews should be provided with sanitary restrooms and handwashing facilities. Workers must wash their hands before starting work, after any breaks, or at any point if they may have become contaminated. Harvesting tools, bags, and containers must be sanitized before use, and all nonporous surfaces should be sanitized with bleach or peroxyacetic acid after cleaning.

Food-safe handling after harvest or during processing is critically important to ensure the fruit does not become contaminated by dirty food-contact surfaces. All fruit-contact surfaces should be cleaned and sanitized before use each day. Frequent cleaning and sanitizing is often required throughout the day depending on the surface material type, amount of fruit contacting that surface throughout the day, initial cleanliness of the fruit being processed, and other factors (e.g., temperature and relative humidity). It is essential to understand that surfaces must be thoroughly cleaned before sanitizing; otherwise, the sanitizer will be ineffective.

All water used to clean the fresh fruit, food contact surfaces, and equipment during or after harvest must contain no detectable generic *E. coli*. Testing can be conducted at several laboratories throughout Georgia, including the University of Georgia Agricultural and Environmental Services Laboratories in Athens, GA. Satsuma processors must follow EPA label instructions regarding appropriate surface use, concentration, and contact time. Incorrect use of a sanitizer is a violation of federal law (Sanitary Operations, 2016).

To ensure food safety, satsuma mandarins and derived products (e.g., juices, jellies, and essential oils) must also be processed under hygienic conditions. For fresh fruit or processed products that require cold storage (such as juice), minimize food safety risks by following best practices such as checking for contamination from water condensation or dripping, ensuring all doors and windows are properly sealed, monitoring and recording the cooler temperature(s) and calibrating temperature devices used to monitor coolers. Lastly, trucks used to transport fresh or processed products should be cleaned, sanitized correctly, and inspected for cleanliness before transporting the products.

In addition, facilities should be appropriately designed for citrus processing: this means everything from the equipment, roof, walls, floors, ceilings, walkways, and stairways to the windows, doors, utilities, ventilation, lighting, drainage, and all waste pathways. Food contact surfaces should be easy to clean and sanitize.

One of the best ways of reducing the risk of potential health hazards during the packing and processing of satsuma mandarins is to create and implement a food safety plan. For help developing a farm food safety plan, growers and packers can contact their county Extension office.

The U.S. Citrus Industry

Most of the citrus fruits in the United States are produced in four states: Arizona, California, Florida, and Texas. During the 2019–2020 season, California and Florida produced 54% and 42% of the total U.S. citrus production, respectively. Meanwhile, Arizona and Texas made up 4% of U.S. citrus production. The United States had an estimated 681,300 acres of citrus-bearing production during that season.

Georgia will soon become a major player in the U.S. citrus industry. Lindy Savelle, president of the Georgia Citrus Association, estimates that by the end of 2024, Georgia could produce around 59 million pounds of citrus. Estimates from the end of 2022 showed that Georgia had 3,300 acres or 473,000 citrus trees that could potentially produce around 87 million pounds of citrus fruits by the end of 2025.

Although satsuma mandarins are an emerging and relatively new crop in southern Georgia, they already are the main citrus fruit grown in the state, making up 85% of Georgia's citrus industry. Young satsuma trees take about

3 to 4 years to produce marketable fruits. In addition, young trees produce fruit that is unsuitable for the fresh market (because of their general appearance and flavor profile). Therefore, the fruit from young trees is often harvested and discarded. This practice allows the satsuma trees to grow strong enough to support a high fruit yield by their 4th year. This discarded fruit from young trees may be used to produce novel food ingredients.

In 2021, citrus was grown in 45 counties of southern Georgia. The main cultivar of satsuma mandarin grown in the state is 'Owari', which makes up 75% of all satsuma trees. In Georgia, the harvesting season of satsuma mandarins is in November. However, Georgia farmers are looking to extend the citrus harvesting season by planting other citrus cultivars that ripen earlier, such as 'LA Early', 'Early St. Ann', 'Armstrong', 'Xie Shan', 'Miho', 'Miyagawa', 'Shiranui', or 'Tango' mandarins, as well as 'Cara Cara' navels, grapefruit, and lemons. This will allow them to harvest citrus from October to January.

Challenges and Commercial Opportunities for Georgia-Grown Satsumas

The satsuma mandarin industry in Georgia is currently experiencing tremendous growth and economic success, but it also faces many challenges. For example, the potential for expected fruit production in the next few years to exceed demand in the fresh market which may result in lower prices for premium fresh fruits. Therefore, it will be essential for the industry to find alternatives to the fresh market to maintain success.

To overcome future challenges, the Georgia satsuma mandarin industry should consider adding value to underutilized fruits and maximizing profits from different fruit components. For example, satsuma peels contain high-value essential oils, pectin, and dietary fiber that can be utilized in food, beverages, and cosmetic products. Essential oils are commonly used in a variety of consumer goods; at the same time, pectin and dietary fiber are utilized as gelling and thickening agents. Extracts of satsuma peels contain natural antimicrobials, which can be used in several food and animal feed applications. An increased demand for such products is expected because of the growing concern over antibiotic-resistant bacteria and consumers' increasing preference for natural food ingredients.

Food dehydration can help preserve the sensory and nutritional quality of fresh fruits. Moreover, fruit juice powders are high-value products that can be used in several food applications. Satsuma juice powders have several benefits over liquid fruit juice, including reduced volume, mass, and packaging, extended shelf life, and ease of handling and transportation. As a result, fruit juice powders are used in different commercial applications.

Satsuma mandarin peels are a good source of pectin, a soluble fiber that can be used as a gelling, stabilizing, and thickening agent. The peels are rich in flavonoids and vitamin C with antioxidant properties. These compounds can be extracted from the peels and used as natural antioxidants to improve the nutritional quality of foods. The peels are rich in carotenoids, an orange-yellow pigment that can be used as a natural coloring agent in foods.

To summarize, the satsuma mandarin industry in Georgia has a great economic potential, but it will need to find creative ways to overcome new challenges such as excess fruit production. Adding value to underutilized fruits while developing new products such as essential oils, pectin, and carotenoids will help the industry maintain success and competitiveness in today's market.

Conclusions

The satsuma mandarin industry is a fast-growing industry in Georgia due in part to the state's warm climate and optimal growing conditions. However, this fast growth will create new challenges for the industry in the next few years, such as a surge in fruit production during the short harvest season. This may affect prices for premium fruit. In addition, food safety practices are essential to ensure the industry's long-term viability.

Several opportunities in the value-added sector have been identified that can provide economic growth for the industry. Satsuma mandarins are not only tasty but also healthy and nutritious. They are packed with nutrients and phytonutrients that can offer numerous health benefits to modern consumers.

Modern and emerging technologies are constantly revealing new possibilities for creating functional foods from satsuma mandarins. Developing food ingredients from satsuma by-products would help meet modern consumers' demands for more natural ingredients. This would diversify the industry's product portfolio and contribute to its long-term sustainability. Overall, the future of the Georgia satsuma industry looks bright, with exciting opportunities for innovation and growth.

Acknowledgments

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