Evaluating microbial safety, postharvest quality, and consumer acceptability of fresh produce engraved with QR codes using a CO_2 laser labeling technology

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Abstract

Fresh produce is traditionally labeled with plastic price lookup (PLU) stickers that are attached to the produce surface using edible glue. However, both the stickers and glue are environmental contaminants, and the stickers can detach from the produce surface during handling and disrupt the food traceability system. An alternative method of labeling, the CO_2 laser labeling technology (LLT), widely used in other industries (e.g., automotive, healthcare, etc.) for engraving information on various surfaces, has been gaining attention in the horticultural industry lately. However, due to large variations among produce types (size, shape, color), the performance of this technology varies, and little information is known about its effects on postharvest quality, microbial safety, and consumer acceptability.

The first chapter of the thesis provides background information on the importance of food traceability, methods of produce labeling, and the potential of new alternative CO_2 LLT. The second research chapter focused on investigating the effect of CO_2 LLT on i) postharvest quality, ii) microbial safety of fresh produce, and iii) economic analysis of this technology. Three horticultural crops, 'Red Delicious' apples, green bell peppers (*Capsicum annuum*), and cucumbers (*Cucumis sativus*) were procured from a local grocery store. Each produce item was engraved with a Quick Response (QR) code or 6-digit alphanumerical (text) code using the commercially available Trotec Speedy 300 CO_2 laser engraver, followed by the application of edible wax. Fresh weight loss for laser-labeled produce was higher than the nontreated control, but no difference in visual quality ratings was observed compared to the control. The laser-labeled produce was assessed for microbial contamination by artificially inoculating rifampicin-resistant *Escherichia coli* (*E. coli*) at the initial concentration of log 6 colony forming unit (CFU)/mL to the

labeled fruit. The results showed that the population of rifampicin-resistant *E. coli* in QR-code labeled apples was statistically similar to the control.

The third research chapter assessed consumers' perception and acceptability of the laser-labeled ‘Red Delicious’ apple (*Malus domestica*) fruit. A consumer study (N=75) was conducted to assess consumers' perception and acceptability of laser-labeled apples with three treatments: 1) apple with QR-code printing, 2) apple with PLU plastic sticker, and 3) non-labeled control. A randomized set of the three treatment samples was given to respondents at the Sensory and Consumer Research Center facility at Kansas State University, Olathe. The ranking of three treatments based on overall physical quality revealed that before providing educational information on product labeling, consumers ranked QR-code labeled apples as the lowest group, followed by sticker-labeled and unlabeled apples. In contrast, after sharing information on the CO_2 LLT, the ranking scores from the same consumers were statistically similar. Results indicate that CO_2 LLT has the potential for industrial application from the consumers' perspective, and providing consumer education seems essential to make this technology more accepted by consumers.

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Dedication

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Chapter 1 - Introduction

Economics of fresh produce

Consumption of fruit and vegetables promotes a healthy lifestyle because of their high concentration of dietary fiber, vitamins, minerals, electrolytes, and antioxidants (Slavin & Llyod, 2012). Several researchers have associated lower intake of fruits and vegetables with chronic diseases such as cardiovascular diseases, high blood pressure, hypercholesterolemia, osteoporosis, many cancers, chronic obstructive pulmonary diseases, respiratory problems, and mental health challenges (Adebawo et al., 2006; Celik & Topcu, 2006; Dhandevi & Rajesh, 2015; Park et al., 2011; Payne et al., 2012; Williamson, 1996). As the nutrients from produce are hard to replace with other foods, the 2020-2025 dietary guidelines for Americans advise incorporating more fruits and vegetables into U.S. residents' diets as part of a healthy diet (Lee et al., 2022). The USDA's MyPlate recommends that adults consume 1.5-2 cups of fruits and 2-3 cups of vegetables daily as part of a balanced diet (Marcus, 2013; Lee et al., 2022). In the U.S., the intake of fresh fruits and vegetables has increased in recent years as the United States Department of Agriculture (USDA) estimated that per capita consumption of fresh produce in 2010 and 2016 was 67.2 and 68.7 kg, respectively (USDA-Economic Research Service, 2023). The intake of fresh produce, however, varies by socioeconomic demographics (Lee et al., 2022); for example, in 2019, the proportion of U.S. adults meeting vegetable intake recommendations was 12.5% for people aged ≥ 51 years and 6.8% for low-income adults (Lee et al., 2022). Due to increasing demands, the U.S. fruits and vegetables market is growing steadily, and a report suggested that the market size for fruit and vegetables was valued at USD 92.8 billion in 2022 and is expected to grow at an annual growth rate of 4.1% from 2023 to 2030 (Grand View Research, 2023). To meet the demand, besides the increase in produce imports, the domestic production of fresh fruits and vegetables, particularly fruit crops, increased from 1990 to 2018 (USDA-Economic Research Service, 2019).

As consumers continue to increase their daily intake of fresh fruits and vegetables, the ability to deliver high-quality produce with a longer shelf-life is critical. The quality of fresh produce is a combination of attributes, properties, or characteristics that determine the value for the consumer. The quality parameters include appearance, texture, flavor/aroma, and nutritional value (Gallagher et al., 2016). The quality of fresh produce also depends upon the cultivar, preharvest practices, climacteric conditions, maturity at harvest, harvesting methodology, and postharvest conditions, making shelf-life prediction a difficult task compared to other food products (Gallagher et al., 2016). For the growers, produce quality may be defined differently, such as good physical appearance, fewer blemishes, higher yield, increased resistance to disease, and insect pests are important. For wholesalers and retailers, appearance quality, firmness, and long storage life are important quality parameters. Similarly, for the consumers, good appearance, good flavor, firmness, and safety is the quality they want in their fresh produce. Furthermore, handling procedures, storage, transportation environment, and distance traveled also impact the quality of fresh produce. (Gallagher et al., 2016).

Foodborne disease outbreaks related to fresh produce

Fresh produce is often consumed in its raw state, generally minimally processed (e.g., washed, sanitized, packaged) since it does not go through additional processing steps (such as kill step) that would further reduce the microbiological load and eliminate harmful pathogens (Sy et al., 2005). Fresh produce en route to the kitchen from the farm could encounter microbial pathogens and thus has the potential to cause foodborne illnesses. With the increase in production, imports, and consumption of fresh produce, the number of foodborne disease outbreaks associated with fresh produce is rising (Buck et al., 2003; Gould et al., 2017; Lynch et al., 2009). For instance, the Centers for Disease Control and Prevention (CDC) reported that from 2004 to 2010, 163 cases of foodborne outbreaks associated with fresh produce were recorded in the U.S., of which 27% (45) of cases occurred in multiple states (CDC, 2022). These outbreaks resulted in 4,949 illnesses, 895 hospitalizations, and nine deaths. Similarly, from 2010 to 2017, 228 foodborne outbreaks related to fresh produce with a confirmed food vehicle and etiology occurred in the U.S. (CDC, 2022). These outbreaks, including 23 multistate outbreaks, resulted in 4,748 illnesses, 1,190 hospitalizations, and 55 deaths.

Produce-related foodborne disease outbreaks have severe consequences on human health and thus have become a significant public health concern. A total of 23 multistate produce-related outbreaks were attributed to pathogenic *E. coli*, of which five outbreaks were associated with Romaine lettuce. Similarly, multistate outbreaks of *Salmonella enterica* were associated with seeded vegetables and cucumbers. A large foodborne disease outbreak in terms of both the number of states affected (40) and case counts (907), which occurred in 2015, was linked to cucumbers imported from Mexico that were contaminated with *S. enterica Poona* (CDC, 2016). A total of 147 listeriosis cases (caused by the bacteria *Listeria monocytogenes)* were reported to the US Centers for Disease Control (CDC) between July and October 2011, resulting in 33 known deaths in 28 states (CDC, 2011; McCollum et al., 2013). Between October 2014 and January 2015, 35 illnesses from 12 states were reported to the CDC due to the consumption of *Listeria monocytogenes*-contaminated pre-packaged caramel apples (CDC, 2015). This increase in foodborne disease outbreaks associated with fresh produce represents a shift from outbreaks associated with foods of animal origin, such as eggs, meat, and dairy products (Gould et al., 2017).

The rate of frequent foodborne illness caused by the consumption of fresh produce remains high throughout the U.S., causing a strain on public health and significant economic loss (Berger et al., 2010). According to the CDC (2018), an estimated annual 47.8 million illnesses, 127,839 hospitalizations, and 3,037 deaths that occur in the U.S. alone are related to food-borne illnesses. The cost estimate of food safety incidents to the U.S. economy is around USD 7 billion per year, which includes notifying consumers, removing food from shelves, and paying damages on legal litigations (Hussain & Dawson, 2013). This is a significant public health burden that is largely preventable. A foodborne disease outbreak's potential impact can devastate any food company, including a fresh produce farm. A single event of an outbreak can bring unimaginable financial loss. The economic analysis of food safety-related costs showed that it is much cheaper for a producer to invest in preventing foodborne outbreaks than responding to the legal consequences of an outbreak (Ribera et al., 2012). The fresh produce industry in many countries has responded to this by adopting various risk management practices designed to reduce the likelihood of contamination. However, the current risk management practices are insufficient to reduce foodborne outbreaks, as depicted by the increased number of outbreaks in recent years. (Sivapalasingam et al, 2004). There are several possible routes for the pathogenic contamination of produce along the production, processing, and retailing chain, which poses a significant challenge in tracing the sources and routes of produce contamination (Carstens et al., 2019).

Food Safety Modernization Act

To cope with the food safety challenge, the U.S. Food and Drug Administration (FDA) implemented the Food Safety Modernization Act (FSMA), which was signed into law in 2011. This act allows the FDA to develop prevention-based and response-based strategies for food contamination events and foodborne outbreaks (FDA, 2023a). The FDA added seven rules to

FSMA in November 2015, including the Produce Safety Rule, which provides comprehensive science-based guidance for growing, harvesting, packing, and holding of produce for human consumption (FDA, 2023b). The final produce safety rule was enacted in January 2016 and indicates that all fresh produce facilities implement mandatory preventive controls and produce safety standards.

The FDA rule on Additional Traceability Records for Certain Foods (Food Traceability Rule) establishes traceability recordkeeping requirements for persons who manufacture, process, pack, or hold foods included on the Food Traceability List (FDA, 2023c; FDA, 2023d). The commodities under the Food Traceability List include fresh fruits, fresh leafy greens, cucumbers, peppers, tomatoes, etc. (FDA, 2023d). The Food Traceability Rule requires the horticultural industry to maintain records containing key data elements associated with specific critical tracking events (FDA, 2023c). The Rule covers domestic and foreign firms producing food for U.S. consumption and the entire food supply chain (FDA, 2023c). The effective implementation of this Rule will allow for faster identification of contaminated food and removal of specific items without endangering the entire supply line from the market (FDA, 2023c). The compliance date for all persons subject to the Traceability rule recordkeeping requirements is January 20, 2026. The small-farm growers with annual monetary sales below $25,000 (adjusted annually for inflation) during the previous three-year period (on a rolling basis) are, however, exempt from the Produce Safety Rule and the Traceability rule.

Traceability in the produce supply chain

Food traceability is the ability to follow the movement of a food product and its ingredients through all steps in the supply chain, both backward and forward. Traceability involves documenting and linking the production, processing, and distribution chain of food products and ingredients (Badia-Melis et al., 2015; Bosona & Gebresenbet, 2013). With the development of information technology, the food traceability system, which can reduce individuals' concerns about food safety by providing unambiguous information about the safety and quality of the whole supply process from producers to consumers, has been broadly disseminated in the food industries (Badia-Melis et al., 2015; Cozzolino, 2014). In the case of a microbial contamination event, efficient product tracing helps government agencies, producers, and sellers to rapidly find the source of the product and where contamination may have occurred (Aung & Chang, 2014; Badia-Melis et al., 2015). This enables faster recall/removal of contaminated product from the marketplace, reducing incidences and containing the spread of foodborne illnesses (Badia-Melis et al., 2015; Bosona & Gebresenbet, 2013). An efficient traceability system can provide aggregated information related to all stages of production in the farm to fork continuum if needed (Bertolini et al., 2006; Peres et al., 2007).

According to Folinas et al. (2006), traceability schemes can be distinguished into two types based on supported functions. Logistics traceability primarily focuses on monitoring the physical movement of a product, treating food as a commodity. In contrast, qualitative traceability incorporates additional product quality and consumer safety details. This includes information on preharvest and postharvest techniques, storage conditions, distribution processes, and more. Folinas et al. (2006) further explain that logistics traceability offers valuable business insights, covering details like quantity, origin, destination, and dispatch date. This allows for swift tracking of a product's current location, origin, and destination, particularly in situations requiring immediate recall or removal from the market. In such cases, a qualitative traceability system is crucial in identifying hazards' sources and causes. It provides comprehensive data to assess the conditions and methods of producing, processing, and distributing the product. Importantly, it is essential to clarify that an efficient qualitative traceability system does not directly enhance product safety or quality. Instead, its primary function is to ensure consumer health and safety by facilitating the rapid recall and withdrawal of potentially hazardous products during a food crisis (Folinas et al., 2006).

In recent years, there has been a growing demand for enhanced traceability in food systems, driven by the desire of retailers and consumers to gain a more precise understanding of the origins of the food they receive. This shift is also influenced by increasing concerns about social justice and sustainability. The traceability implementation improves food safety and enhances public confidence in the supply chain. In the unfortunate event of food contamination, an effective traceability system can precisely identify the affected product, minimizing the risk of compromising the entire product line (Welt & Blanchfield, 2012).

For traceability to be fully effective and streamlined, every item within the supply chain must be identified, ranging from raw materials to finished products and including packages and logistical units. Moreover, each component should have seamless linkage and communication, appropriately coded for efficient tracking. Early traceability systems used to rely on records kept by workers on the field and manually entered in paper or computer-based systems. With technological advancements, particularly with the Internet of Things (IoTs) and machine learning, the traceability system is becoming more efficient and trustworthy (Rose & Chilvers 2018). The computerized system supports various technologies involved in any stage of the food supply chain so that recording and exchanging important information can be done more efficiently. Various data carrier technologies play a crucial role in achieving this. These technologies encompass bar codes, two-dimensional codes (such as multi-row bar codes and matrix codes), composite codes, contact memory, Wireless Sensor Network (WSN), and radio frequency identification (RFID) data carriers. (Demestichas et al., 2020, Duan et al., 2020). Linear bar codes are the most commonly used data carrier technology due to their simplicity. However, it is essential to note that scanning devices necessitate the visibility and illumination of the bar code before they can be scanned, and some scanners may have line-of-sight constraints (Furness & Osman, 2006). Integrating such technologies is vital for successfully implementing traceability measures in the complex web of modern supply chains.

Prompt and rapid responses from governmental bodies and the food industry are crucial in halting the escalation of foodborne illnesses and fatalities. However, a significant obstacle to preventing these recurring outbreaks and potential harm to consumers is the absence of an efficient traceability system. Investigating outbreaks or conducting surveillance demands meticulously integrating epidemiological, laboratory, food, and environmental testing data to establish connections between illnesses and food sources while identifying specific outbreak characteristics. Consumers seek accurate traceability information to ensure food safety and protection against potential counterfeiting and adulteration. Traceability has evolved into a critical process for ensuring the safety of food and consumers' satisfaction (Aung & Chang, 2014).

Traditional method of produce labeling

The current industry practice is to label fresh produce with 4-digit Price Look-Up (PLU) plastic stickers attached to the individual produce items to meet the FDA's Food Traceability Rule. The PLU labeling of fresh fruit and vegetables has been widely used in the United States and around the globe for the past ten years, ideally to manage inventory and facilitate checkout in retail stores. The National Grocers Association (NGA), USA, requires the PLU labels to be placed on all types of fresh fruits and certain individually sold vegetables. These labels help quickly access product information and prevent theft at the point of sale (Eyahanyo, 2020; Liu et al., 2019; Marx, Schultz, et al., 2013).

The International Federation for Produce Standards (IFPS), an umbrella association of producers' association worldwide, assign these PLU codes. The PLU sticker carries a universal product code, aka UPC number, standardized around the globe, that identifies the type of produce, source of origin, and growing methodology (whether conventionally or organically grown) and facilitates checkout at retail stores. Although these PLU stickers are helpful for various purposes, they have certain drawbacks to adopting them for long-term system use. Those stickers are made of plastic and glue, both non-compostable environmental contaminants. However, in an effective system, adhesive tags are not permanent and generate secondary problems ranging from tag detachment, tag buildup along the packing line, and fouling of processing equipment to the need for special storage rooms. In addition, they are not permanent and may be removed at any postharvest handling stage, negatively affecting traceability. With regard to consumers, many consumers do not care for adhesive labels. Some customers do not like having to peel the label off the produce. In addition, customers sometimes inadvertently eat or bite into the adhesive label (Etxeberria et al., 2006; Eyahanyo, 2020). Furthermore, the stickers are too small to be screened out in the waste sorting and do not break down during composting. As a result, they end up sprinkled as "foreign matter" through the finished compost product in gardens and farms (Kachook, 2021).

Legislation in European countries that addresses pollution caused by plastic use, including PLU stickers, is on the horizon (Lindsey, 2021; Tucker, 2023). France became the first country to bring a comprehensive law known as Anti Waste and Circular Economy Law, which ultimately seeks to ban all plastic packaging by 2040 (Boring, 2022). The French government issued a decree on October 8, 2021, providing more details on implementing the plastic ban (USDA-Foreign Agricultural Service, 2021). Specifically, the decree established a phased implementation of the ban on single-use plastic packaging, to begin on January 1, 2022, for about 30 types of fruits and vegetables, including bell peppers, cucumbers, and apples. The French legislation is the first of its kind to include PLU stickers on the banned list. The legislators have changed laws to limit waste, preserve natural resources and biodiversity, and protect against climate change for the circular economy. The proposed Break Free from Plastic Pollution Act in the United States includes provisions for guidelines to nationally standardize labeling for recycling and composting receptacles (Rachal, 2023). In New Zealand, the Auckland City Council has also proposed a ban on non-compostable produce stickers (Ministry for the Environment, NZ, 2023).

The United States is the largest supplier of fruits and vegetables, mostly grapefruit and sweet potatoes, to France. Most U.S.-grown grapefruit and sweet potatoes have PLU plastic stickers attached for traceability and marketing. The non-home-compostable plastic ban in France is especially problematic for U.S. citrus exports. A French ban on selling fruits and vegetables with PLU stickers threatens exports of U.S. sweet potatoes (approx. $20 million in sales annually) and grapefruits ($8 million annually) (USDA-Foreign Agricultural Service, 2021).

Modern methods of produce labeling

With new innovations, several types of automatic identification data capture technologies have been developed and used in the horticultural industry for labeling. Bar codes, radio frequency identification (RFID), and direct part marking (DPM) are some of the commonly used technologies for labeling developed in recent years. Barcodes have been extensively used in the horticultural industry in the form of stickers/labels as they provide a cheaper and convenient system for retrieving information. Barcodes are machine-readable vertical black stripes with white spaces.

There are different types of barcodes, which include numeric-only barcodes, UPC (Universal Product Code), alpha-numeric barcodes, 2D (two-dimensional) barcodes, such as Data Matrix codes, QR codes (Dutta et al., 2016; Katona & Nyul, 2012). The 2D barcodes are the advancement of 1D barcodes, which can be created in various shapes and forms using geometric patterns (e.g., dots, squares, etc.). The increased data storage capabilities and ease of data reading make 2D barcodes more popular than 1D barcodes. However, automation with barcodes has a few issues: as a line of sight is required for reading, multiple barcodes cannot be read at one time with laser scanners, and there is a risk of losing some barcodes (stickers) in the distribution process (Creusot & Munawar, 2015; Dutta et al., 2016; Fang et al., 2012). A relatively newer RFID technology, which uses radio frequencies to transmit data wirelessly for identifying products affixed with tags or chips, was introduced to solve the problems mentioned above with barcode automation (Erbach, 2023). An RFID label contains a chip that stores data and a small inbuilt antenna that allows the chip to transmit and receive radio waves for data transmission (Erbach, 2023). The increased speed and accuracy of quickly scanning large volumes of produce has increased the merit of RFID labeling in the horticultural industry. However, this technology has its limitations with automation due to its reliance on radio signal strengths, which can be inconsistent (Andrade-Sanchez, 2007; Tate et al., 2008).

Unlike stickers or labels, DPM is a permanent way of imprinting, usually a 2D barcode, directly on the surface of a product (Li et al., 2016; Ventura et al., 2016). The DPM technology has been widely used in the automotive, computer, and healthcare industries and is slowly gaining interest in horticulture (Li et al., 2016; Ventura et al., 2016). The durability of the labeling from permanent marking has increased the capability to trace the product throughout the whole supply chain from beginning to end, and this has made DPM a fast and increasingly popular technology in various fields (Denkena et al., 2016; Li et al., 2016; Ventura et al., 2016). The different methods of DPM are available in the market, such as chemical etching, inkjet printing, dot peening, and laser marking, of which laser marking is the most popular and rapid method as it provides high contrast on several surfaces such as metal, wood, glass, etc. for better visibility and scanning (Li et al., 2016). Several researchers have studied the laser labeling technology in the horticultural industry for labeling fresh produce as an alternative to traditional PLU sticker labeling (Danyluk et al., 2010; Etxeberria et al., 2006; Eyahanyo & Rath, 2020; Marx, Hustedt, et al., 2013; Nasution et al., 2017; Sood et al., 2008; Sood et al., 2009; Sree & Natarajan, 2022; Yuk et al., 2007).

CO_2 laser labeling technology on produce labeling

A CO_2 laser labeling technology utilizes a laser (light amplification by stimulated emission of radiation) beam to produce permanent markings on the skin of fruits and vegetables. A typical laser marking system comprises three main parts: a scanning head, a low-power CO_2 laser source, and a computer equipped with the application software (The scanning head deflects the laser beam and keeps it always focused on the surface of the workpiece. The laser source and scanning head are controlled by software that, fed with the correct parameters, achieves the marking process of the desired design. The laser beam's speed, position, and power can be controlled to produce all images, logos, codes, and markings (Elen Laser, 2023). The use of laser-engraving machines in industries such as automotive, healthcare, manufacturing, etc., is common and is gaining attention in the horticultural industry.

Initially, fruits with non-edible outer skins (e.g., pomegranates, avocadoes, coconuts, and melons) were laser-marked (Samoggia & Nicolodi, 2017). The initial laser markings were etched with logos, numbers, symbols, country of origin, and words (Eppenberger, 2018; Samoggia & Nicolodi, 2017). After the European Commission approved the use of matrices, bars, and QR codes on laser labeling for certain fruits, the interest in laser labeling has gained momentum in the industry (Eppenberger, 2018; European Commission, 2013; Samoggia & Nicolodi, 2017). Laser etching on the skin of fresh fruits and vegetables provides permanent labels and environmental benefits by reducing the use of plastic, paper, ink, and glue. This would also allow the horticulture industry to comply with the regulations banning single-use plastic (e.g., in France and New Zealand). Furthermore, unlike self-adhesive labels, laser labeling on individual produce (e.g., apple, cucumber) limits the risks of mixing and loss of labels, prevents adulteration and counterfeiting, improves inventory management, and builds an efficient traceability system (Eppenberger, 2018; Pullman, 2017; Samoggia & Nicolodi, 2017).

To meet the FDA's Food Traceability Rule, using laser labeling technology to etch QR codes on produce skin could be promising. Compared to barcodes, the QR code system is an advancing technology in automatic data identification, offering quicker readability and increased storage capacity. For instance, barcodes are limited to storing up to 20 digits, and QR codes have a much higher capacity, accommodating a maximum of 7,089 characters (Ali & Farhan, 2020; Shirley et al., 2021; Vardhan et al., 2016). A significant advantage of QR codes is their versatility in scanning, as they can be read from any angle or position (Vardhan et al., 2016). The encoded information within a QR code is contained within the three distinct squares positioned at its corners (Vardhan et al., 2016). In today's context, virtually every smartphone has a built-in QR code scanner application, allowing users to read QR codes and access the stored information easily. This information can take various forms, such as a web address or personal details (Ali & Farhan, 2020; Shirley et al., 2021; Vardhan et al., 2016). However, the water content, texture, color, shape, and skin thickness of the produce pose challenges in successfully marking and decoding the labels, including QR codes (Denkena et al., 2016; Li et al., 2016; Ventura et al., 2016).

Effects of CO_2 laser labeling on produce quality and safety

Since the CO_2 laser energy disrupts the outer epidermal layer on the skin of fresh fruits and vegetables, the quality and safety of produce following laser labeling is questionable, and such effects could vary from produce to produce due to variations in intrinsic properties. The etching of skin could affect its properties to protect against mold, bacteria, and other agents, resulting in the deterioration of the organoleptic properties and decline in taste and aesthetic quality. The CO_2 laser labeling on fresh produce is a novel process; thus, it lacks a standard operating procedure. Variations in form, shape, size, texture, and color of different produce pose challenges for optimal engraving and scanning. Despite the substantial amounts of wax and lignin formed by the surrounding and underlying cells, laser engraving compromises the produce's protective barrier. It may eventually serve as an entrance point for bacteria that cause deterioration and places for increased water loss (Etxeberria et al., 2006). Little information is available about the effect of laser labeling technology on produce postharvest quality and microbial safety. A previous study has reported that applying a secondary coating or waxing shortly after laser labeling helps reduce water loss and prevents unwanted shrinkage (Sood et al., 2009). Also, laser labeling interrupts the natural cuticular barrier of the fresh produce surface and potentially opens a route allowing pathogenic organisms to be penetrated. Storage temperature also affects the survival and growth of pathogens on cut surfaces of produce items (Huff et al., 2012). A study reported that six human pathogens, including bacteria and viruses, were all found to survive for 14 days on the phyllosphere of cantaloupe, romaine lettuce, and green bell pepper under controlled environmental conditions (22 to 24 °C and 45 to 90% RH), demonstrating that human pathogens can survive in this ecological environmental for commercially relevant periods (Stine et al., 2005).

Consumer perceptions about laser labeling technology on fresh produce

In recent years, food labeling has gained importance to provide consumers with information on healthier, safer, and more eco-friendly food products (Loureiro & McCluskey, 2002). Past research explored consumers' perception of environmentally-oriented innovation focused on labels: sustainable food packaging (Fernqvist et al., 2015), different food labeling (Loureiro & McCluskey, 2002), and food label understanding (Grunert et al., 2014). In addition, produce can be labeled to inform the consumer about other characteristics of the products, such as organic certification or company brand. Despite the opportunity to reduce environmental pollutants (plastic, glue, paper) and carbon emissions through CO_2 laser labeling, fruit-processing manufacturers are still doubtful about the consumer acceptance of this innovative and eco-friendly laser labeling method (Samoggia & Nicolodi, 2017). In an X (formerly Twitter) poll (n=726) conducted in 2017 by Domino Printing UK, 43% of the respondents were concerned about the health and safety of laser printing on fresh fruits (Hall, 2017). This shows that most people associate lasers with danger as there is a lack of knowledge in the public about laser technology, particularly on produce labeling (Hall, 2017). Also, terminology (e.g., laser tattoo) could be misleading as it could convey the usage of ink in the process, thus creating misinformation among the public on laser-labeled produce. Research showed that organoleptic characteristics, such as taste, storability, and the general lifespan of the fruit, are not affected by CO_2 laser labeling (Exteberria et al., 2006; Samoggia & Nicolodi, 2017; Sood et al., 2009). Nonetheless, retailers are welcoming the new technology because, in addition to the advantages mentioned above, it is an innovative approach to improving the traceability of the produce. However, it is apparent that retailers are concerned about label readability, and consumers are worried about the integrity of the product (Samoggia & Nicolodi, 2017).

To sum up, there is a need to find an environmentally friendly alternative to PLU sticker labeling as government legislation restricting the use of plastic is growing around the globe, including the United States. The CO_2 laser-labeling technology has been widely used for engraving labels on a number of materials such as metal, leather, fabric, plastic, glass, etc., but the use in the produce industry is not documented. Since the produce surface varies by produce type due to variations in texture, shape, color, skin thickness, etc., the performance of the CO_2 laser-labeling technology on produce labeling is unknown. Furthermore, the laser-etched surface could increase water loss and deteriorate postharvest quality. The laser engraver machine disrupts the outer cuticular surface of the produce, which may result in increased respiration and water loss. Also, this method could facilitate the entry and attachment of microbial pathogens through the etched surface. Additionally, research on consumers' perception of laser labeling is needed before rolling out the technology in the commercial market. There is very limited information available on the effect of using the CO_2 laser-labeling technology on postharvest quality, microbial safety, and consumers' acceptability. As such, the objectives of the thesis are to:

1. Investigate the effect of CO_2 laser labeling of three horticultural produce ('Red Delicious' apple, cucumber, and green bell pepper) on postharvest quality
2. Evaluate the effect on the microbial safety of laser-labeled horticultural produce
3. Perform economic feasibility of the CO_2 laser labeling technology
4. Evaluate consumers' acceptability of the CO_2 laser labeling technology compared to more conventional technology, using 'Red Delicious' apples as an example

References

Adebawo, O., Salau, B., Ezima, E., Oyefuga, O., Ajani, E., Idowu, G., Famodu, A., & Osilesi, O. (2006). Fruits and vegetables moderate lipid cardiovascular risk factor in hypertensive patients. *Lipids in Health and Disease*, *5*(1), 1–4.

Ali, A. M., & Farhan, A. K. (2020). Enhancement of QR code capacity by encrypted lossless compression technology for verification of secure E-Document. *IEEE Access*, *8*, 27448–27458.

Andrade-Sanchez, P., Pierce, F. J., & Elliott, T. V. (2007). Performance assessment of wireless sensor networks in agricultural settings. *2007 ASAE Annual Meeting*, 1.

Angelo, K. M., Nisler, A. L., Hall, A. J., Brown, L. G., & Gould, L. H. (2017). Epidemiology of restaurant-associated foodborne disease outbreaks, United States, 1998–2013. *Epidemiology & Infection*, *145*(3), 523–534.

Aung, M. M., & Chang, Y. S. (2014). Traceability in a food supply chain: Safety and quality perspectives. *Food Control*, *39*, 172–184.

Badia-Melis, R., Mishra, P., & Ruiz-García, L. (2015). Food traceability: New trends and recent advances. A review. *Food Control*, *57*, 393–401.

Bertolini, M., Bevilacqua, M., & Massini, R. (2006). FMECA approach to product traceability in the food industry. *Food Control*, *17*(2), 137–145.

Boring, N. (2022) France: Government Bans Single-Use Plastic Packaging for Various Perishable Products. [Web Page] Retrieved from the Library of Congress, https://www.loc.gov/item/global-legal-monitor/2022-01-18/france-government-bans-single-use-plastic-packaging-for-various-perishable-products/

Bosona, T., & Gebresenbet, G. (2013). Food traceability as an integral part of logistics management in food and agricultural supply chain. *Food Control*, *33*(1), 32–48.

Buck, J. W., Walcott, R. R., & Beuchat, L. R. (2003). Recent trends in microbiological safety of fruits and vegetables. *Plant Health Progress*, *4*(1), 25.

Carstens, C. K., Salazar, J. K., & Darkoh, C. (2019). Multistate outbreaks of foodborne illness in the United States associated with fresh produce from 2010 to 2017. *Frontiers in Microbiology, 10*, 2667.

Celik, F., & Topcu, F. (2006). Nutritional risk factors for the development of chronic obstructive pulmonary disease (COPD) in male smokers. *Clinical Nutrition*, *25*(6), 955–961.

Centers for Disease Control and Prevention. (2011, October, 7). *Multistate outbreak of listeriosis associated with Jensen Farms cantaloupe–United States, August–September 2011*. Morbidity and mortality weekly report 60(*39*): 1357–1358.

Centers for Disease Control and Prevention. (2015, February 12). *Multistate outbreak of listeriosis linked to commercially produced prepackaged caramel apples made from Bidart Bros. apples (final update)*.

Centers for Disease Control and Prevention. (2016, March 18). *Multistate outbreak of Salmonella Poona infections linked to imported cucumbers (final update)*.

Centers for Disease Control and Prevention. (2018, November 5). *Burden of foodborne illness: Questions and answers*.

Centers for Disease Control and Prevention. (2022, February 3). *National outbreak reporting system*.

Cozzolino, D. (2014). An overview of the use of infrared spectroscopy and chemometrics in authenticity and traceability of cereals. *Food Research International*, *60*, 262–265.

Creusot, C., & Munawar, A. (2015). Real-time barcode detection in the wild. *2015 IEEE Winter Conference on Applications of Computer Vision*, 239–245.

Danyluk, M. D., Villeda, L. O. I., Friedrich, L. M., Schneider, K. R., & Etxeberria, E. (2010). Natural-Light Labeling of Tomatoes Does Not Facilitate Growth or Penetration of Salmonellainto the Fruit. *Journal of Food Protection*, *73*(12), 2276–2280.

Demestichas, K., Peppes, N., Alexakis, T., & Adamopoulou, E. (2020). Blockchain in agriculture traceability systems: A review. *Applied Sciences*, *10*(12), 4113.

Denkena, B., Grove, T., & Seibel, A. (2016). Direct part marking by vibration assisted face milling. *Procedia Technology*, *26*, 185–191.

Dhandevi, P. E. M., & Jeewon, R. (2015). Fruit and vegetable intake: Benefits and progress of nutrition education interventions-narrative review article. *Iranian Journal of Public Health*, *44*(10), 1309.

Duan, J., Zhang, C., Gong, Y., Brown, S., & Li, Z. (2020). A content-analysis based literature review in blockchain adoption within food supply chain. *International journal of environmental research and public health*, *17*(5), 1784.

Dutta, K., Gupta, S., & Kaur, M. (2016). Fast Algorithm for recognition of 2D barcode: A Review. *International Journal of Emerging Trends in Science and Technology (IJETST)*, *2*(7), 4334–4339.

Elen Laser. (2017, May 5). *Laser labeling of food with laser marking*.

Eppenberger, D. (2018, February 28). *New: Less packaging thanks to laser marking*. Gabot.de.

Erbach, C. (2023, August 3). *Learn RFID labeling basics*. Weber Packaging Solutions.

Etxeberria, E., Miller, W. M., & Achor, D. (2006). Anatomical and morphological characteristics of laser etching depressions for fruit labeling. *HortTechnology*, *16*(3), 527–532.

European Commission. (2013, June 3). *Commission Regulation (EU) No. 510/2013 of 3 June 2013*, Official Journal of the European Union, L 150/17-L150/20. Retrieved on October 11, 2023.

Eyahanyo, F. A. (2020). *Computer vision reading on stickers and direct part marking on horticultural products: challenges and possible solutions [Doctoral dissertation, Leibniz University Hannover]*.

Eyahanyo, F., & Rath, T. (2020). Investigations on the effects of low laser infrared marking energy and barcode size on 2D data matrix code detection on apples. *Applied Engineering in Agriculture*, *36*(6), 829–838.

Fang, J. P., Chang, Y.-L., Chu, W.-C., & Chen, K. W. (2012). Incomplete barcode reading mechanism with remote database access. *Recent Advances in Computer Science and Information Engineering: Volume 1*, 705–710.

Fernqvist, F., Olsson, A., & Spendrup, S. (2015). What's in it for me? Food packaging and consumer responses, a focus group study. *British Food Journal*, *117*(3), 1122–1135.

Folinas, D., Manikas, I., & Manos, B. (2006). Traceability data management for food chains. *British Food Journal*, *108*(8), 622–633.

Furness, A., & Osman, K. A. (2006). Developing traceability systems across the food supply chain: an overview. *Improving Traceability in Food Processing and Distribution*, 3–25.

Gould, L. H., Kline, J., Monahan, C., & Vierk, K. (2017). Outbreaks of disease associated with food imported into the United States, 1996–2014. *Emerging Infectious Diseases*, *23*(3), 525.

Grand View Research. (2023). *U.S. fruit and vegetables market size, share & trends analysis report, by product (fresh fruits & vegetables, frozen fruits & vegetables), by distribution channel (online), by region, and segment forecasts, 2023 - 2030*.

Grunert, K. G., Hieke, S., & Wills, J. (2014). Sustainability labels on food products: Consumer motivation, understanding and use. *Food Policy*, *44*, 177–189.

Hall, J. (2017, September 15*). Key considerations when using lasers to code fruit and vegetables*. Domino North America.

Huff, K., Boyer, R., Denbow, C., O'keefe, S., & Williams, R. (2012). Effect of storage temperature on survival and growth of foodborne pathogens on whole, damaged, and internally inoculated jalapenos (Capsicum annuum var. annuum). *Journal of Food Protection*, *75*(2), 382–388.

Hussain, M. A., & Dawson, C. O. (2013). Economic impact of food safety outbreaks on food businesses. *Foods*, *2*(4), 585–589.

Kachook. O. (2021, May 5). *Produce stickers: A small but mighty problem*. Sustainable Packaging Coalition.

Katona, M., & Nyúl, L. G. (2012). A novel method for accurate and efficient barcode detection with morphological operations. *2012 Eighth International Conference on Signal Image Technology and Internet Based Systems*, 307–314.

Lee, S. H., Moore, L. V, Park, S., Harris, D. M., & Blanck, H. M. (2022). Adults meeting fruit and vegetable intake recommendations—United States, 2019. *Morbidity and Mortality Weekly Report*, *71*(1), 1.

Leone, C., Bassoli, E., Genna, S., & Gatto, A. (2018). Experimental investigation and optimisation of laser direct part marking of Inconel 718. *Optics and Lasers in*

Engineering, *111*, 154–166.

Li, X.-S., He, W.-P., Lei, L., Wang, J., Guo, G.-F., Zhang, T.-Y., & Yue, T. (2016). Laser direct marking applied to rasterizing miniature Data Matrix Code on aluminum alloy. *Optics & Laser Technology*, *77*, 31–39.

Lindsey, P. (2021, September 28). *Spain plans ban of plastic packaging for fruits and vegetables*. Food Packaging Forum. *Spain plans ban of plastic packaging for fruits and vegetables*.

Links, E. R. S. (2019). Food Availability (Per Capita) Data System. *Population*, *7*, 31.

Liu, C.-H., Chen, T.-L., Pai, T.-Y., Chiu, C.-H., Peng, W.-G., & Weng, C.-C. (2019). An intelligent robotic system for handling and laser marking fruits. *Technologies and Eco-Innovation towards Sustainability I: Eco Design of Products and Services*, 75–88.

Loureiro, M. L., McCluskey, J. J., & Mittelhammer, R. C. (2002). Will consumers pay a premium for eco-labeled apples? *Journal of Consumer Affairs*, *36*(2), 203–219.

Lynch, M. F., Tauxe, R. V, & Hedberg, C. W. (2009). The growing burden of foodborne outbreaks due to contaminated fresh produce: risks and opportunities. *Epidemiology & Infection*, *137*(3), 307–315.

Marcus, J. B. (2013). *Culinary nutrition: the science and practice of healthy cooking*. Academic Press.

Marx, C., Hustedt, M., Hoja, H., Winkelmann, T., & Rath, T. (2013). Investigations on laser marking of plants and fruits. *Biosystems Engineering*, *116*(4), 436–446.

Marx, C., Schultz, M., Schymik, K., Krüger, A., Ripken, T., & Rath, T. (2013). Re-identification of superficial and sub-epidermal laser markings on plants and fruits. *International Symposium on New Technologies for Environment Control, Energy-Saving and Crop*

Production in Greenhouse and Plant 1037, 709–714.

McCollum, J. T., Cronquist, A. B., Silk, B. J., Jackson, K. A., O’Connor, K. A., Cosgrove, S., Gossack, J. P., Parachini, S. S., Jain, N. S., & Ettestad, P. (2013). Multistate outbreak of listeriosis associated with cantaloupe. *New England Journal of Medicine*, *369*(10), 944–953.

Ministry for the Environment, New Zealand. (2023, July 1). *Phasing out hard-to-recycle and single-use plastics*.

Nasution, I. S. (2018). *Technical optimization of a laser marking process of banana fruits and poinsettia bracts*.

Nasution, I. S., & Rath, T. (2017). Optimal laser marking of 2D data matrix codes on Cavendish bananas. *Research in Agricultural Engineering*, *63*(4), 172–179.

Park, H.-M., Heo, J., & Park, Y. (2011). Calcium from plant sources is beneficial to lowering the risk of osteoporosis in postmenopausal Korean women. *Nutrition Research*, *31*(1), 27–32.

Park, Y., Quinn, J., Florez, K., Jacobson, J., Neckerman, K., & Rundle, A. (2011). Hispanic immigrant women’s perspective on healthy foods and the New York City retail food environment: A mixed-method study. *Social Science & Medicine*, *73*(1), 13–21.

Payne, M. E., Steck, S. E., George, R. R., & Steffens, D. C. (2012). Fruit, vegetable, and antioxidant intakes are lower in older adults with depression. *Journal of the Academy of Nutrition and Dietetics*, *112*(12), 2022–2027.

Peres, B., Barlet, N., Loiseau, G., & Montet, D. (2007). Review of the current methods of analytical traceability allowing determination of the origin of foodstuffs. *Food Control*, *18*(3), 228–235.

Pullman, N. (2017, January 16). Swedish supermarkets replace sticky labels with laser marking. *The Guardian*.

Rachal, M. (2023, October 26). Amped-up 'Break Free From Plastic' legislation reintroduced in Congress. *PackagingDive*. https://www.packagingdive.com/news/break-free-from-plastic-pollution-act-2023-bfppa-congress/697884/

Ribera, L. A., Palma, M. A., Paggi, M., Knutson, R., Masabni, J. G., & Anciso, J. (2012). Economic analysis of food safety compliance costs and foodborne illness outbreaks in the United States. *HortTechnology*, *22*(2), 150–156.

Rose, D. C., & Chilvers, J. (2018). Agriculture 4.0: Broadening responsible innovation in an era of smart farming. *Frontiers in Sustainable Food Systems*, *2*, 87.

Salau, B. (2006). *Fruits and Vegetables Moderate Lipid Cardiovascular Risk Factor in Hypertensive Patients*.

Samoggia, A., & Nicolodi, S. (2017). Consumer's perception of fruit innovation. *Journal of International Food & Agribusiness Marketing*, *29*(1), 92–108.

Shirley, D. R. A., Amruthavarshni, R. B., Durainathan, A., & Karthika, M. P. (2021). QR-based inventory management system (QR-IMS) of passenger luggage using website. *2021 5th International Conference on Intelligent Computing and Control Systems (ICICCS)*, 1180–1185.

Sivapalasingam, S., Friedman, C. R., Cohen, L., & Tauxe, R. V. (2004). Fresh produce: a growing cause of outbreaks of foodborne illness in the United States, 1973 through 1997. *Journal of Food Protection*, *67*(10), 2342–2353.

Slavin, J. L., & Lloyd, B. (2012). Health benefits of fruits and vegetables. *Advances in Nutrition*, *3*(4), 506–516.

Smoley, R. (2021, September 7). *Laser labeling: An alternative to PLU stickers*. Blue Book Services.

Sood, P., Ference, C., Narciso, J., & Etxeberria, E. (2008). Effects of laser labeling on the quality of tangerines during storage. *Proceedings of the Florida State Horticultural Society*, *121*, 297–300.

Sood, P., Ference, C., Narciso, J., & Etxeberria, E. (2009). Laser etching: A novel technology to label Florida grapefruit. *HortTechnology*, *19*(3), 504–510.

Sousa-Gallagher, M. J., Tank, A., & Sousa, R. (2016). Emerging technologies to extend the shelf life and stability of fruits and vegetables. In *The stability and shelf life of food* (pp. 399–430). Elsevier.

Sree, T. K., & Natarajan, V. (2022). *Laser labeling on dragon fruit with different codes and their impact on surface characteristics*.

Stine, S. W., Song, I., Choi, C. Y., & Gerba, C. P. (2005). Effect of relative humidity on preharvest survival of bacterial and viral pathogens on the surface of cantaloupe, lettuce, and bell peppers. *Journal of Food Protection*, *68*(7), 1352–1358.

Swedberg, C. (2010). Dutch horticultural supply chain tests RFID '"From Plant to Customer."' *RFID Journal*, *October 28*.

Sy, K. V, Murray, M. B., Harrison, M. D., & Beuchat, L. R. (2005). Evaluation of gaseous chlorine dioxide as a sanitizer for killing Salmonella, Escherichia coli O157: H7, Listeria monocytogenes, and yeasts and molds on fresh and fresh-cut produce. *Journal of Food Protection*, *68*(6), 1176–1187.

Tate, R. F., Hebel, M. A., & Watson, D. G. (2008). WSN link budget analysis for precision agriculture. *2008 Providence, Rhode Island, June 29–July 2, 2008*, 1.

Tucker, F. (2023, January 3). *New year, new ban: France tackles disposable packaging*. Evironment, Foodscape, Impact. https://impakter.com/new-year-new-ban-france-tackles-disposable-packaging/#:~:text=Disposable%20packaging%20will%20be%20banned,in%20the%20fight%20against%20plastic%3F&text=As%20of%20Jan.,cut%20down%20on%20packaging%20waste

United States Department of Agriculture- Economic Research Service. (2019, April 23). *Fruit and tree nuts lead the growth of horticultural production value*.

United States Department of Agriculture- Economic Research Service. (2023, April 14). *Food availability (per capita) data system*.

United States Department of Agriculture- Foreign Agricultural Service. (2021, July 20). *French legislation threatens millions of dollars of US fruit and vegetable exports*.

United States Food and Drug Administration. (2023, August 18). *Food Safety Modernization Act (FSMA)*.

United States Food and Drug Administration. (2023, August 18). *Food traceability list*.

United States Food and Drug Administration. (2023, September 19). *FSMA final rule on requirements for additional traceability records of certain foods*.

United States Food and Drug Administration. (2023, September 28). *FSMA Final Rule on Produce Safety*.

Vardhan, G. S., Sivadasan, N., & Dutta, A. (2016). QR-code based chipless RFID system for unique identification. *2016 IEEE International Conference on RFID Technology and Applications (RFID-TA)*, 35–39.

Ventura, C. E. H., Aroca, R. V, Antonialli, A. Í. S., Abrão, A. M., Rubio, J. C. C., & Câmara, M.

A. (2016). Towards part lifetime traceability using machined quick response codes. *Procedia Technology*, *26*, 89–96.

Welt, B., & Blanchfield, J. R. (2012, March). *Food traceability*. UFoST Scientific Information Bulletin. International Union of Food Science and Technology. https://iufost.org/iufostftp/IUF.SIB.Food%20Traceability.pdf

Williamson, G. (1996). Protective effects of fruits and vegetables in the diet. *Nutrition & Food Science*, *96*(1), 6–10.

Yuk, H.-G., Warren, B. R., & Schneider, K. R. (2007). Infiltration and survival of Salmonella spp. on tomato surfaces labeled using a low-energy carbon dioxide laser device. *HortTechnology*, *17*(1), 67–71.

Chapter 2 - CO_2 laser labeling on fresh produce: Evaluating postharvest quality, microbial safety, and economic analysis

This chapter has been prepared using the Journal of Food Protection style guidelines.

Abstract

Fresh produce is traditionally labeled with plastic price lookup (PLU) stickers that are attached to the produce surface using edible glue. However, both the stickers and glue are environmental contaminants, and the stickers can still easily detach from the produce surface during handling and disrupt traceability. A novel method of labeling, CO_2 laser labeling technology (LLT), has been gaining attention in recent years. However, the performance of this technology varies from produce type to produce type, and information on its effects on postharvest quality, microbial safety, and economic feasibility is not known to be reported. The objectives of this study were to investigate the effect of laser labeling technology on 1) postharvest quality, 2) microbial safety of fresh produce, and 3) economic analysis of this technology. Three horticultural crops, 'Red Delicious' apples (*Malus domestica*), green bell peppers (*Capsicum annuum*), and cucumbers (*Cucumis sativus*), were procured from a local grocery store. Each produce type was imprinted with a Quick Response (QR) code or 6-digit alphanumerical (text) code using a commercially available Trotec Speedy 300 CO_2 laser engraver, followed by the application of edible wax. Fresh weight loss for laser-printed produce was higher than the nontreated control, but no difference in visual quality ratings was observed compared to the control. The laser-labeled produce was assessed for microbial contamination by artificially inoculating rifampicin-resistant *Escherichia coli* (*E. coli*) $\log_{10}$ 6 CFU/mL to the labeled fruit. The result showed that the population of rifampicin-resistant *E. coli* was statistically higher in all three products labeled with text code compared to the non-treated control. The QR-coded treatments were similar microbially to the control. The wax application did not affect the microbial attachment on the laser-labeled produce. Accordingly, the CO_2 laser labeling technology has the potential for industrial application.

Fresh produce is considered a major vehicle for human ingestion of foodborne pathogens (Greig & Ravel, 2009), mainly because such commodities are usually consumed raw (Sy et al., 2005). With increased consumption of fresh produce, the incidents of produce-related human foodborne infections have been on the rise (Buck et al., 2003; Sivapalasingam et al., 2004).

According to the Centers for Disease Control and Prevention (CDC), in 2021, an estimated 47.8 million illnesses, 127,839 hospitalizations, and 3,037 deaths in the U.S. alone were related to foodborne illnesses. A cost estimate of the impact of food safety incidents on the U.S. economy is around 7 billion USD annually (Hussain & Dawson, 2013). A major challenge to preventing foodborne outbreaks and avoiding risks to public health is the lack of improved traceability in the produce supply chain (Berger et al., 2010).

An efficient food traceability system can contain produce-related outbreaks as it can trace the questionable produce items at various stages in the supply chain without endangering an entire product line (Blanchfield, 2012). Effective traceability can improve public trust by facilitating rapid and effective product recall (Aung & Chang, 2014; Sree & Natarajan, 2022). Traceability is equally important to producers, suppliers, and distributors to protect themselves from fraudulent claims (Blanchfield, 2012).

The U.S. Food and Drug Administration's (FDA) latest proposal to add the Traceability Rule to the Food Safety Modernization Act (FSMA) would require growers covered by FSMA to meet the traceability requirements (Kim & Woo, 2016). To comply with the Traceability Rule and meet marketplace requirements, growers traditionally label the produce with Price Look-Up (PLU) stickers attached to the individual items. Although commonly practiced, PLU sticker labeling method has several issues, including label detachment, label exchange along the supply line, adulteration risk, and their ability to contain limited product information (Etxeberria et al., 2006a).

The consequences of these issues could have a detrimental impact on traceability (Etxeberria et al., 2006a). The non-compostable plastic and glue used on PLU stickers also cause environmental pollution. A few countries (France, Spain, and New Zealand) have started/are planning to enforce an import ban on produce labeled with plastic PLU stickers since the plastic stickers do not comply with home compostable standards (USDA-FAS, 2021). Accordingly, an environmentally-friendly alternative method of produce labeling is needed.

CO_2 laser-printing on fresh produce is a novel practice and has been gaining attention recently. In this method, a laser beam is utilized to etch directly on the produce surface. Although the laser marking of horticultural produce has been authorized (Food and Drug Administration, 2012), only logos, numbers, symbols, and words were previously etched. Now, with the current approval by the European Union (EU), matrix codes, barcodes, quick response (QR)- codes, and additional information can now be etched on produce for marketing and traceability purposes (Pullman N., 2017). Compared to traditional labeling techniques, labeling with laser markings provides various advantages, including relatively high printing speed, creation of permanent labels, improved traceability (as information can be retrieved effectively by scanning codes), and less environmental pollutants.

Since the CO_2 laser labeling is a fairly new practice, it lacks a standard protocol of operation. The complex shape, texture, and color contrast of different produce pose challenges for optimal printing quality. Further, little information is available about the effect of laser labeling technology on postharvest quality and microbial safety. Despite the substantial amounts of wax and lignin formed by the surrounding and underlying cells, laser engraving compromises the protective barrier of the produce surface and may eventually serve as entrance points for bacteria that could deteriorate quality and/or increase water loss (Etxeberria et al., 2006b). Studies reported that the application of a secondary coating or waxing shortly after laser labeling reduced water loss and prevented unwanted shrinkage (Sood et al., 2008; Sood et al., 2009). Furthermore, storage conditions have an impact on the growth and survival of foodborne pathogenic microbes on the produce surface (Huff et al., 2012). A study by Stine et al. (2005) reported that six human pathogens, including bacteria and viruses, were all found to survive for 14 days on the phyllosphere of cantaloupe (*Cucumis melo*), lettuce (*Lactuca sativa*), and bell pepper (*Capsicum* spp.) under controlled environmental conditions (22 to 24 °C and 45 to 90% RH), demonstrating that human pathogens can survive under cooling storage condition for commercially relevant periods.

A study was conducted to investigate the effects of laser marking on the postharvest quality and microbial safety of three different horticultural products, 'Red Delicious' apples (*Malus pumila*), green bell peppers (*Capsicum annuum*), and cucumbers (*Cucumis sativus*). The objectives of this study were to 1) investigate the effect of laser labeling of three horticultural products (apples, cucumbers, and green bell peppers) on postharvest quality, 2) evaluate the microbial safety of laser-labeled horticultural produce, and 3) perform an economic feasibility study of the laser labeling technology.

Materials and Methods

Procurement of Fresh Produce. Three horticultural commodities, 'Red Delicious' apples, green bell peppers, and cucumbers, were selected for this study. These produce types were selected following preliminary trials after evaluating the effects of laser-labeling on fruit quality and readability of labels (Fig. 2.1). The preliminary experiment was conducted over 15 different commonly marketed produce with variability in color, texture, firmness, and shape. The produce was procured from a local grocery store the day before the experiment and stored in an environmental chamber (Thermo Scientific Inc., Waltham, MA) at 90% relative humidity (RH) and 4°C until experimentation.

Figure 2.1 Laser labeling on more than fifteen produce types from a preliminary trial.

Determining optimum laser engraving settings. A commercially available CO_2 laser engraving machine (Trotec Speedy 300; Trotec Laser Inc., Plymouth, MI) was used to engrave the produce with two different types of codes: QR code or alphanumeric code. We chose to engrave the QR code on the produce for our research because the QR code can be read by a scanning device, for instance, a mobile phone. QR codes encompass more information; they can store information both vertically and horizontally. Hence, QR codes have a considerably higher capability of providing information, making them very popular in the food industry.

The Tortec machine is commercially used in laser engraving and cutting in the graphics and design industry. To the best of our knowledge, this machine has not been used in the horticultural industry for laser labeling. Since there was no prior information on the optimal laser settings to engrave labels on produce, a trial method was followed to identify the optimal settings. The engraver was set to a low power of 15 watts and gradually increased by 5-Watt intervals up to 60 Watts until the code was readable by a QR code reader (smartphone application). The lowest power setting, which assured the most constant code readability over eight days for bell pepper and cucumber and 16 days for 'Red Delicious' apple (and would likely confer less damage on the produce), was selected. The engraver's speed was set to 100%, and dots per inch (DPI) were set to 500 for both the QR code and 6-digit alphanumeric text code.

From the preliminary trials (data not shown), the optimal engraving power was determined as 55 watts for 'Red Delicious' apples and 50 watts for green bell peppers and cucumbers. The sample was placed at 3.8 cm deep below the laser head and etched with a lens of 2.03 mm (Fig. 2.2.). The size of the QR and alphanumerical code was 12.7 × 12.7 mm and 12.7 × 2.0 mm, respectively, for all three produce types. The QR code and text code were intentionally printed as small as possible without losing readability to minimize the damage on the produce surface.

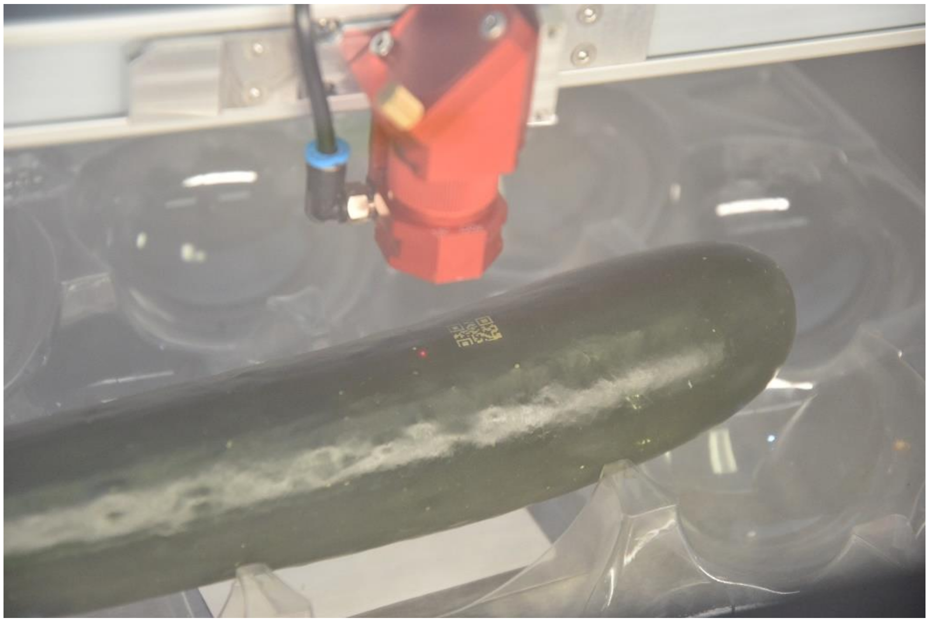

Figure 2.2 Trotec Speedy 300 laser engraver machine etching a QR code label on a cucumber.

Laser labeling of fresh produce for experimentation. On the day of the experiment, the produce were removed from cold storage and allowed to climatize to ambient room temperature (21°C). Prior to laser labeling, the fruit were wiped with a paper towel to reduce condensation. The fruit were then either laser labeled with a QR code or alphanumeric text; unlabeled fruit were used as the control. Immediately after laser printing, edible wax was manually coated over the engraved surface area to prevent water loss. For apples and cucumbers, Peach, Nectarine, & Plum Lustr® 251 mineral oil-based emulsion (DECCO US PostHarvest Inc., Monrovia, CA) was applied in a dilution of 1:4 with water. For green bell peppers, DECCO Lustr® 651 Carnauba-based coating (DECCO US PostHarvest Inc., Monrovia, CA) was used without dilution. The dilution and type of wax were selected based on the preliminary observation of the effect on produce quality and code readability. After waxing, the produce were air-dried for 10 min before collecting data.

Study 1: Postharvest Quality Study

After laser-printing, the fruit were stored in the environmental chamber at 90% RH and 4°C. Fresh weight, visual quality, and QR code readability were assessed at 0, 2, 4, 6, and 8 days after treatment (DAT) for the green bell peppers and cucumbers, and 0, 4, 8, 12, and 16 DAT for the 'Red Delicious' apples (Fig. 2.3). Fresh weight was measured using a balance (Sartorius Entris, Data Weighing Systems, Inc., Wood Dale, IL), and percent weight loss was determined based on the initial weight at 0 DAT. The visual quality of the laser-labeled produce was rated through a visual inspection of external appearance on a scale of 0-5 using a produce quality rating scale and color chart where 0 is total label collapse and is the worst quality and 5 is no shrinkage and is the best quality (Kader & Cantwell, 2010). For the QR code readability, a QR code scanning application on iPhone 11 Pro (Apple Inc., Cupertino, CA) was used to determine if the code was still readable, and readability for text-coded labels was inspected visually. Pictures were taken on every measurement date using a Nikon D5600 camera (Nikon Inc., Melville, NY) mounted on a tripod.

Study Design. The experiment consisted of three treatments: i) QR code label, ii) 6-digit alphanumeric (text) code label, and iii) nontreated control. The laser-printed samples were followed by wax coating, while the control treatment did not receive any printing or waxing. The experiment was arranged in a randomized complete block design (RCBD) and repeated thrice in time, where time was a blocking factor. Each replication had a unique set of fruits and included nine subsamples for the laser-printed treatment and six subsamples for the control. The subsamples were averaged to obtain aggregate means for each parameter before conducting the analysis of variance (ANOVA). All data were subjected to ANOVA using the proc glimmix procedure in SAS 9.4 (SAS Institute, Cary, NC), where treatment and DAT were considered the fixed effects. Means were separated using a Tukey Kramer test at $\alpha = 0.05$.

Study 2: Microbiology Study

Produce Pre-treatment. 'Red Delicious' apples, cucumbers, and green bell peppers were used for the microbiology study (Fig 2.3). For the 'Red Delicious,' the apples were dipped into hot water at 55°C for 30 s in a water bath (Ultrasonic Bath, Thermo Fisher Scientific Inc., Waltham, MA) and let air dry for 15 min at ambient room temperature before laser labeling. This procedure was followed to remove the commercially coated wax from the apple surface to increase the bacterial attachment to the surface of the apple. Based on our preliminary trials, without removing the coated wax, bacterial attachment was found in green bell peppers and cucumber but not in apples. The process of selecting the printing of labels was previously described in study 1. Three codes - either QR or text - were printed on the different sides of the same fruit to account for variability on the fruit surface.

Strain Selection. Rifampicin-resistant *E. coli* (ATCC 25922) was used as an inoculant to reduce the impact of the produce's background microflora so that only the inoculated rifampicin-resistant *E. coli* can be enumerated. The frozen culture maintained at -80°C was streaked onto tryptic soy agar (TSA; Remel Inc., San Diego, CA) with 80 µg/mL rifampicin and incubated at 35 ± 2ºC for 24 ± 2 h. One isolated colony from the strain was transferred to 10 mL of tryptic soy broth with 80 µg/mL rifampicin (TSBR; Remel Inc., San Diego, CA) and incubated at 35 ± 2ºC for another 24 ± 2 h. A portion (100 mL) of the incubated subculture was transferred to 30 mL of fresh TSBR and incubated at 35 ± 2ºC for another 24 ± 2 h. The cells were prepared for experiment by centrifugation (Allegra X-30 R, Beckman Coulter, Brea, CA; 10,000 rpm for 10 min at 20ºC) and washed twice with 0.1% phosphate buffer saline (PBS; Thermo Fisher Scientific, Waltham, MA). The volume was then adjusted to 30 mL to achieve a concentration of *E. coli* cells of at least 8 log CFU/mL.

Inoculation. Inoculum was prepared to a final concentration of ~6 logs using 10 mL of 3x washed cell culture added to 990 mL of 0.1% buffer peptone water (BPW; Remel Inc., San Diego, CA) solution. The laser-labeled produce ('Red Delicious' apples, green bell peppers, and cucumbers) were dipped and submerged into the inoculum for 10 min. Each fruit was dipped into an individual sterile 794 g (28 oz.) whirl-pack bag (Whirl-Pak, Nasco, Modesto, CA) containing 500 mL of inoculum. Samples were held in a biological safety cabinet (BSC) with the blower on for 15 min to allow the inoculum to dry. After drying, the fruit was transferred onto a dry sterile Petri dish for microbial enumeration.

Microbial enumeration. The surface layer of the etched area was excised using sterile single-use retractable safety scalpels. Samples from nontreated controls were obtained by cutting the exact size of the QR-code label (12.7 x 12.7 mm). Three subsamples from each fruit type were placed into a 15 mL sterile centrifuge tube containing 10 mL of 0.1% BPW solution and vortexed for one minute. Serial dilutions were prepared in 9 mL 0.1% BPW, and 0.1 mL samples were withdrawn and plated in duplicates onto 80 µg/mL rifampicin TSA plates via the spread plate method. The plates were incubated at 35 ± 2ºC for 24 ± 2 h. After incubation, plates yielding between 25 and 250 colony-forming units (CFU) were counted manually, and *E. coli* population levels were expressed as log CFU/cm^2.

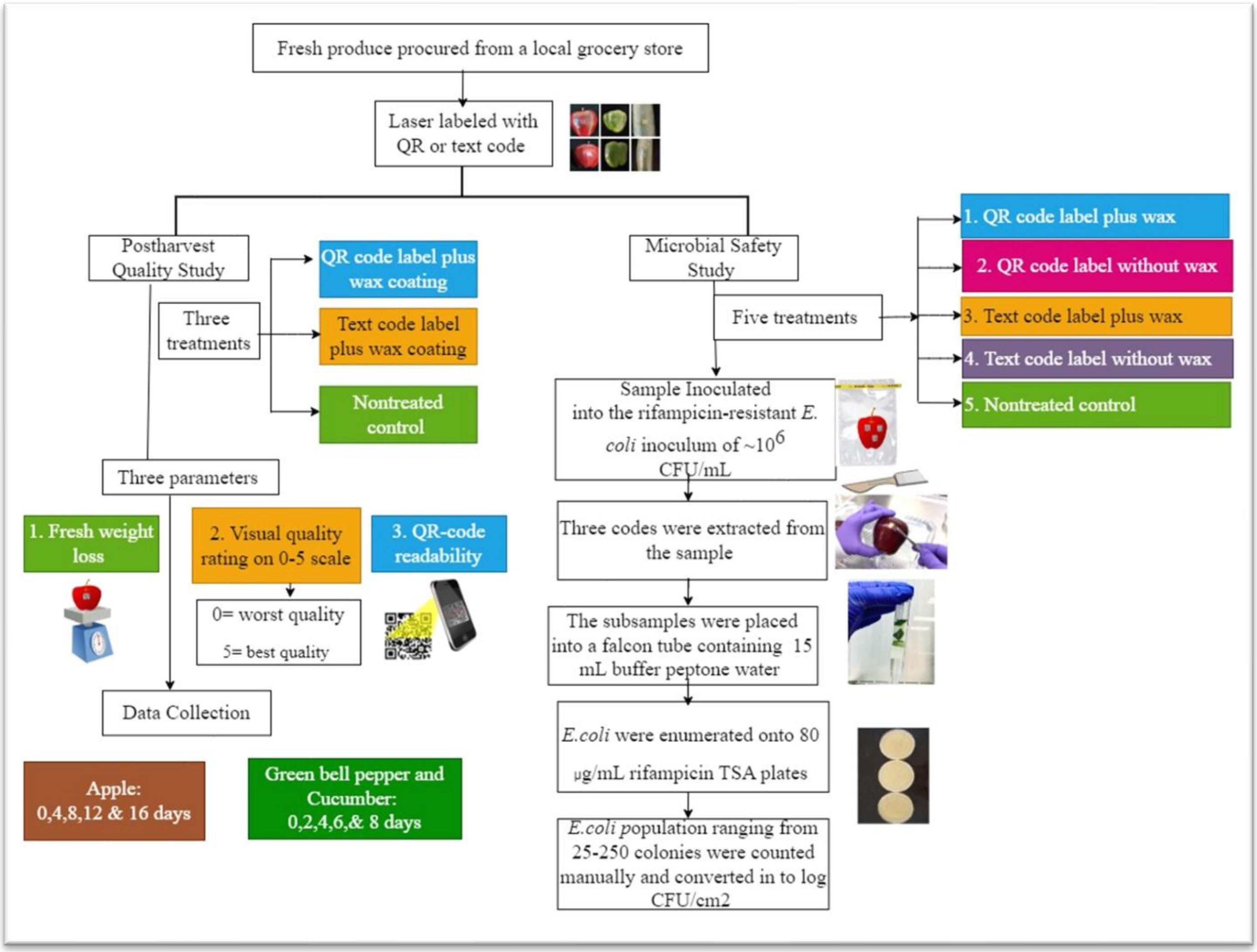

Figure 2.3 Flowchart diagram of methodology of postharvest quality and microbial safety study.

Study Design. The experiment consisted of five treatments: i) QR-code label followed by waxing, ii) QR-code label without wax, iii) 6-digit alphanumerical text-code label followed by waxing, and iv) 6-digit alphanumerical text-code label without wax, and v) nontreated control (no printing/waxing). The experiment was arranged in a one-way randomized complete block design and repeated thrice in time, where time was a blocking factor. Total number of fruits (N=45 for each produce). The microbial population data were transformed to log CFU/cm^2 before conducting ANOVA in SAS 9.4. The ANOVA was conducted using a glimmix procedure, and treatment means were separated using a Tukey Kramer test at $\alpha = 0.05$.

Study 3: Economic Analysis

Methods. A partial budgeting analysis was used to assess the financial feasibility of the new technology. Partial budgeting is commonly employed to determine the net benefits of changing an enterprise by accounting for the positive effects of added returns and reduced costs and the negative effects of reduced returns and added costs. Studies have used this method when changing production practices in food production (Djidonou et al., 2013). This process also allows for the calculation of break-even price and/or quantity of products sold (Nian et al., 2022).

The costs for laser labeling and PLU sticker labeling are estimated based on the current market (Table 2.3). In the analysis, it is assumed that each system will label 1,000 produce items and run enough to yield such output. We assumed five printers and application machines for the PLU-sticker-labeling system and one laser engraver for the laser labeling system due to the volume of produce to simulate how a normal business would operate (Muth et al., 2022). It is assumed that labor hours will be marginally higher in the PLU sticker-labeling system due to adjustments needed with adhesive labels on produce items. The labor wage was assumed to be $12.49/ hour according to the U.S. Bureau of Labor Statistics average pay for agricultural workers in 2021.

Results & Discussion

Study 1: Postharvest quality analysis

Fresh weight loss. The QR-coded treatment in apples had the highest fresh weight loss on each sampling date as compared to text-coded and control apples (Fig. 2.4).

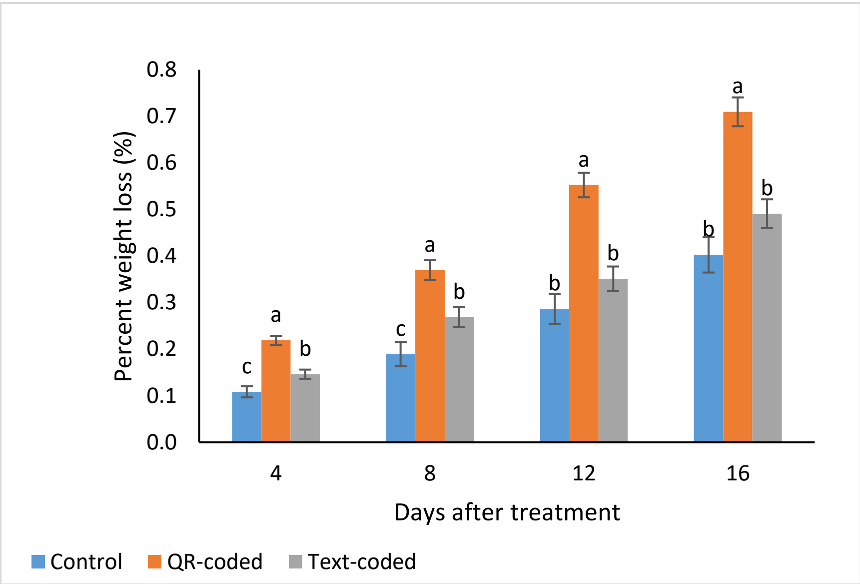

Figure 2.4 Percentage fresh weight loss as affected by laser labeling and days after treatment in 'Red Delicious' apples. Error bars represent the standard error of the mean. Different letters on bars indicate statistical significance according to the Tukey Kramer test at α = 0.05.

The text-coded treatment had a higher percent weight loss than the control on 4 and 8 Days After Treatment (DAT) and similar weight loss compared to the control on 12 and 16 DAT (Fig. 2.4. There was a significant interaction of treatment × DAT in apples ($P < 0.0001$) so results were presented by DAT (Fig. 2.4). However, in cucumbers and bell peppers, due to nonsignificant treatment × DAT interactions (P = .255 and .146, respectively*)* means were averaged over DAT. In cucumbers, QR-code (1.56%) and text-coded (1.54%) treatments had higher weight loss than the control (1.28%) but were statistically similar to each other (Fig. 2.5A). In bell peppers, the QR-coded (2.14%) and text-coded (1.92%) treatments had statistically similar weight loss to the control (2.08%) but were different from one another (Fig. 2.5B).

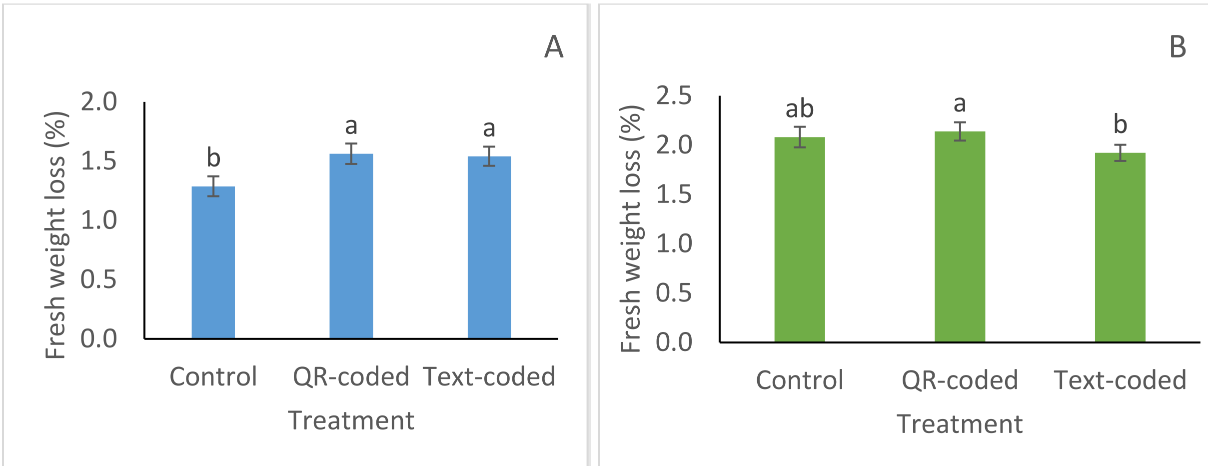

Figure 2.5 Percentage of fresh weight loss as affected by laser labeling in cucumber (A) and green bell pepper (B). Means were pooled over days after treatment. Error bars represent the standard error of the mean. Different letters on bars indicate statistical significance according to the Tukey Kramer test at α = 0.05.

According to Sree and Natarajan (2022), laser-labeled dragon fruit (*Hylocereus undatus*) experienced little difference in fresh weight loss in comparison to the control of non-laser-labeled dragon fruit. The vaporization from the burned tissue and water loss from the laser-engraved surface are possible contributing factors to the weight loss (Nasution & Rath, 2017).

<u>Visual Quality Analysis.</u> In apples, visual quality ratings of QR-coded fruit were significantly inferior to text-coded but similar to the control (Table 2.1). In cucumbers, all three treatments had statistically similar visual quality (Table 2.1). The text-coded treatment in green bell peppers maintained quality better than others, as the ratings were statistically higher than the control and QR-coded treatment (Table 2.1). In general, the decline in quality reported in Table 2.1 was concentrated near the engraved area, and the rest of the produce surface area had minimal visual differences (Fig. 2.6).

Table 2.1 Visual quality ratings of apples (16 days after treatment [DAT]), cucumbers (8 DAT), and green bell peppers (8 DAT) following laser labeling.

Treatment	Visual Ratings		
	Apple	Cucumber	Bell pepper
Control	4.92[ab†]	4.69[a]	4.56[b]
QR-coded	4.88[b]	4.66[a]	4.63[b]
Text-coded	5.00[a]	4.70[a]	4.78[a]

[†]Different letters within a column indicate statistical significance according to the Tukey Kramer test at $\alpha = 0.05$

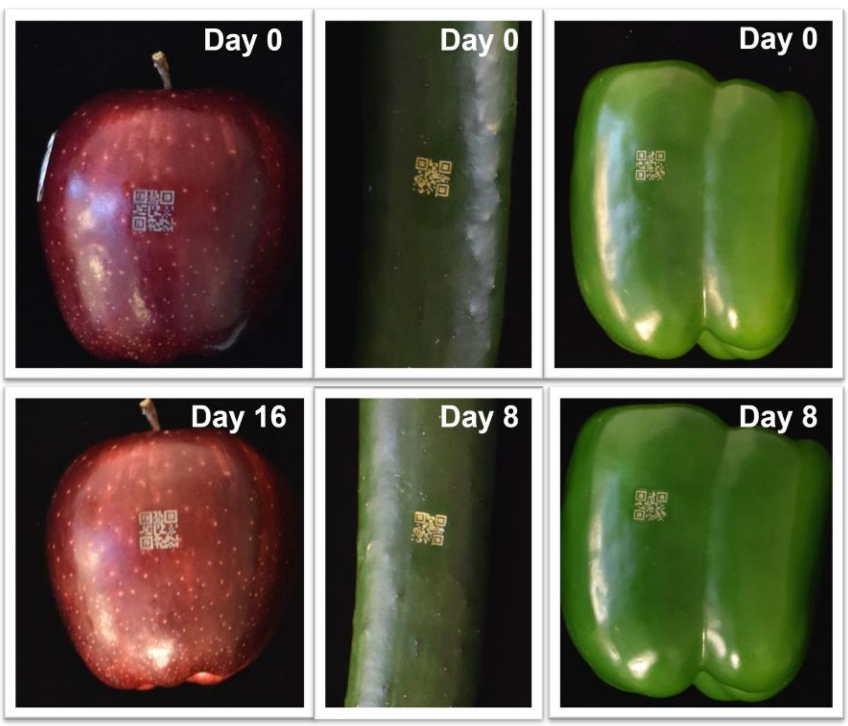

Figure 2.6 Visual quality of horticultural produce following QR-code labeling.

<u>*Code readability:*</u> The average QR code failure rate was 3.0%, 13.5%, and 18.3% in apple, cucumber, and bell pepper, respectively. The failures were more concentrated in the later days

after treatment. The possible reason behind the high readability failure in the bell pepper and cucumber was the effect of the wax application over the engraved area. Edible wax was applied (in grapefruits and tangerines) to prevent fresh weight loss because waxing shortly after laser labeling helps to reduce water loss and prevents unwanted shrinkage (Sood et al., 2008; Sood et al., 2009). Edible coatings can protect perishable fresh products from deterioration by retarding dehydration, suppressing respiration, improving texture quality, helping retain volatile flavor compounds, and reducing microbial contamination (Gallagher & Mahajan, 2011). However, different waxes could perform differently in preventing water loss from the laser engraved area, as Sood et al.(2009) reported that the performance of different waxes varied in preventing water loss in laser-labeled tangerine fruits. As reported by Sree and Natarajan (2022), laser-printed barcodes on dragon fruits were not scannable due to a brownish color after engraving. The laser energy, code size, color, shape, texture, firmness of produce, and days of storage are important factors that affect fruit's marking, quality, and code readability (Eyahanyo & Rath, 2020). For example, in our preliminary experiment, the laser-printed QR code is visible to human eyes, but the scanner could not decode the code due to the excessive shrinkage in tomato (*Solanum lycopersicum*), curved shape in banana (*Musa acuminata*) and poor color contrast in pomegranate (*Punica granatum*).

Study 2: Microbial Study

Data for the *E. coli* population were analyzed for each produce type separately. In all three produce types, the treatment effect was significant (Table 2.2). In 'Red Delicious' apples, the text-coded treatment with or without wax had significantly higher CFU of *E. coli* than the nontreated control; however, the QR-coded treatments were similar to the nontreated control (Table 2.2). The results were similar in cucumbers and green bell peppers. This indicates that QR code laser labeling in the studied produce did not increase the chance of microbial contamination, whereas text code laser labeling could promote microbial contamination. Furthermore, the effect of waxing was not significant in either of the laser labeling treatments across all three produce (Table 2.2). This suggests that waxing after laser printing has no statistically significant effect on the microbial load. A possible reason behind the higher microbial attachment in the text-coded treatment would be that all the text codes are in solid lines, whereas the QR code contains more dots than solid lines. The greater engraved surface area of text codes than that of QR codes likely contributed to increased microbial attachment in text code labeled produce.

Table 2.2 Effect of laser labeling with or without wax on microbial load in apples, cucumbers, and green bell peppers.

Treatment	**log CFU/cm^2**		
	Apple	Cucumber	Bell pepper
QR-coded + wax	3.1$^{c\,\dagger}$	3.8^{bc}	3.9^{ab}
QR-coded	3.6^{bc}	4.0^{abc}	3.7^{b}
Text-coded + wax	3.9^{ab}	4.0^{ab}	4.2^{a}
Text-coded	4.2^{a}	4.2^{a}	4.3^{a}
Nontreated control	3.3^{c}	3.6^{c}	3.6^{b}
P value	<0.0001	0.0012	0.0001

†Different letters within a column indicate statistical significance according to the Tukey Kramer test at $\alpha = 0.05$.

Our study results were in agreement with the findings of Yuk et al. (2007) and Danyluk et al. (2010), who demonstrated that laser-etched surfaces did not facilitate *Salmonella* growth and infiltration in fresh tomato fruit. Yuk et al., (2007) conducted a study on S*almonella* infiltration and survival in laser-etched tomato surfaces for 14 d. That study used a low-energy CO_2 laser engraver machine (model XY mark 10; Durand-Wayland, Lagrange, GA.) to print an alphanumerical label pattern on fully ripe beefsteak tomatoes (*Solanum lycopersicum*) and treated it with *Salmonella* dip inoculation. They found that the laser labeling does not support the penetration of *Salmonella* to the internal tissue. Similarly, a study was conducted to identify the impact of natural-light labeling on the fate of *Salmonella* inoculated on tomatoes at the mature green stage and with the treatment of co-inoculation with *P. carotovorum* subsp. *carotovorum* on *Salmonella* growth capacity for 14 d (Danyluk et al., 2010). Results indicated that the *Salmonella* growth or penetration into mature green tomatoes is not facilitated by the natural-light labeling.

Study 3: Economic Analysis

The result of the laser engraver partial budget analysis yields a net decrease in returns of $29,317. The total cost of PLU sticker application on 1000 produce items was $75,266. With a total cost of $45,949 for the new engraver machine to label 1000 produce items, a break-even price per fruit or vegetable would be $45.95 per produce item. It is important to note that the net return would increase, and the break-even price would decrease with an increase in produce output. Yet, some strong assumptions are present in this analysis. It is noted that the efficiency of labeling is quite different between the two systems. The laser engraver system can apply a QR code on produce every 15 seconds compared to the PLU sticker-labeling system, which has the capacity to apply labels every 0.3 seconds. It takes nearly 11 times longer for the laser labeling system to yield the same output as the PLU sticker-labeling system. Yet, with the high installation costs of the laser labeling system, the break-even price would not sustain profitable margins for businesses. Technological advances may allow for larger quantities of produce to be labeled in a shorter amount of time with the engraver system. With the larger throughput of the engraver system, profitability becomes more likely.

Table 2.3 Estimated costs of laser labeling and Price lookup (PLU) sticker-labeling systems (USD)

Expenses	Descriptions	Laser labeling[a]	PLU-sticker labeling[a]
		Fixed costs	
Machine		33,400.00	14,000.00
Computer		800.00	n/a
QR code scanner		51.29	n/a
Software		600.00	n/a
Repair/replacement costs		1,500.00	5,000.00
		Variable costs	
PLU stickers	per sticker	n/a	0.13
Maintenance	every 2 years	1,500.00	n/a
Laser replacement	every 1 year	4,000.00	n/a
Energy (600 kWh)	per h	3.90	7.80
Labor	per h	12.49	12.49

[a]Rounded to the nearest dollar.

Conclusions

The result of our study demonstrates that CO_2 laser labeling minimally deteriorates the postharvest quality in fresh ‘Red Delicious’ apples, green bell peppers, and cucumbers stored at 95% RH and 4°C temperature during the study period. QR-code labeling did not increase the susceptibility of microbial (rifampicin-resistant *E. coli*) contamination compared to the control. In addition, the wax application following laser printing did not change the microbial attachment. Results suggest that laser labeling technology could potentially be used in a commercial application to improve food traceability as a potentially safe alternative to the PLU stickers in ‘Red Delicious’ apples, green bell peppers, and cucumbers.

Acknowledgments

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References

Aung, M. M., & Chang, Y. S. (2014). Traceability in a food supply chain: Safety and quality perspectives. *Food Control*, *39*, 172–184.

Berger, C. N., Sodha, S. V, Shaw, R. K., Griffin, P. M., Pink, D., Hand, P., & Frankel, G. (2010). Fresh fruit and vegetables as vehicles for the transmission of human pathogens. *Environmental Microbiology*, *12*(9), 2385–2397.

Buck, J. W., Walcott, R. R., & Beuchat, L. R. (2003). Recent trends in microbiological safety of fruits and vegetables. *Plant Health Progress*, *4*(1), 25.

Danyluk, M. D., Villeda, L. O. I., Friedrich, L. M., Schneider, K. R., & Etxeberria, E. (2010). Natural-Light Labeling of Tomatoes Does Not Facilitate Growth or Penetration of Salmonellainto the Fruit. *Journal of Food Protection*, *73*(12), 2276–2280.

Djidonou, D., Gao, Z., & Zhao, X. (2013). Economic analysis of grafted tomato production in sandy soils in northern Florida. *HortTechnology*, *23*(5), 613–621.

Etxeberria, E., Miller, W. M., & Achor, D. (2006a). Anatomical and morphological characteristics of laser etching depressions for fruit labeling. *HortTechnology*, *16*(3), 527–532.

Etxeberria, E., Miller, W. M., & Achor, D. (2006b). Characteristics of laser etching depressions on Florida fruits and vegetables. *Proceedings of the Florida State Horticultural Society*, *119*, 353–357.

Eyahanyo, F., & Rath, T. (2020). Investigations on the effects of low laser infrared marking energy and barcode size on 2D data matrix code detection on apples. *Applied Engineering in Agriculture*, *36*(6), 829–838.

Food and Drug Administration. (2012, June 11). Rules and Regulations. Irradiation in the Production, Processing, and Handling of Food. *Docket No. FDA–2007–F–0390*. https://casetext.com/federal-register/irradiation-in-the-production-processing-and-handling-of-food-27

Gallagher, M. J. S., & Mahajan, P. V. (2011). The stability and shelf life of fruit and vegetables. In *Food and beverage stability and shelf life* (pp. 641–656). Elsevier.

Greig, J. D., & Ravel, A. (2009). Analysis of foodborne outbreak data reported internationally for source attribution. *International Journal of Food Microbiology*, *130*(2), 77–87.

Huff, K., Boyer, R., Denbow, C., O’keefe, S., & Williams, R. (2012). Effect of storage temperature on survival and growth of foodborne pathogens on whole, damaged, and internally inoculated jalapenos (Capsicum annuum var. annuum). *Journal of Food Protection*, *75*(2), 382–388.

Hussain, M. A., & Dawson, C. O. (2013). Economic impact of food safety outbreaks on food businesses. *Foods*, *2*(4), 585–589.

Kader, A. A., & Cantwell, M. (2010). *Produce quality rating scales and color charts* (No. 23). Postharvest Technology Center, University of California, Davis. https://ucanr.edu/sites/Postharvest_Technology_Center_/files/356146.pdf

Kim, Y. G., & Woo, E. (2016). Consumer acceptance of a quick response (QR) code for the food traceability system: Application of an extended technology acceptance model (TAM). *Food Research International*, *85*, 266–272.

Muth, F. V, Heilig, M., Marquardt, D., Mittelberg, L., Sebald, A., & Kunde, W. (2022). Lightness perception of structured surfaces. *Color Research & Application*, *47*(2), 377–387.

Nasution, I. S., & Rath, T. (2017). Optimal laser marking of 2D data matrix codes on Cavendish bananas. *Research in Agricultural Engineering*, *63*(4), 172–179.

Nian, Y., Zhao, R., Tian, S., Zhao, X., & Gao, Z. (2022). Economic Analysis of Grafted Organic Tomato Production in High Tunnels. *HortTechnology*, *32*(5), 459–470.

Pullman, N. (2017, January 16). Swedish supermarkets replace sticky labels with laser marking. *The Guardian*. https://www.theguardian.com/sustainable-business/2017/jan/16/ms-and-swedish-supermarkets-ditch-sticky-labels-for-natural-branding

Sivapalasingam, S., Friedman, C. R., Cohen, L., & Tauxe, R. V. (2004). Fresh produce: a growing cause of outbreaks of foodborne illness in the United States, 1973 through 1997. *Journal of Food Protection*, *67*(10), 2342–2353.

Sood, P., Ference, C., Narciso, J., & Etxeberria, E. (2008). Effects of laser labeling on the quality of tangerines during storage. *Proceedings of the Florida State Horticultural Society*, *121*, 297–300.

Sood, P., Ference, C., Narciso, J., & Etxeberria, E. (2009). Laser etching: A novel technology to label Florida grapefruit. *HortTechnology*, *19*(3), 504–510.

Sree, T. K., & Natarajan, V. (2022). Laser labeling on dragon fruit with different codes and their impact on surface characteristics. *The Pharma Innovation Journal*, *11*(7), 4717–4723.

Stine, S. W., Song, I., Choi, C. Y., & Gerba, C. P. (2005). Effect of relative humidity on preharvest survival of bacterial and viral pathogens on the surface of cantaloupe, lettuce, and bell peppers. *Journal of Food Protection*, *68*(7), 1352–1358.

Sy, K. V, Murray, M. B., Harrison, M. D., & Beuchat, L. R. (2005). Evaluation of gaseous chlorine dioxide as a sanitizer for killing Salmonella, Escherichia coli O157: H7, Listeria monocytogenes, and yeasts and molds on fresh and fresh-cut produce. *Journal of Food Protection*, *68*(6), 1176–1187.

United States Department of Agriculture- Foreign Agricultural Service. (2021, July 20). *French legislation threatens millions of dollars of US fruit and vegetable exports*. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=French%20legislation%20threatens%20millions%20of%20dollars%20of%20US%20fruit%20and%20vegetable%20exports_Paris_France_07-14-2021.pdf

Welt, B., & Blanchfield, J. R. (2012, March). *Food traceability*. UFoST Scientific Information Bulletin. International Union of Food Science and Technology. https://iufost.org/iufostftp/IUF.SIB.Food%20Traceability.pdf

Yuk, H.-G., Warren, B. R., & Schneider, K. R. (2007). Infiltration and survival of Salmonella spp. on tomato surfaces labeled using a low-energy carbon dioxide laser device. *HortTechnology*, *17*(1), 67–71.

Chapter 3 - Evaluating consumers' acceptability of laser-labeled fruit

This chapter has been prepared using style guidelines for Food Quality and Preference.

Abstract

Fresh produce is traditionally labeled with plastic price lookup (PLU) stickers that are attached to the produce surface using glue to trace product origin. However, both the stickers and glue are environmental contaminants, and the stickers can still easily detach from the produce surface during handling and disrupt traceability. A novel method of labeling, the CO_2 laser labeling technology (LLT), has been gaining attention in recent years. However, the performance of this technology varies by produce type, and information on consumer perception and acceptability has not been well studied. The objective of this study was to observe consumers' perception and acceptability of laser-labeled 'Red Delicious' apple (*Malus domestica* Borkh) fruit. 'Red Delicious' apples were procured from a local grocery store and printed with a Quick Response (QR) code using a commercially available Trotec Speedy 300 CO_2 laser engraver, followed by the application of edible wax. A consumer study (N=75) was conducted to assess consumers' perception and acceptability of laser-labeled produce with three treatments: 1) Apple with QR-code printing, 2) Apple with PLU plastic sticker, and 3) non-labeled control. The study was conducted at the Sensory and Consumer Research Center facilities at Kansas State University-Olathe. A randomized set of the three treatment samples was given to respondents, and questionnaires were completed. The ranking of three treatments based on overall physical quality revealed that before providing educational information, consumers ranked QR-code-labeled apples as the lowest preferred group, followed by sticker-labeled and unlabeled apples. In contrast, after sharing information on the QR code technology, the ranking scores from the same consumers were statistically similar. According to this survey study, CO_2 laser labeling technology has the potential for industrial application from consumers' perspectives, and providing consumer education seems important to make this technology more successful.

Introduction

In recent decades, consumption of fresh fruits and vegetables has increased across the globe, including in the US (Berger et al., 2010; Pilone et al., 2017; Pollack, 2001; Zając & Van Der Lans, 2009). Increased domestic production, increased importation, public health promotion of healthier lifestyles, increased purchasing capacity, and other influences have factored into the growing demand for fresh fruit and vegetables in the US (Berger et al., 2010; Nzaku et al., 2010).

With the increased exposure of the general public to fresh produce, the incidence of produce-related foodborne diseases has been on the rise (Buck et al., 2003; Sivapalasingam et al., 2004). Some of the possible reasons are linked to changes in the agricultural, processing, and distribution practices, dietary habits, and others. According to the US Centers for Disease Control and Prevention (CDC), in 2021, an estimated 47.8 million illnesses, 127,839 hospitalizations, and 3,037 deaths (Berger et al., 2010; Buck et al., 2003) in the United States alone are related to foodborne illnesses. The cost estimate of food safety incidents to the U.S. economy is around US$7 billion annually (Hussain & Dawson, 2013). Consumption of fresh fruits and vegetables, generally eaten raw or minimally processed, has a higher propensity for infection by contaminating human pathogenic bacteria (Greig & Ravel, 2009; Sy et al., 2005). Two enteric pathogens, *Salmonella* and *E. coli* O157:H7, are the most problematic produce-related pathogens due to their potential for growth prior to consumption and having a low infectious dose (Buck et al., 2003). Pathogens could adhere to produce at several stages in the supply chain, including preharvest and postharvest. Fruits such as apples have a relatively lower chance of contamination; however, cross-contamination from highly sensitive produce (e.g., romaine lettuce) or from handlers en route to the dinner plate is possible. Once attached, it is almost impossible to remove pathogens from the contaminated produce. Increasing produce-related illness and food recall incidents undermine consumers' trust in the produce supply system and thus negatively impact the produce industry (Moruzzo et al., 2020). Due to these reasons, there is increasing interest in improving food traceability to cope with these challenges (Folinas et al., 2006).

The International Organization for Standardization defines traceability as "the ability to trace the history, application or location of an entity by means of recorded identification" (Olsen & Borit, 2013). Food traceability is critical to providing safer foods throughout the supply chain (Aung & Chang, 2014). Effective traceability can improve public trust as it facilitates the rapid and effective recall of products to determine and minimize the impact of safety hazards (Sree & Natarajan, 2022a). A solid and reliable food traceability system can effectively curb produce-related outbreaks and ease the severity of produce-related illnesses. This system could locate the particular questionable produce at various stages in the supply chain without endangering an entire supply line (Blanchfield, 2012). Traceability is equally important to producers, suppliers, and distributors to protect themselves from fraudulent claims.

The US Food and Drug Administration (FDA) recently finalized the traceability rule of the Food Safety Modernization Act (FSMA) that would require growers to meet established traceability requirements. To this end, fresh produce is generally labeled with Price Lookup (PLU) labels attached to the individual produce, which also makes it easier for the sales checkout in retail stores. The traditional method of produce labeling with PLU stickers has several pitfalls, including label detachment/loss, label misplacement, adulteration risk, and the ability to convey limited product information, which all have a detrimental impact on traceability (Etxeberria et al., 2006a). Additionally, PLU stickers and adhesives are non-biodegradable materials that do not meet the home compostable standard in some countries, leading to the diversion of waste containing PLU stickers to landfills and the production of difficult to manage micro-plastics. Furthermore, PLU labels are a nuisance to consumers as they are annoying to discard before eating.

In 2020, France passed an Anti-waste and Circular Economy law, which includes a ban on single-use plastics in produce packaging weighing less than 1.5 kg (USDA-FAS, 2021). Since this law came into effect in January 2022, the ban on the use of plastic stickers affixed on produce has been a major concern in the produce industry as there are no viable alternatives to the industry standard price lookup labels. Since these plastic labels are non-biodegradable and do not meet a home compostable standard, the use of these labels would be prohibited in France. The New Zealand government was the first to bring a ban on single-use plastic and set a deadline of 1 July 2025 to ban non-home-compostable labels and adhesives (Ministry for the Environment, NZ, 2023) Also, the Spanish government is working on a similar decree to impose a ban on plastic use on produce (Lindsey, 2021). At this point, it is imminent that more countries in the EU and around the globe will follow the trend of bringing new ordinances on plastic use (Tucker, 2023).

An alternative method of produce labeling is CO_2 laser marking, where the laser beam (aka light amplification by stimulated emission of radiation) is utilized to etch directly onto the surface of produce. There are several methods of produce labeling that are currently in use at a commercial scale: pattern, logo, text, one-dimensional, and two-dimensional codes. Laser markings of horticultural products have been authorized (US Food and Drug Administration, 2012). However, only logos, numbers, symbols, and words were previously allowed. Currently, with the new approval by the European Union (EU), matrix codes, barcodes, and Quick Response (QR)- codes with additional information can now be etched for marketing and traceability purposes (Pullman N., 2017a). The QR code helps digitize data through blockchain technology by encoding the detailed information of produce from production to retailing. With this technology, anyone can quickly access relevant information by scanning the QR code with the use of a smartphone (Feng et al., 2020). Compared to the traditional PLU labeling technique, laser labeling provides various advantages, including a relatively high printing speed, the creation of permanent labels, improved traceability, and reduction of environmental pollutants (Berger et al., 2010; Pullman N., 2017). QR-code technology provides useful information for consumers when making food purchasing decisions (Kim & Woo, 2016; Yang et al., 2022).

The CO_2 laser labeling on fresh produce is a novel practice and has been gaining momentum recently; however, it lacks a standard protocol of operation. There is scant literature on CO_2 laser labeling technology, although it has shown promising results in various fruits (apple, tangerine, grapefruit, dragon fruit, mango, and avocado) and vegetables (tomato, green bell pepper, and cucumber) (Etxeberria et al., 2006a, 2006b; Sood et al., 2008; Sood, et al., 2009a; Sood, et al., 2009b; Sree & Natarajan, 2022). These practices are mostly confined to small pilot projects. Prior to changing to the use of new technology for commercial production, there is a need to assess consumers' acceptance and the factors driving the consumers' acceptability of this technology. To the best of our knowledge, this study is the first of its kind to evaluate consumers' response towards produce labeled with CO_2 laser technology in the United States of America. Apples were used in this study as an example because of their soft surface and ease of printing. The CO_2 laser labeling technology is not a technology that can be used in all produce, but it is a step towards reducing plastic waste and improving the sustainability of produce production. The objectives of this study were to 1) evaluate consumers' acceptability of the laser labeling technology compared to a more conventional technology, using ‘Red Delicious’ apples as an example, and 2) to discover consumers' perceptions and opinions of this type of technology.

Materials and Methods

Laser labeling of produce

Fresh ‘Red Delicious’ apples were selected due to their plain surface, appropriate color contrast for better printing resolution, and high QR-code readability. Also, apples are the most consumed fresh fruit in the U.S. and have a significant value to the U.S. economy (ERS, 2021). Fresh apples were procured from a local grocery store before the day of the experiment and stored at 90% relative humidity (RH) and 4°C temperature in a cooler chamber (Thermo Scientific Inc., Waltham, MA) overnight. On the day of the experiment, all produce were kept at ambient room temperature and dried with a paper towel before the initiation of laser labeling treatment.

A commercially available Trotec Speedy 300 CO_2 laser engraving machine (Trotec Laser Inc., Plymouth, MI) was used to engrave apples with a QR-code label. The optimal settings were determined through the preliminary trial where speed was 100%, dots per inch was 500, power was 55 watts, and the object's height was 3.8 cm. A laser head lens of 2.03 mm was used to print a QR code of size 0.5 mm by 0.5 mm for better printing resolution while minimizing the possible damage to the produce**.**

Immediately after laser printing, an edible wax was manually coated over the engraved region to prevent freshwater loss. A Nectarine, Peach & Plum Lustr® 251 mineral oil-based emulsion (DECCO US PostHarvest Inc., Monrovia, CA) was applied with a dilution of 1:4 with water. After applying the wax, the apples were air-dried for 10 minutes at room temperature and then stored overnight at 90% RH and 4°C in a cooler chamber before the day of the study. The consumer study was conducted the following day.

Participants

The study was conducted at the Sensory and Consumer Research Center (SCRC) at Kansas State University, Olathe (Olathe, KS, USA). Participants (n = 75) lived in the Kansas City Metro area in the United States of America and had self-registered on a database by submitting a research participant form managed by the SCRC. Criteria were that participants must be 18 to 65 years old, not work for any institution with a conflict of interest, had no allergies, had purchased fresh apples in the last three months, and were not involved in any product survey within the last two months (Table 3.1).

Table 3.1 Demographics of respondents.

Age (yr)	**Percentage (%)**
18-25	4
26-35	19
36-45	21
46-55	27
56-64	29
Gender	
Male	29
Female	71

Human ethics statement

IRB approval was obtained at Kansas State University for testing with human subjects. Before beginning the study, participants were asked to provide a voluntary consent in an electronic media by clicking a button that confirmed their agreement to take part in the study voluntarily. Participants were made aware that their responses were anonymous and would remain confidential.

They read that they could withdraw the survey at any time without penalty. Participants received a monetary incentive for their participation.

Experimental approach

The study was conducted in one day. Treatments included ‘Red Delicious’ apples 1) engraved with a QR-code label, 2) affixed with a PLU label, and 3) nontreated control that had no label (Fig. 3.1). The study was set up with ten visual stations equipped with a tablet computer and each station had all three treatment apples on display following a randomized order. To accommodate the schedules of the participants, the study was conducted in 12 different sessions, and each session lasted approximately 20 minutes. All treated apples were replaced every four sessions to maintain freshness and consistency in quality and to account for apple variability. Participants completed the survey in English from a station using a tablet device.

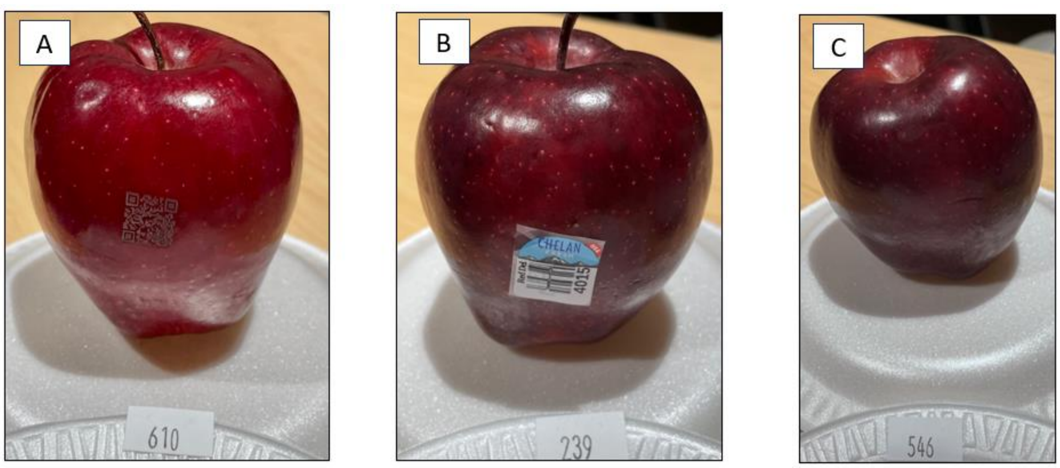

Figure 3.1 Products included in the study. A) Engraved with QR-code label, B) Affixed with PLU label, and C) Nontreated control that had no label.

Participants were asked a set of quantitative and open-ended questions (supplementary material in Appendix A has the full details). They were asked to observe the treatment apples and answer questions based on the physical appearance of the apples and labeling methods. Each treatment apple was assigned a three-digit code. The questionnaires were designed to record scores on overall liking, label liking, purchase intent, label concerns, and recommendation intent. Liking questions were responded to using a 9-point hedonic scale, where scores of 1 indicated dislike extremely and 9 indicated like extremely. The purchase intent question was responded to on a 5-point scale, where 1 indicated definitely would not purchase and 5 indicated definitely would purchase. Concern for the label was responded to on a 9-point scale, where 1 indicated not at all concerned, and 9 indicated extremely concerned. Recommend others to purchase question was responded to on a 5-point scale, where 1 indicated definitely would not recommend and 5 indicated definitely recommend. Open-ended questions were also asked to receive qualitative feedback on each labeling technology, including particular concerns. Those comments were typed in by the respondents on a tablet.

After completing the initial survey, participants were asked to peruse brief information about QR-code laser labeling and PLU labeling. The same set of questions on like/dislike labeling and purchase intent were again asked after providing this information to record concept liking and concept purchase intent. Also, participants were again asked to rank the three treatment apples in order of preference, similar to the beginning of the survey. Participants were asked to indicate their agreement using a Likert scale on a set of six statements; for example, one of the statements read, “When possible, all produce should be laser labeled instead of using sticker labels” (Supplementary material in Appendix A has full details). Preference between laser labeling and PLU sticker labeling was also asked, followed by the "why" question at the end of the survey.

Study design and analysis

The study was conducted in one day. Stations were set up with a tray with all three apples, each on individual plates labeled with a 3-digit code. Products were evaluated following a randomized balanced design. Respondents were asked to evaluate each product and then answer the questions when prompted. First, individually and then ranking all 3 products together. All data was analyzed using XLSTAT (Lumivero, Denver, Colorado, USA). Individual data was analyzed using a one-way Analysis of Variance (ANOVA) with product as the main effect with 95% confidence. Ranking data was analyzed with Friedman's test for non-parametric data.

Results and Discussion

In the initial survey (before providing educational information), overall liking of the product, liking of labels, and purchase intent scores were all lower for QR-code labeled apples compared to both the sticker label and no label treatments (Fig. 3.2). Similarly, respondents rated statistically higher concern for laser labeling for QR-code labels versus for sticker labels (Fig. 3.3). This clearly shows that the "unknown" factor of QR-code labels already puts them at a disadvantage from the other more widely familiar option- the sticker label. For the same reason, 52% of the respondents preferred QR-code labeled apples vs. sticker labels but provided a significantly lower score when asked if they would recommend laser labels to others in comparison to PLU sticker-labeled apples (Fig. 3.2). Most open-ended comments related to why people preferred the laser label were related to sustainability, less waste, less plastic, and better for the environment. The comments related to why they preferred the plastic labels were that "that's what I am used to," easier to see, and the fact that they could remove them. Some people were concerned about the "unknown" chemicals that may be in the laser label and that it was difficult to see. Some respondents were actually under the impression that the section of the product that had the printed code had to be removed, so it would actually be more waste if that was the case. It is important to mention that laser labels do not use any "ink" or chemicals, so the printed section is completely edible.

At the end of the study, respondents were asked to rank the three options (QR label, current plastic label, and no label) before and after providing educational information related to the potential benefits of QR labels. The ranking of the three treatments based on overall physical quality revealed that before consumers were provided educational information on the different labeling methods, respondents ranked QR-code-labeled apples as the lowest ranking group, followed by sticker-labeled and not-labeled apples (Fig. 3.4). In contrast, after reading information on laser labeling and PLU stickers labeling methods, the ranking scores from the same consumers were statistically at parity between the different treatments (Fig.3. 4). This shows the important effect of education on the consumer acceptability of sticker labels.

When asked if they agreed with different statements, 83% of the respondents agreed that laser labeling is a sustainable option, but only 61% of them agreed that they would consume such produce, and only 49% agreed that they would recommend such produce to others (Fig. 3.5).

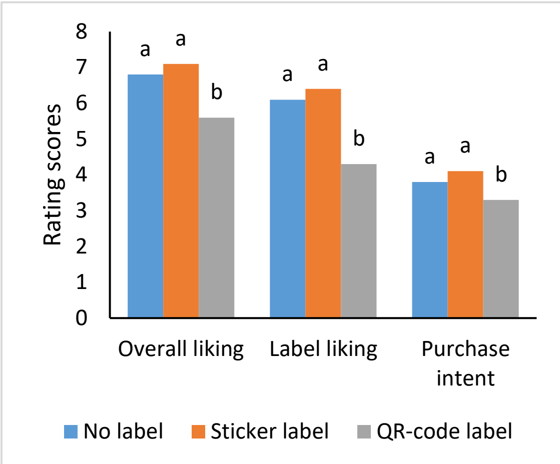

Figure 3.2 Respondents' initial scores on overall liking, label liking, and purchase intent on 'Red Delicious' apples labeled with a price lookup sticker, QR-code laser printer, and no label. Different letters within bars indicate statistical significance according to the Tukey test at α = 0.05.

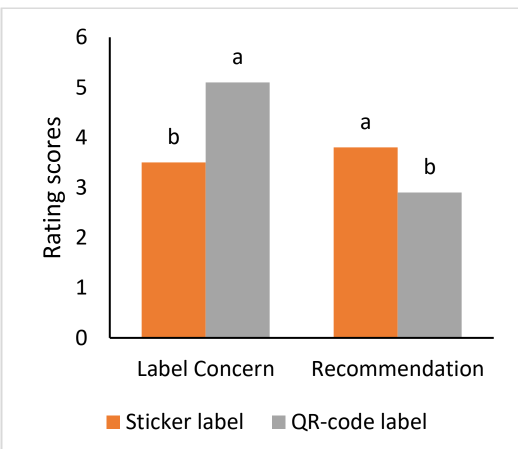

Figure 3.3 Respondents' initial scores on label concern and intent to recommend to others on 'Red Delicious' apples labeled with price lookup sticker and QR-code laser printing. Different letters within bar indicate statistical significance according to Tukey test at α = 0.05.

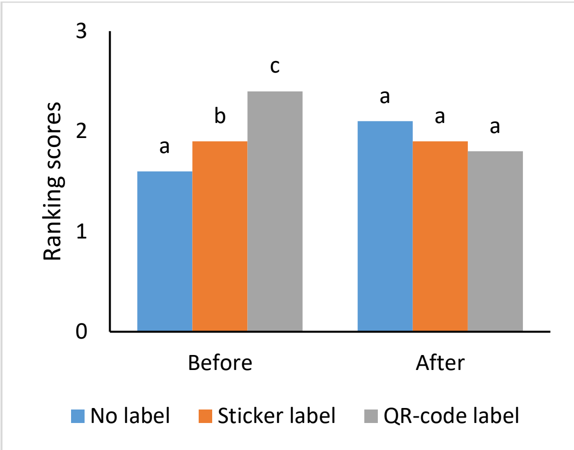

Figure 3.4 Respondents' ranking scores on physical appearance and labeling method on 'Red Delicious' apples labeled with price lookup sticker, QR-code laser print, and no label. Educational information on produce labeling was provided to respondents after taking the first survey to obtain before and after ranking scores. Different letters within bar indicate statistical significance according to Tukey test at α = 0.05

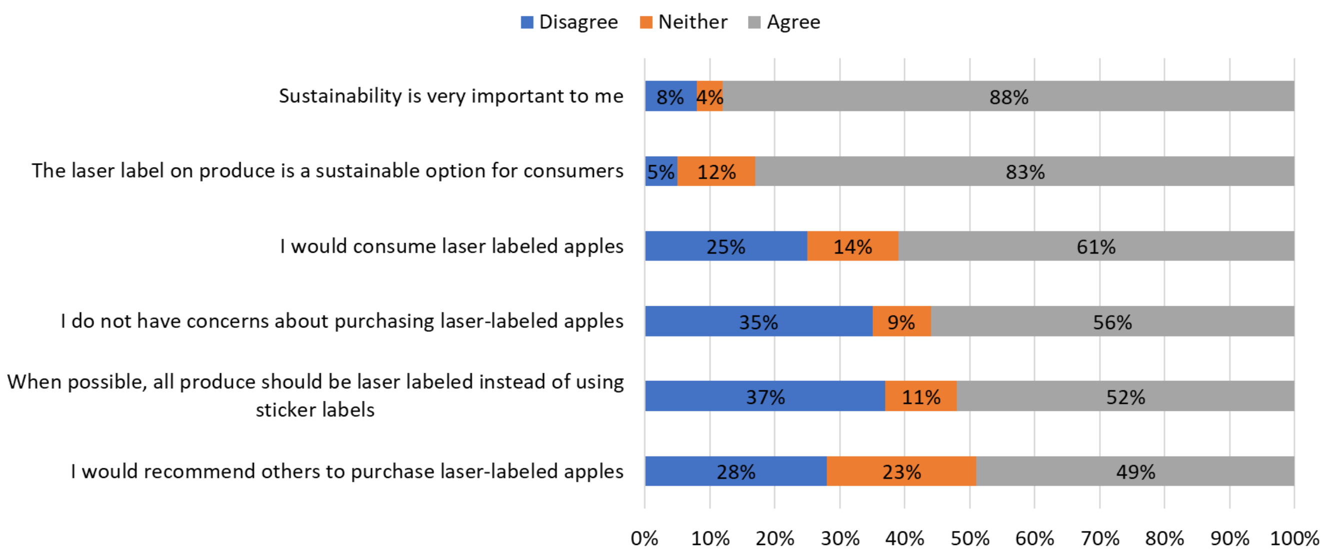

Figure 3.5 Statement (dis)agreements on 'Red Delicious' apples labeled with price lookup sticker, QR-code laser print, and no label.

To the best of our knowledge, this is a pioneer study to evaluate consumers' perception of laser-printed produce in the US. American consumers are generally not aware of new practices such as laser labeling adopted in fruit and vegetable production and marketing due to less promotion of such new practices (Collart et al., 2013; Onken et al., 2011; Patterson et al., 1999). Fresh fruits and vegetables generally receive less priority in terms of branding, packaging, and marketing compared to other commercial goods (Sun-Waterhouse, 2011; Williams et al., 2005). Consumers generally are not aware of supply chain management strategies, including production, processing, shipping, and selling, and they do not anticipate a high level of technological application on fruit and fruit products (Sabbe et al., 2009). As a result, consumers may not be willing to accept significant changes in product innovations (Petrescu et al., 2020; Samoggia & Nicolodi, 2017). Although technological advancement may enhance and add value to produce, customers frequently worry about the purity of nature in novel fruit products (Frewer et al., 2011; Siegrist & Hartmann, 2020). Consumer opinion is generally that more technologically advanced fruit and fruit products have less nutritional value and natural integrity or possibly more health concerns and detrimental environmental effects (Frewer et al., 2011; Mesías et al., 2021).

In recent years, there has been increasing interest in the improvement of food labeling as consumers are willing to learn more about the food they consume (Asioli et al., 2017; Loureiro et al., 2002; Sloan, 2003). Research shows that sensory characteristics, storability, and the general lifespan of the fruit are not affected by the CO_2 laser labeling process (Eyahanyo & Rath, 2020; Sood et al., 2008; Sood, et al., 2009a; Sood, et al., 2009b). Also, retailers are welcoming the new technology because, in addition to the aforementioned advantages, it is an innovative approach to ensure the traceability of the products (Samoggia & Nicolodi, 2017). Retailers are mainly concerned about label readability, and consumers worry about the integrity of the product (Samoggia & Nicolodi, 2017).

Samoggia and Nicolodi (2017) conducted research on consumers' perceptions of laser-labeled fruits and vegetables in Italy. The study was conducted as a face-to-face interview with structured questionnaires. The questionnaires included respondents' attitudes, buying intentions, naturalness of produce, and whether the technology is eco-friendly. They reported that most consumers in Italy (59%) have a positive perception of laser-labeled fruits. The majority of respondents in that study were positive that this technology does not deteriorate the produce quality (87%), is eco-friendly (73%), and is willing to buy the laser-labeled produce (60%). The same study also suggested that consumers are more inclined toward fruit innovation if they have a higher education level, are young or middle-aged, or have a higher income. The physical appearance of the produce was the main driving factor for consumers' acceptance. Any modification altering the physical appearance, such as laser-labeling, could be perceived as an alteration of its natural essence. Consumers' positive perceptions toward new practices could also be influenced by the socioeconomic characteristics of consumers (Loureiro et al., 2002; Urala, 2005).

Conclusions

Although consumers generally liked the concept of laser labeling, people were less likely to recommend or have purchase intentions of laser-labeled produce. Information on innovative laser labeling technology improved consumers' perception and overall liking compared to the other labeling options, thus warranting education and outreach programs for consumers on laser labeling. Laser labeling technology has no limitations on what information can be encoded in the QR code and does not endanger the product's quality and safety. The results of this study suggest that laser labeling technology could potentially be used in a commercial application to improve food traceability as a potentially safe alternative to PLU stickers in ‘Red Delicious’ apples, but strong education is needed to communicate the positive aspects of the technology while minimizing concerns and the "unknown" factor of this new technology. However, the limited sample size and geography of this study present limitations for these conclusions. A nationally-scaled study eliciting consumer perceptions and attitudes toward the use of laser labeling QR codes on produce will not only provide more robustness to the conclusions but will further determine the potential for its adoption within the produce industry.

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References

Asioli, D., Aschemann-Witzel, J., Caputo, V., Vecchio, R., Annunziata, A., Næs, T., & Varela, P. (2017). Making sense of the "clean label" trends: A review of consumer food choice behavior and discussion of industry implications. *Food Research International*, *99*, 58–71.

Aung, M. M., & Chang, Y. S. (2014). Traceability in a food supply chain: Safety and quality perspectives. *Food Control*, *39*, 172–184.

Berger, C. N., Sodha, S. V, Shaw, R. K., Griffin, P. M., Pink, D., Hand, P., & Frankel, G. (2010). Fresh fruit and vegetables as vehicles for the transmission of human pathogens. *Environmental Microbiology*, *12*(9), 2385–2397.

Buck, J. W., Walcott, R. R., & Beuchat, L. R. (2003). Recent trends in microbiological safety of fruits and vegetables. *Plant Health Progress*, *4*(1), 25.

Collart, A. J., Palma, M. A., & Carpio, C. E. (2013). Consumer response to point of purchase advertising for local brands. *Journal of Agricultural and Applied Economics*, *45*(2), 229–242.

Etxeberria, E., Miller, W. M., & Achor, D. (2006a). Anatomical and morphological characteristics of laser etching depressions for fruit labeling. *HortTechnology*, *16*(3), 527–532.

Etxeberria, E., Miller, W. M., & Achor, D. (2006b). Characteristics of laser etching depressions on Florida fruits and vegetables. *Proceedings of the Florida State Horticultural Society*, *119*, 353–357.

Eyahanyo, F., & Rath, T. (2020). Investigations on the effects of low laser infrared marking energy and barcode size on 2D data matrix code detection on apples. *Applied Engineering in Agriculture*, *36*(6), 829–838.

Feng, H., Wang, X., Duan, Y., Zhang, J., & Zhang, X. (2020). Applying blockchain technology to improve agri-food traceability: A review of development methods, benefits and challenges. *Journal of cleaner production*, *260*, 121031.

Folinas, D., Manikas, I., & Manos, B. (2006). Traceability data management for food chains. *British Food Journal*, *108*(8), 622–633.

Food and Drug Administration. (2012, June 11). Rules and Regulations. Irradiation in the Production, Processing, and Handling of Food. *Docket No. FDA–2007–F–0390*. https://casetext.com/federal-register/irradiation-in-the-production-processing-and-handling-of-food-27

Frewer, L. J., Bergmann, K., Brennan, M., Lion, R., Meertens, R., Rowe, G., Siegrist, M., & Vereijken, C. (2011). Consumer response to novel agri-food technologies: Implications for predicting consumer acceptance of emerging food technologies. *Trends in Food Science & Technology*, *22*(8), 442–456.

Greig, J. D., & Ravel, A. (2009). Analysis of foodborne outbreak data reported internationally for source attribution. *International Journal of Food Microbiology*, *130*(2), 77–87.

Hussain, M. A., & Dawson, C. O. (2013). Economic impact of food safety outbreaks on food businesses. *Foods*, *2*(4), 585–589.

Kim, Y. G., & Woo, E. (2016). Consumer acceptance of a quick response (QR) code for the food traceability system: Application of an extended technology acceptance model (TAM). *Food Research International*, *85*, 266–272.

Lindsey, P. (2021, September 28). *Spain plans ban of plastic packaging for fruits and vegetables*. Food Packaging Forum. https://www.foodpackagingforum.org/news/spain-plans-ban-of-plastic-packaging-for-fruits-and-vegetables

Loureiro, M. L., McCluskey, J. J., & Mittelhammer, R. C. (2002). Will consumers pay a premium for eco-labeled apples? *Journal of Consumer Affairs*, *36*(2), 203–219.

Mesías, F. J., Martín, A., & Hernández, A. (2021). Consumers' growing appetite for natural foods: Perceptions towards the use of natural preservatives in fresh fruit. *Food Research International*, *150*, 110749.

Ministry for the Environment, New Zealand. (2023, July 1). *Phasing out hard-to-recycle and single-use plastics*. https://Environment.Govt.Nz/What-Government-Is-Doing/Areas-of-Work/Waste/Plastic-Phase-Out/

Moruzzo, R., Riccioli, F., Boncinelli, F., Zhang, Z., Zhao, J., Tang, Y., Tinacci, L., Massai, T., & Guidi, A. (2020). Urban consumer trust and food certifications in China. *Foods*, *9*(9), 1153.

Nzaku, K., Houston, J. E., & Fonsah, E. G. (2010). Analysis of US Demand for fresh fruit and vegetable imports. *Journal of Agribusiness*, *28*(345-2016–15289), 163–181.

Olsen, P., & Borit, M. (2013). How to define traceability. *Trends in Food Science & Technology*, *29*(2), 142–150.

Onken, K. A., Bernard, J. C., & Pesek, J. D. (2011). Comparing willingness to pay for organic, natural, locally grown, and state marketing program promoted foods in the mid-Atlantic region. *Agricultural and Resource Economics Review*, *40*(1), 33–47.

Patterson, P. M., Olofsson, H., Richards, T. J., & Sass, S. (1999). An empirical analysis of state agricultural product promotions: A case study on Arizona Grown. *Agribusiness: An International Journal*, *15*(2), 179–196.

Petrescu, D. C., Vermeir, I., & Petrescu-Mag, R. M. (2020). Consumer understanding of food quality, healthiness, and environmental impact: A cross-national perspective. *International Journal of Environmental Research and Public Health*, *17*(1), 169.

Pilone, V., Stasi, A., & Baselice, A. (2017). Quality preferences and pricing of fresh-cut salads in Italy: new evidence from market data. *British Food Journal*, *119*(7), 1473–1486.

Pollack, S. L. (2001). Consumer demand for fruit and vegetables: the US example. *Changing Structure of Global Food Consumption and Trade*, *6*, 49–54.

Pullman, N. (2017, January 16). Swedish supermarkets replace sticky labels with laser marking. *The Guardian*. https://www.theguardian.com/sustainable-business/2017/jan/16/ms-and-swedish-supermarkets-ditch-sticky-labels-for-natural-branding

Sabbe, S., Verbeke, W., & Van Damme, P. (2009). Analysing the market environment for açaí (Euterpe oleracea Mart.) juices in Europe. *Fruits*, *64*(5), 273–284.

Samoggia, A., & Nicolodi, S. (2017). Consumer's perception of fruit innovation. *Journal of International Food & Agribusiness Marketing*, *29*(1), 92–108.

Siegrist, M., & Hartmann, C. (2020). Consumer acceptance of novel food technologies. *Nature Food*, *1*(6), 343–350.

Sivapalasingam, S., Friedman, C. R., Cohen, L., & Tauxe, R. V. (2004). Fresh produce: a growing cause of outbreaks of foodborne illness in the United States, 1973 through 1997. *Journal of Food Protection*, *67*(10), 2342–2353.

Sloan, A. E. (2003). What consumers want and don’t want-on food and beverage labels. *Food Technology (Chicago)*, *57*(11), 26–36.

Sood, P., Exteberria, E., Narciso, J., & Ference, C. (2009a). Laser labeling and its effect on the storage quality of citrus fruits. *Proceedings of the American Society of Horticulture Science*, 1004.

Sood, P., Ference, C., Narciso, J., & Etxeberria, E. (2008). Effects of laser labeling on the quality of tangerines during storage. *Proceedings of the Florida State Horticultural Society*, *121*, 297–300.

Sood, P., Ference, C., Narciso, J., & Etxeberria, E. (2009b). Laser etching: A novel technology to label Florida grapefruit. *HortTechnology*, *19*(3), 504–510.

Sree, T. K., & Natarajan, V. (2022). Laser labeling on dragon fruit with different codes and their impact on surface characteristics. *The Pharma Innovation Journal*, *11*(7), 4717–4723.

Sun-Waterhouse, D. (2011). The development of fruit-based functional foods targeting the health and wellness market: a review. *International Journal of Food Science & Technology*, *46*(5), 899–920.

Sy, K. V, Murray, M. B., Harrison, M. D., & Beuchat, L. R. (2005). Evaluation of gaseous chlorine dioxide as a sanitizer for killing Salmonella, Escherichia coli O157: H7, Listeria monocytogenes, and yeasts and molds on fresh and fresh-cut produce. *Journal of Food Protection*, *68*(6), 1176–1187.

Urala, N. (2005). *Functional foods in Finland: Consumers' views, attitudes and willingness to use* [Ph.D. Dissertation, University of Helsinki]. https://helda.helsinki.fi/server/api/core/bitstreams/082e3748-6fd4-4e9e-a089-90271ecc82d9/content

United States Department of Agriculture- Foreign Agricultural Service. (2021, July 20). *French legislation threatens millions of dollars of US fruit and vegetable exports*. https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=French%20legislation%20threatens%20millions%20of%20dollars%20of%20US%20fruit%20and%20vegetable%20exports_Paris_France_07-14-2021.pdf

Welt, B., & Blanchfield, J. R. (2012, March). *Food traceability*. UFoST Scientific Information Bulletin. International Union of Food Science and Technology. https://iufost.org/iufostftp/IUF.SIB.Food%20Traceability.pdf

Williams, E., Stewart-Knox, B., & Rowland, I. (2005). A qualitative analysis of consumer perceptions of mood, food and mood-enhancing functional foods. *Journal of Nutraceuticals, Functional & Medical Foods*, *4*(3–4), 61–83.

Yang, S.-H., Phan, H. T. T., Hsieh, C.-M., & Li, T.-N. (2022). What Intentions and Interesting Information Can Attract Consumers to Scan QR Code While Buying Eggs? *Foods*, *11*(9), 1259.

Zając, J., & Van Der Lans, I. A. (2009). An inventory of recent innovations in fruit and fruit products. *The Journal of Horticultural Science and Biotechnology*, *84*(6), 22–27.

Chapter 4 - Extension education handouts

The Food Safety Modernization Act (FSMA) Produce Safety Rule specifies that all agricultural water must be safe and of adequate sanitary quality for its intended use (FDA, 2023a; FDA, 2023b). A study conducted in Kansas and Missouri showed a critical need to educate produce growers on the importance of using safe agricultural water on their farm operations, as 38% of the respondents said they had never tested their agricultural water (Zhao, 2022). The same study also reported that 7% of respondents used untreated surface water for postharvest activities on their farms. To meet the Produce Safety Rule requirements, growers covered under FSMA must use postharvest water containing no detectable generic *E. coli*/100 mL water (FDA, 2023b). This chapter outlines the three separate handouts targeted to produce growers in Kansas and Missouri as extension outreach materials in topics related to maintaining safe agricultural water for postharvest operations. The first handout discusses the importance of understanding the microbial quality of postharvest water. The second handout aims to educate growers on two different methods of treating postharvest water. It provides a comparative analysis of using FDA-approved pesticides, chlorine versus peroxyacetic acid, as two options for treating postharvest water. The third handout discusses the importance of sanitizing postharvest water and farm equipment/tools to reduce the risk of pathogenic biofilm buildup. These extension handouts can serve as resources for growers, education educators, wholesalers, distributors, retailers, and other stakeholders in understanding the importance and practical application of maintaining safe agricultural water for postharvest operation.

As part of the Urban Food Systems program, the graduate curriculum requires that students provide four deliverables. Hence, as part of the course requirement fulfillment, four factsheets were developed.

Ag Water Contamination and Why it is a Food Safety Risk?

QUICK REFERENCE GUIDE

Ag Water Contamination and Why it is a Food Safety Risk?

According to the Centers for Disease Control and Prevention (CDC), in 2021, an estimated 47.8 million illnesses, 127,839 hospitalizations, and 3,037 deaths in the U.S. alone were attributed to foodborne illnesses. Fresh produce is commonly associated with foodborne illnesses and agricultural water is suspected as a major causative agent. The Food Safety Modernization Act (FSMA) Produce Safety Rule (PSR) specifies that all agricultural water must be safe and of adequate sanitary quality for its intended use.

What is Agricultural Water?

Agricultural (Ag) water is water that is intended or likely to contact the edible portions of produce or food contact surfaces during growing (pre-harvest) or during/after harvest (post-harvest). The PSR outlines three common sources of agricultural water: **ground water**, **surface water**, and **municipal water**.

Ag Water Microbial Safety The PSR currently uses a bacteria category called generic *E. coli* as an indicator of water quality. *E. coli* is a type of bacteria that is commonly found in animal and human waste (feces). For post-harvest water, there must be no detectable generic *E. coli*/100 mL of the water sample.

Potential sources of water contamination:

- Agricultural land
- Livestock farms
- Septic tanks
- Sewage treatment facilities
- Industrial runoff
- Storm water
- Wildlife

Why is Ag water a produce safety risk?

Contaminated agricultural water sources can pose a serious food safety risk on your farm. For example, if a water source is contaminated with *E. coli*, it can spread this contamination when the water is used for activities like irrigation, spraying, or washing especially if it comes into direct contact with the harvestable portion of produce commodity. Water can spread contamination from an individual produce item to the whole batch of harvested produce during bulk washing.

⚠ Once produce is contaminated with a pathogen, it is challenging to remove the contamination later. Post-harvest washing or sanitizing would not be effective in eliminating the contamination; therefore, it is better to prevent the contamination from occurring by using best practices throughout the entire production continuum.

Why is it important to test Ag water quality?

- ✓ Pathogens can be introduced into the water thorough the various routes and are easily spread through the water. Both irrigation and wash water were implicated in various produce foodborne outbreaks. Therefore, understanding risks associated with the ag water is important to reducing the risks on your farm.
- ✓ To understand the long-term microbial quality of the source water.
- ✓ To identify any sources of contamination and implement corrective actions as needed.

In one study, these were the most commonly implicated sources of *E.coli* in Ag water used by produce growers in Kansas and Missouri :

Bovine- 53% Human- 38% Ovine- 17 % Poultry- 11 % Caprine- 8%, and Deer 2 %. ([1]Manville et al., 2023).

K-STATE | University of Missouri Extension

[1]Manville, E., M.S. Bhullar, L. Nwadike, A. Mustapha, V. Trinetta (2023). Characterization of Escherichia coli Isolates from Agricultural Water on Kansas and Missouri Fresh Produce Farms by Whole-Genome Sequencing. *Food Protection Trends,* Vol 43, no 4, pp. 329-342. Jul 2023

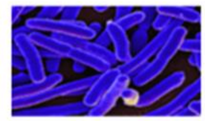
QUICK REFERENCE GUIDE

Ag Water Contamination and Why it is a Food Safety Risk?

How to address agricultural water contamination on the farm?

Some important steps you can take to mitigate the risk of spreading microbial contamination on the farm:

- ✓ Understand/identify the source of contamination and implement a corrective action (for example; if there are livestock near your water sources, adequate measures should be in place to prevent the presence of cattle near the water source and limit the chances of runoff from the cattle to the water source)
- ✓ Change the water application method (switch to a lower risk method of irrigation such as drip for most crops)
- ✓ Prolong the time between water application and harvesting
- ✓ Shock your well with disinfectants and/or treat your water if needed
- ✓ Install backflow preventers if you don't have them or ensure that they are working correctly.
- ✓ Check for any damage in your water system and perform any necessary repairs.
- ✓ Re-test your water after performing any corrective actions.



Water Treatment

FDA recognizes that agricultural water treatments could be a valuable tool in helping prevent foodborne outbreaks associated with fresh produce. Various water treatment methods are available: use of Chlorine, Peroxyacetic acid, Hydrogen peroxide, UV-light, Ozone, etc. Any kind of treatments **MUST** be used as per defined by the federal, state, or local regulations.

⚠ **Any method used to treat the Ag water must be effective to make the water safe and of adequate sanitary quality for use and/or meet the relevant microbial quality criteria.**

Follow all label instructions when using any disinfectant products.

Things to consider to keep your ag water clean and safe:

- ✓ Keep your domestic animals out of the agricultural water sources
- ✓ Keep composting or manure sites away from the water sources.
- ✓ Maintain sewage and septic systems.
- ✓ Always keep an eye on if wild animals are accessing your water sources.
- ✓ Use backflush water prevention methods or devices.
- ✓ Develop ag water management strategies, for example; water system surveys to identify and reduce risks.
- ✓ Test your ag water quality- more information available here: www.ksre.k-state.edu/foodsafety/produce/testing.html or contact your local produce safety personnel more information on water testing services.

Knowing your microbial water quality through long-term testing will help to establish management practices for appropriate use of the water!

Prepared by: Durga Khadka Reviewed by: Manreet Bhullar, Katelynn Stull and Londa Nwadike.

Approaches for Treating Ag Water for Postharvest Use

QUICK REFERENCE GUIDE

Approaches for Treating Ag Water for Postharvest Use

The Food Safety Modernization Act (FSMA) Produce Safety Rule specifies that all agricultural water must be safe and of adequate sanitary quality for its intended use. For postharvest water, this means no detectable generic *E. coli* in a 100 mL water sample. Therefore, managing the quality of postharvest water both a) at the start of use (ensure potable water), and b) during use (reduce cross-contamination risks), using physical or chemical treatments, is very important to reduce contamination risks.

Postharvest water is any water that contacts fresh produce or food contact surfaces during or after harvest. This includes water used for rinsing, washing, cooling, waxing, icing, or moving fruits and vegetables.

Note: Water used for hand washing also counts as postharvest water since it can potentially contact the produce surface.

How do you treat your postharvest water?

There are several ways to treat postharvest water. Chlorine (Cl) and peroxyacetic acid (PAA) are two examples of antimicrobial pesticide products that have been approved for postharvest water treatment. It is essential to read and follow product label directions for any postharvest treatments.

How do you decide the best intervention for your operation?

1. Disinfection volume (how much water needs to be treated and the flow rate of the system)
2. Contact time (time needed for the disinfectant to work)
3. Interaction with organic matter
4. Cost/benefit of the available options

There is no "one size fits all" selection for ag water treatment!

What are chlorine and PAA and how do they work?

Chlorine: Chlorine is a strong oxidizer and reacts with other compounds in the source water, including pathogens.

Advantages

- Cost-effective.
- Available in powder, liquid, and gas.
- Longest historical use to disinfect water.
- Effective in preventing plant pathogens.

Disadvantages

- Formation of by-products, including chlorine gas, which can be harmful to those working nearby.
- Irritable and toxic at high concentrations.
- Efficacy affected by pH and the presence of organic matter in water.
- Need to ensure that available chlorine level is adequate, not just total chlorine level.

Chlorine can be corrosive to certain materials; for instance, stainless steel

PAA is widely used in postharvest washing to prevent microbial cross-contamination in produce.

Advantages

- Widely used in postharvest washing.
- More resilient to organic matter compared to chlorine.
- Greater activity in the presence of organic material and inorganic soils.
- Non-corrosive.

Disadvantages

- More costly than chlorine.
- Irritative to the skin at high temperatures.
- Strong vinegar-like smell.

Factors affecting the efficacy of chlorine and PAA *(note: must follow product label directions)*

- Water pH
- Cl and PAA concentration
- Contact time
- Organic matter in the water
- Water temperature

K·STATE Research and Extension

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ksre.k-state.edu/foodsafety/produce/index.html

QUICK REFERENCE GUIDE

How to use chlorine and PAA to sanitize your postharvest water

How to adjust the treatment parameters

Monitoring pH:

- pH can be monitored by pH test strips, pH meters, and/or titration kits.
- pH should be adjusted to be within the parameters listed on the label.
- To reduce the pH, add food-grade acids like sodium bisulfate or citric acid; to increase the pH, add a base such as sodium carbonate or sodium hydroxide.
- pH adjustment kits are available.

Turbidity:

- Turbidity is the level of cloudiness in water. It can be used as an indicator of when to change your postharvest water.
- Turbidity can be monitored visually or by using the Secchi method.
- Turbidity can affect the treatment efficacy, so may need to add more sanitizer to keep the effectiveness.

Temperature:

- Large temperature differences between the post-harvest water and the produce may cause infiltration of micro-organisms to occur.
- Use properly calibrated thermometers to monitor the water temperature.
- Ensure water temperature on product label is followed.
- Chemical activity slows as the temperature drops, so it needs more contact time.

If water temperature is too high and pH is too low, toxic chlorine may "off gas" and can be hazardous for humans.

Primary things to consider when using chlorine and PAA in postharvest water

- Follow label directions for the following parameters: temperature; pH; contact time; product concentration.

Follow all label instructions when using any disinfectant products.

Things to consider to ensure the safety of postharvest water

- Avoid water contact with harvested produce, unless necessary.
- Single pass water use is generally safer than batch or multiple pass water use.
- Start with clean water; water must have no detectable generic *E. coli* in a 100 mL water sample.
- Best practice: treat water with sanitizers or in some other way to maintain water quality during use and to prevent biofilm formation.
- Change batch tank water regularly.
- Make sure the water temperature is appropriate to avoid infiltration.
- Always monitor the water pH and temperature for the best use of sanitizing products.
- Clean and sanitize tanks/bins and contact surfaces regularly.
- Always empty any used wash water into the appropriate drain.
- If using a sanitizer, ensure that workers are trained to handle the antimicrobial appropriately.
- Record keeping/ log sheet of water treatments is essential.
- Test your water quality regularly, if using a source other than municipal water.

The project is generously funded by a United States Department of Agriculture National Institute of Food and Agriculture Food Safety Outreach Program Grant (FSOP FY19 – 2019-04239). The information and viewpoints do not necessarily reflect the viewpoints and policies of the supporting organizations, cooperating organizations, FDA or USDA.

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Extension University of Missouri K·STATE Research and Extension

MF3641 August 2023

Use of Sanitizers in Postharvest Water

Use of Sanitizers in Postharvest Water

The Food Safety Modernization Act (FSMA) Produce Safety Rule (PSR) sets a standard for preventing contamination from agricultural water for postharvest use. Only use water that has been tested and confirmed to meet the standard of no detectable generic *E. coli* in a 100 mL water sample for postharvest use. Postharvest water refers to water used for rinsing, cooling, or icing harvested produce. It also includes water used for handwashing and cleaning food contact surfaces. Postharvest water, even if it is clean at the start, can become contaminated by produce that contacts the water. One way to maintain water quality is to add sanitizers to all batch/bulk water. Adding a sanitizer does not clean each individual piece of produce, but it helps to prevent cross-contamination from the water to the produce by limiting the buildup of pathogens and other microorganisms in the water.

Using a sanitizer in the water can also help reduce the risk of pathogenic biofilm buildup on food contact surfaces when using single pass spraying of produce. (Biofilm is a cluster of microbes that are attached to a surface, particularly in a moist environment

Understanding the terms

Always remember that cleaning, sanitizing, and disinfecting of food contact surfaces are not the same, although these terms are often used interchangeably.

Cleaning: Physically removes dirt and debris from food contact surface using clean water and detergents. Cleaning works by using warm, soapy water to physically remove impurities. It does not kill the germs but removes them from the surface.

Sanitizing: Reduces pathogens on the food contact surface to non-harmful levels.

Disinfecting: Kills almost all pathogens/ germs on food contact surfaces using chemicals.

Cleaning always needs to be done before sanitizing and disinfecting!

What is a sanitizer?

Sanitizers are antimicrobial pesticides when used properly, that lower the number of bacteria to safe limits. Sanitizers are usually used on surfaces that come into contact with food or in water. The antimicrobial product label will outline allowed uses, such as for water or food contact surfaces, as well as approved concentrations.

How are sanitizers regulated?

In the USA, sanitizers are considered antimicrobial pesticides, and their use is regulated by the US Environmental Protection Agency (EPA). Just like other pesticide types, **the label is the law**. Make sure the sanitizer you choose is labeled for the intended use and follow the use instructions. Do not use untreated surface water for postharvest uses. If you use surface water, you must treat the water (using a validated, controlled treatment) before use and regularly monitor it to make sure the treatment is effective.

Use the sanitizers in the water system, but not directly in the water source, such as into the pond.

Details on EPA pesticide regulation can be found at: https://www.epa.gov/pesticide-registration/antimicrobial-pesticide-registration

Some important things to consider while using sanitizers:

- ✓ Follow the label directions to limit the possible risks to humans, wildlife, and the environment.
- ✓ EPA- approved sanitizers will always include the EPA registration and label.
- ✓ Pesticide regulations could vary from state to state. Consult with state regulatory agencies for the regulation of pesticide use.

- ✓ **How to select sanitizers for intended use?** 
- ➢ Always consider worker and environmental safety when choosing sanitizers.
- ➢ Remember to follow label use instructions for appropriate personal protective equipment (PPE) when handling and mixing sanitizers.
- ➢ Some sanitizers may be corrosive when interacting with the environment.

Commonly used sanitizers for food contact surfaces and postharvest water:

A number of chemical sanitizers are labeled for use in postharvest water including options for organic certified produce. Commonly used sanitizers include chlorine, chlorine dioxide, peroxyacetic (peracetic) acid, and hydrogen peroxide.

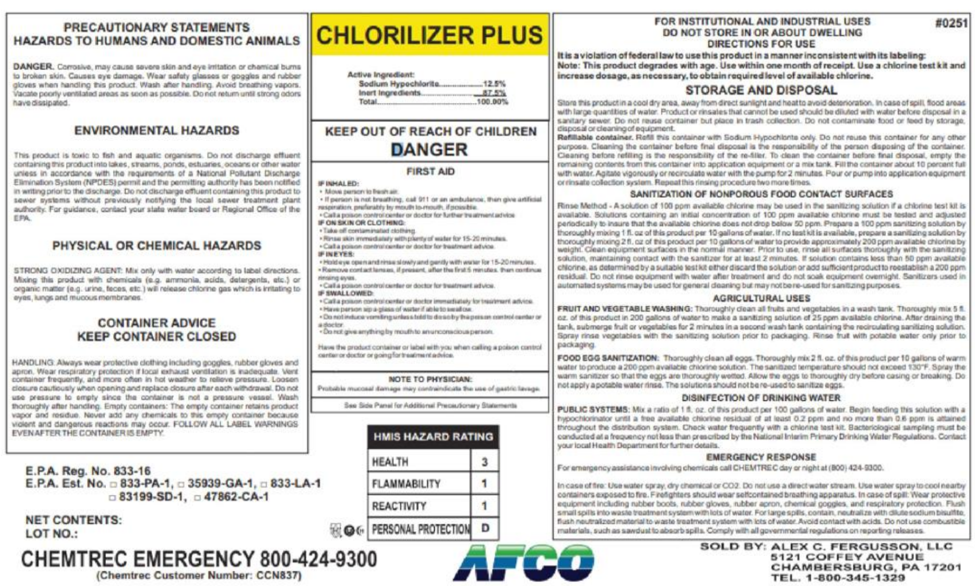
Understanding sanitizer labels:

All sanitizers approved by the EPA have labels, and the **label is the Law**.

If a grower uses a sanitizer that does not have an EPA label, the grower should be able to prove that the product is suitable for the intended use (such as washing fresh produce) and for reducing contamination risks.

Things to look for on the product label:

- ✓ Name of the product.
- ✓ EPA registration numbers
- ✓ Ensure that the sanitizer is labeled for its intended use, for instance nonporous food contact surfaces or fruit and vegetable wash water.
- ✓ Active ingredients.
- ✓ Hazards to humans and domestic animals.
- ✓ Proper storage and disposal of the product or the containers.
- ✓ Directions for use and proper concentration.
- ✓ Efficacy statement regarding the microorganism(s) the particular sanitizer controls.



PRECAUTIONARY STATEMENTS
HAZARDS TO HUMANS AND DOMESTIC ANIMALS

DANGER. Corrosive, may cause severe skin and eye irritation or chemical burns to broken skin. Causes eye damage. Wear safety glasses or goggles and rubber gloves when handling this product. Wash after handling. Avoid breathing vapors. Vacate poorly ventilated areas as soon as possible. Do not return until strong odors have dissipated.

ENVIRONMENTAL HAZARDS

This product is toxic to fish and aquatic organisms. Do not discharge effluent containing this product into lakes, streams, ponds, estuaries, oceans or other water unless in accordance with the requirements of a National Pollutant Discharge Elimination System (NPDES) permit and the permitting authority has been notified in writing prior to the discharge. Do not discharge effluent containing this product to sewer systems without previously notifying the local sewer treatment plant authority. For guidance, contact your state water board or Regional Office of the EPA.

PHYSICAL OR CHEMICAL HAZARDS

STRONG OXIDIZING AGENT: Mix only with water according to label directions. Mixing this product with chemicals (e.g. ammonia, acids, detergents, etc.) or organic matter (e.g. urine, feces, etc.) will release chlorine gas which is irritating to eyes, lungs and mucous membranes.

CONTAINER ADVICE
KEEP CONTAINER CLOSED

HANDLING: Always wear protective clothing including goggles, rubber gloves and apron. Wear respiratory protection if local exhaust ventilation is inadequate. Vent container frequently, and more often in hot weather to relieve pressure. Loosen closure cautiously when opening and replace closure after each withdrawal. Do not use pressure to empty since the container is not a pressure vessel. Wash thoroughly after handling. Empty containers: The empty container retains product vapor and residue. Never add any chemicals to this empty container because violent and dangerous reactions may occur. FOLLOW ALL LABEL WARNINGS EVEN AFTER THE CONTAINER IS EMPTY.

E.P.A. Reg. No. 833-16
E.P.A. Est. No. □ 833-PA-1, □ 35939-GA-1, □ 833-LA-1
□ 83199-SD-1, □ 47862-CA-1

NET CONTENTS:
LOT NO.:

CHEMTREC EMERGENCY 800-424-9300
(Chemtrec Customer Number: CCN837)

CHLORILIZER PLUS

Active Ingredient:
Sodium Hypochlorite....................12.5%
Inert Ingredients.........................87.5%
Total.......................................100.00%

KEEP OUT OF REACH OF CHILDREN
DANGER

FIRST AID

IF INHALED:
• Move person to fresh air.
• If person is not breathing, call 911 or an ambulance, then give artificial respiration, preferably by mouth-to-mouth, if possible.
• Call a poison control center or doctor for further treatment advice.
IF ON SKIN OR CLOTHING:
• Take off contaminated clothing.
• Rinse skin immediately with plenty of water for 15-20 minutes.
• Call a poison control center or doctor for treatment advice.
IF IN EYES:
• Hold eye open and rinse slowly and gently with water for 15-20 minutes.
• Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eyes.
• Call a poison control center or doctor for treatment advice.
IF SWALLOWED:
• Call a poison control center or doctor immediately for treatment advice.
• Have person sip a glass of water if able to swallow.
• Do not induce vomiting unless told to do so by the poison control center or a doctor.
• Do not give anything by mouth to an unconscious person.

Have the product container or label with you when calling a poison control center or doctor or going for treatment advice.

NOTE TO PHYSICIAN:
Probable mucosal damage may contraindicate the use of gastric lavage.

See Side Panel for Additional Precautionary Statements

HMIS HAZARD RATING	
HEALTH	3
FLAMMABILITY	1
REACTIVITY	1
PERSONAL PROTECTION	D

FOR INSTITUTIONAL AND INDUSTRIAL USES #0251
DO NOT STORE IN OR ABOUT DWELLING
DIRECTIONS FOR USE

It is a violation of federal law to use this product in a manner inconsistent with its labeling:
Note: This product degrades with age. Use within one month of receipt. Use a chlorine test kit and increase dosage, as necessary, to obtain required level of available chlorine.

STORAGE AND DISPOSAL

Store this product in a cool dry area, away from direct sunlight and heat to avoid deterioration. In case of spill, flood areas with large quantities of water. Product or rinsates that cannot be used should be diluted with water before disposal in a sanitary sewer. Do not reuse container but place in trash collection. Do not contaminate food or feed by storage, disposal or cleaning of equipment.
Refillable container. Refill this container with Sodium Hypochlorite only. Do not reuse this container for any other purpose. Cleaning the container before final disposal is the responsibility of the person disposing of the container. Cleaning before refilling is the responsibility of the re-filler. To clean the container before final disposal, empty the remaining contents from this container into application equipment or a mix tank. Fill the container about 10 percent full with water. Agitate vigorously or recirculate water with the pump for 2 minutes. Pour or pump into application equipment or rinsate collection system. Repeat this rinsing procedure two more times.

SANITIZATION OF NONPOROUS FOOD CONTACT SURFACES

Rinse Method - A solution of 100 ppm available chlorine may be used in the sanitizing solution if a chlorine test kit is available. Solutions containing an initial concentration of 100 ppm available chlorine must be tested and adjusted periodically to insure that the available chlorine does not drop below 50 ppm. Prepare a 100 ppm sanitizing solution by thoroughly mixing 1 fl. oz of this product per 10 gallons of water. If no test kit is available, prepare a sanitizing solution by thoroughly mixing 2 fl. oz of this product per 10 gallons of water to provide approximately 200 ppm available chlorine by weight. Clean equipment surfaces in the normal manner. Prior to use, rinse all surfaces thoroughly with the sanitizing solution, maintaining contact with the sanitizer for at least 2 minutes. If solution contains less than 50 ppm available chlorine, as determined by a suitable test kit either discard the solution or add sufficient product to reestablish a 200 ppm residual. Do not rinse equipment with water after treatment and do not soak equipment overnight. Sanitizers used in automated systems may be used for general cleaning but may not be re-used for sanitizing purposes.

AGRICULTURAL USES

FRUIT AND VEGETABLE WASHING: Thoroughly clean all fruits and vegetables in a wash tank. Thoroughly mix 5 fl. oz. of this product in 200 gallons of water to make a sanitizing solution of 25 ppm available chlorine. After draining the tank, submerge fruit or vegetables for 2 minutes in a second wash tank containing the recirculating sanitizing solution. Spray rinse vegetables with the sanitizing solution prior to packaging. Rinse fruit with potable water only prior to packaging.

FOOD EGG SANITIZATION: Thoroughly clean all eggs. Thoroughly mix 2 fl. oz. of this product per 10 gallons of warm water to produce a 200 ppm available chlorine solution. The sanitized temperature should not exceed 130°F. Spray the warm sanitizer so that the eggs are thoroughly wetted. Allow the eggs to thoroughly dry before casing or breaking. Do not apply a potable water rinse. The solutions should not be re-used to sanitize eggs.

DISINFECTION OF DRINKING WATER

PUBLIC SYSTEMS: Mix a ratio of 1 fl. oz. of this product per 100 gallons of water. Begin feeding this solution with a hypochlorinator until a free available chlorine residual of at least 0.2 ppm and no more than 0.6 ppm is attained throughout the distribution system. Check water frequently with a chlorine test kit. Bacteriological sampling must be conducted at a frequency not less than prescribed by the National Interim Primary Drinking Water Regulations. Contact your local Health Department for further details.

EMERGENCY RESPONSE

For emergency assistance involving chemicals call CHEMTREC day or night at (800) 424-9300.

In case of fire: Use water spray, dry chemical or CO2. Do not use a direct water stream. Use water spray to cool nearby containers exposed to fire. Firefighters should wear selfcontained breathing apparatus. In case of spill: Wear protective equipment including rubber boots, rubber gloves, rubber apron, chemical goggles, and respiratory protection. Flush small spills into waste treatment system with lots of water. For large spills, contain, neutralize with dilute sodium bisulfite, flush neutralized material to waste treatment system with lots of water. Avoid contact with acids. Do not use combustible materials, such as sawdust to absorb spills. Comply with all governmental regulations on reporting releases.

SOLD BY: ALEX C. FERGUSSON, LLC
5121 COFFEY AVENUE
CHAMBERSBURG, PA 17201
TEL. 1-800-345-1329

Understanding Personal Protective Equipment (PPE).

- ✓ Remember to follow label use instructions for (PPE) use when handling and mixing sanitizers
- ✓ Long sleeve shirt and pants.
- ✓ Chemical resistant gloves.
- ✓ Non-absorbent rubber boots.
- ✓ Eye googles or face shields.

Use PPE fully especially when using undiluted sanitizers.

Mixing the sanitizers in proper concentration.

- ✓ The concentration of the active ingredient must be routinely monitored, along with other requirements of the label use instructions such as pH, turbidity, water temperature, etc. to ensure that the treatment is effective and reduces risks
- ✓ Make sure the sanitizer is not expired for the best effectiveness.
- ✓ Follow the instructions regarding storage conditions to limit degradations and effectiveness.
- ✓ Use appropriate test kits or test strips to measure the desired concentration of the finished sanitizing solution.
- ✓ The concentration of the sanitizing solution is described in terms of parts per million (ppm), so it is important to measure the ratio of sanitizer and mixing solution.

Make sure the water used for mixing sanitizers is potable in all cases!

Record Keeping:

Always keep records after using sanitizers. Records may include name of sanitizer, purchase and opened date, surface, tools or equipment that sanitizer was used for, method of use, etc.

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Acknowledgments

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References

United States Food and Drug Administration. (2023, August 18). *Food Safety Modernization Act (FSMA)*. https://www.fda.gov/food/guidance-regulation-food-and-dietary-supplements/food-safety-modernization-act-fsma

United States Food and Drug Administration. (2023, September 28). *FSMA Final Rule on Produce Safety*. https://www.fda.gov/food/food-safety-modernization-act-fsma/fsma-final-rule-produce-safety

Zhao, Y. (2022). *Improving produce safety by reducing pathogen load in soil using cover crops and developing food safety educational resources for produce growers* [Master's thesis, Kansas State University].

Chapter 5 - Conclusions

CO_2 laser labeling minimally deteriorated the postharvest quality in fresh 'Red Delicious' apples, green bell peppers, and cucumbers stored at 95% RH and 4°C temperature during the study period. Also, QR-code labeling did not increase the susceptibility of microbial (rifampicin-resistant *E. coli*) contamination compared to control. A wax application following laser printing did not change the microbial attachment. Results suggest that laser labeling technology could potentially be used in a commercial application to improve food traceability as a potentially safe alternative to PLU stickers.

The consumer study showed that although consumers liked the concept of laser labeling, people were less likely to recommend or have purchase intentions of laser-labeled produce. Information on innovative laser labeling technology improved consumers' perception and overall liking compared to the other labeling options, thus warranting education and outreach programs for consumers on the technology. A strong outreach program is needed to communicate the positive aspects of this new technology and address its "unknown" factor. Yet, the limited sample size and geography of this study present limitations for these conclusions. A nationally-scaled study eliciting consumer perceptions and attitudes toward the use of laser labeling QR codes on produce will not only provide more robustness to the conclusions but further determine the potential for adoption within the produce industry.

Future Work

Since the Trotec Speedy 300 laser engraving machine was developed for cutting and engraving a number of materials like glass, metal, wood, fabric, leather, plastic, etc., that would be useful in the automotive industry, medicinal equipment, electronics, and others, the potential of using this technology on produce labeling was unknown before this study. This study was a pioneering investigation to explore the potential application of CO_2 laser labeling technology on fresh produce commodities, but it possesses a few major limitations. The major drawback of this technology right now is the speed of engraving on the produce surface. It is estimated that it would take about 15 seconds to engrave a QR-code label on an apple fruit, and with that rate, it would require 30 minutes to label one bushel of apple. Multiple laser heads on a machine or coordinated activities to reduce time on preparation could be explored. Additionally, we used 50 and 55 Watts of power, and this machine's power could be increased up to 120 Watts. So, because this is a powerful machine, something simpler with less power and features could be developed that could be used just for produce industry. The machine developed specifically for produce surfaces could have increased engraving speed and could cost less. Another limitation of the technology is the cost of the machine itself. With the high initial cost and slow printing speed, the break-even point would not sustain profitable margins for businesses. With the reduction in cost and increase in printing speed, the net return would increase, and thus, the lower break-even price could be achieved. Extension and outreach programming are needed to address the unknown fear about the laser-labeling technology on consumers' health.

Appendix A - Consumer Analysis Questionnaires

Survey questionnaires utilized in chapter 3 can be found below:

22505 WILLOW - KSU Apple Labeling
Test Date: 5/25/22
N=90

Sensory and Consumer Research Center

Welcome Panelist name!

Click the *next* button to begin

1. I agree to participate as a panelist in research conducted by the Sensory & Consumer Research Center.
2. I understand that the purpose of this project is to participate in an Apple Labeling Study.
3. I understand that this is a **confidential test** and I will not talk with others about what I tasted.
4. I will receive participation payment when I complete this study.
5. I understand my performance as an individual will be treated as research data and will in no way be associated with me for anything other than identification purposes, thereby assuring confidentiality of performance and responses.
6. I understand that I do not have to participate in this research and may choose not to participate without penalty.
7. I understand that I may withdraw at any time.
8. If I have any questions concerning this study, I understand that I may contact Martin Talavera at 913-307-7324 at the KSU Olathe Campus.
9. If I have any questions about my rights as a consumer or about the manner in which this research was conducted, I may contact Dr. Rick Scheidt, Chair, Committee on Research Involving Human Subjects, 1 Fairchild Hall (532-2334), Manhattan, KS, 66506.
10. I understand that I will need to eat an unsalted saltine cracker during the study.

By typing my name in the space below, I am providing my electronic signature and acknowledging that I understand the above statements.

Today we are asking you to **evaluate three types of labels** you would find on fruits and vegetables in the produce section of the grocery store.

Follow the instructions on the screen and make sure you are looking at the correct apple number (sticker on plate and bottom of apple). You may pick up and handle the apple but please make sure to place it back on the correct plate. Note: We have sanitized the apples between each person.

DO NOT EAT THE APPLES!

Click *NEXT* to continue.

Assume you are at a grocery store and want to buy individual Red Delicious apples. You see apples labeled with three different methods:
1. Apples with Price Look-Up Plastic Sticker
2. Apples with Laser QR code
3. Apples with No Label
Based on the physical appearance of the apples and labeling method, what are your thoughts/opinions for the following questions?

WILLOW 1/10

Please look at how each apple is labeled and RANK them in order of PREFERENCE.

- Click & drag the code of the MOST PREFERRED sample into the box labeled "1st".
- Click & drag the code of the SECOND MOST PREFERRED sample into the box labeled "2nd".
- Repeat for the THIRD MOST PREFERRED (3rd box).

1st	2nd	3rd

BC111 BC222 BC333

Please look at Apple BC111 again.

Click *NEXT* to continue.

Sample: BC111

Considering everything, including the way this apple is labeled, how much do you like or dislike this apple OVERALL?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

WILLOW 2/10

Sample: BC111

How much do you like or dislike the LASER PRINTED LABEL on this apple?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

Sample: BC111

How much do you like or dislike the STICKER LABEL on this apple?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

Sample: BC111

How much do you like or dislike the LACK OF A LABEL on this apple?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

What did you LIKE about this labeling method?

Sample: BC111

What did you DISLIKE about this labeling method?

Sample: BC111

Sample: BC111

How likely would you be to purchase this apple if it was sold at your grocery store at a reasonable price?

Definitely would not purchase	Probably would not purchase	May or may not purchase	Probably would purchase	Definitely would purchase

Sample: BC111

How concerned are you about the LASER PRINTED LABEL on this apple?

Not at all concerned								Extremely concerned

Sample: BC111

How concerned are you about the PLASTIC STICKER LABEL on this apple?

Not at all concerned								Extremely concerned

What, in particular, are your concerns regarding this type of apple label?

Sample: BC111

Sample: BC111

Would you recommend others to purchase this laser printed apple?

Definitely not recommend	May not recommend	May or may not recommend	May recommend	Definitely recommend
1	2	3	4	5

Sample: BC111

Would you recommend others to purchase this sticker labeled apple?

Definitely not recommend	May not recommend	May or may not recommend	May recommend	Definitely recommend
1	2	3	4	5

Laser-Printed QR Code labeling aims to replace plastic stickers on fresh produce with the intent to reduce environmental waste (no use of plastic stickers and glue), and improve food traceability (identify the origin of the food).

In times of foodborne illness outbreaks, it will be easier and quicker to trace the contamination source and identify the cause of the problem. It would prevent blanket food recalls as this approach can specifically locate the contaminated food (location, store, etc.) and significantly reduce food loss.

The Laser Printed QR Code:

- Reduces environmental waste
- Scanable at the checkout stand
- Increases food safety - identifies exactly what farm the produce came from
- Potentially allows consumers to scan for nutritional information or recipes

Sample: BC111

How much do you like or dislike this method of labeling apples?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like Nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

Sample: BC111

How likely would you be to purchase apples with laser labels if they were sold at your grocery store at a reasonable price?

Definitely would not purchase	Probably would not purchase	May or may not purchase	Probably would purchase	Definitely would purchase

The **Price Look-Up Sticker** is the current method used to label fresh produce. The sticker provides a UPC code and/or a code number for the cash register to identify the price.

The Price Look-Up Sticker:

- Made of plastic and applied with glue to produce
- Must be removed by consumer prior to eating
- Scanable at the checkout stand **IF** UPC bar code is included

Sample: BC111

How much do you like or dislike this method of labeling apples?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like Nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

Sample: BC111

How likely would you be to purchase stickered apples if they were sold at your grocery store at a reasonable price?

Definitely would not purchase	Probably would not purchase	May or may not purchase	Probably would purchase	Definitely would purchase

After learning about the laser and sticker labeling methods, from the apples you evaluated today, please RANK them in order of PREFERENCE.

- Click & drag the code of the MOST PREFERRED sample into the box labeled "1st".
- Click & drag the code of the SECOND MOST PREFERRED sample into the box labeled "2nd".
- Repeat for the THIRD MOST PREFERRED (3rd box).

1st	2nd	3rd

BC111 BC222 BC333

Please read the following statements and indicate how much you agree or disagree.

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
I do not have concerns about purchasing laser-labeled apples							
I would consume laser labeled apples							
I would recommend others to purchase laser-labeled apples							
Sustainability is very important to me							
The laser label on produce is a sustainable option for consumers							
When possible, all produce should be laser labeled instead of using sticker labels							

What is your gender?

- Male
- Female

Which of the following includes your current age?

- Under 18 years old
- 18-25 years old
- 26-35 years old
- 36-45 years old
- 46-55 years old
- 56-65 years old
- 66 years or older

How often do you purchase apples?

- Once a week
- 2 times a month
- 1 time a month
- Less than once a month

Which varieties of apples do you prefer to buy? (select all that apply)

- ☐ Red Delicious ???
- ☐ Gala ???
- ☐ Granny Smith ???
- ☐ Empire ???
- ☐ Rome ???
- ☐ Honey Crisp ???
- ☐ Fuji ???
- ☐ McIntosh ???
- ☐ Other (please specify) ____

How do you normally purchase your apples? (select all that apply)

- ☐ Crate
- ☐ Box
- ☐ Bag
- ☐ Individual
- ☐ Other (please specify) ____

If you had to choose between laser-labeled and plastic stickers on apples, which one would you prefer?

- ○ Laser Label
- ○ Plastic Sticker

Why do you prefer the type of label?

Sensory and Consumer Research Center

Thank you for completing this test!

Please sign out.

Return to the check-out table to receive your payment.

Finished