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INTRODUCTION

Efforts to improve environmental stewardship and sustainability have heightened the discussion around the use of plastics, including those in the fresh produce industry (17, 26, 28, 32). Numerous stakeholders are independently and collaboratively working on systematic approaches to address concerns of plastic waste, recyclability, and non-plastic alternatives (26, 32). Plastic packaging is a broad category of materials, used across almost all industries, with 95–99% of all plastic packaging variations being created from non-renewable resources and petrochemical origins (29). The produce industry has become increasingly engaged in addressing the rising interests of consumers, regulations, and the industry's own desires to create a more sustainable supply chain (7, 24, 26). In recent years, new proposed and adopted regulations from global governments, including those of the European Union, the United Kingdom, and Canada, have passed or proposed expansive regulations aimed at reducing the amounts of plastic packaging used by the produce industry; specific regulations have been created for primary food contact packaging given the complexities and concern for human health within this category (16, 32). The expanding global export market creates a heightened need for global conversations to ensure that consistent approaches are adopted to facilitate trade and provide consumers safe, sustainable food options (28, 32).

On April 18, 2023, the Government of Canada introduced a draft proposal entitled the Regulatory Framework Paper for Recycled content and labelling rules for plastics (15). Within this proposal, the Ministry addressed the steps and framework by which Canada would work toward the goal of reaching zero plastic waste. An additional document, titled the *Pollution prevention planning notice (P2) for primary plastic food packaging: Targets for reduction, reuse, redesign, and recycled content*, was released to specifically address requirements pertaining to primary food packaging reduction (14). Primary food packaging, unlike other non-food contact packaging materials, introduces human health considerations and regulatory requirements regarding the types of materials that are allowed to ensure the safety of the consumer (12). The list of allowable materials (e.g., resins) under current regulations for food packaging in Canada is limited, and the recycled material options that may be solutions for other non-food applications would be prohibited for use as primary food packaging (14). The P2 plan accounts for these food-contact packaging constraints and introduces new considerations and specific requirements for plastic food-contact packaging reduction by Canadian retailers; specifically, fresh fruit and vegetable products must meet at least 75% reduction in plastic use by 2026, and at least 95% by 2028 (14).

The fresh fruit and vegetable category covers a broad variety of items ranging from intact whole fruits and vegetables such as citrus, avocados, and potatoes, to processed ready-to-eat items such as chopped salads, sliced apples, peeled baby carrots, and chopped vegetable trays (5). A 2023 study released by the International Fresh Produce Association (IFPA) reports that the global fresh vegetable and fresh fruit segments are $691 and $621 billion (USD) categories, respectively (19). A fast-growing area within the produce industry is the fresh-cut fruit and vegetable segment representing multi-billion-dollar sales (5, 38). Fresh-cut produce items are minimally processed, often ready-to-eat, and offer consumers a convenient option to easily incorporate more fruit and vegetable consumption (5, 39). Numerous global initiatives,

including those from the World Health Organization (WHO) and Food and Agriculture Organization (FAO), have identified the critical importance of increasing fruit and vegetable consumption for overall health and well-being (11, 38, 39). The U.S. Department of Health and Human Services (HHS) Healthy People 2030 project identifies the importance that fruits and vegetables have on an individual's overall health, well-being, and onset of chronic diseases (e.g., diabetes, heart disease, cancer) and has many efforts within the program aimed at increasing availability and consumption amongst U.S. consumers (37). The 2019 update to Canada's Food Guide encourages half of a person's diet to originate from fruits and vegetables to improve overall health and well-being (13).

Fresh fruits and vegetables are packaged utilizing a diversity of primary packaging types and materials dependent on the product, their unique characteristics, agricultural production practices, harvest and processing practices, logistics network, and retail and customer preferences. Packaging within the food industry, for produce or otherwise, is carefully developed to ensure the quality of the food is preserved, the package materials are not known to pose a food safety risk, critical consumer handling and nutritional information are communicated to consumers, and food waste and environmental impacts are minimized (2, 7, 16, 17, 29). Examples of plastic produce packaging types can vary and include flexible film bags, clamshells, and even Price Look Up (PLU) stickers (18). Produce packaging's role may be cosmetic, marketing-related, informational for consumers (e.g., handling directions, nutritional labeling, origin information), and/or utilized for retailer inventory and sale management systems (18, 29). In certain applications, packaging is not solely cosmetic and may serve a critical role in product safety and foodborne illness prevention (5). This paper aims to further explore and address the food safety considerations relative to removing primary plastic packaging within the fresh and fresh-cut produce categories.

FRESH-CUT PLASTIC PACKAGING CONSIDERATIONS

The fresh fruit and vegetable segment, whether fresh-cut or whole fruits and vegetables, has intrinsic complexity with respect to product quality, shelf-life, and food safety risks (5, 7, 22). While fruits and vegetables are critical for human health and nutrition, they also represent a food segment associated with multiple foodborne outbreaks and subsequently require focused attention to the risks associated with each produce item and packaged product (5, 7, 39). The U.S. Centers for Disease Control and Prevention (CDC) National Outbreak Reporting System reports that between 2000 and 2018, 60% of outbreaks were linked to fresh produce (39). Produce items are, in general, grown outdoors negating a growers' ability to control all variables (i.e., weather patterns, wildlife intrusion, contaminated water, adjacent land use) (7). During the growing period, these uncontrollable variables may introduce opportunities for exposure to foodborne pathogens (7, 9). Produce items are intended for fresh consumption and are frequently prepared without post-harvest intervention steps such as cooking, retort, and high-pressure processing (5). Fresh produce items are also unique in that they continue to respire and continue several metabolic processes post-harvest (5). These ongoing metabolic systems create a dynamic package environment designed to control microbial growth and plant tissue degradation by managing respiration rates when stored at the proper refrigerated temperatures (5, 7).

For fresh-cut fruit and vegetables, packaging is a critical product design component, selected to optimize the shelf life (i.e., quality) of the items and maintain safety for the consumer (1, 5, 28). Many fresh-cut fruits and vegetable items are designed to be ready-to-eat, with little to no preparation required by the consumer, and packaging is a critical element in controlling post-processing exposure (7, 39). The packaged fresh-cut industry has made fruit and vegetable consumption accessible to consumers resulting in increased access, and better nutrition overall (5, 7, 39). Plastic packaging helps ensure that a high-quality, consistent product is delivered to the consumer year-round despite crop variety changes, handling variability, and overall product pre-harvest and post-harvest quality challenges (1, 5). As an example, in the packaged salad industry, primary packaging serves as a barrier to protect from post-processing contamination by microorganisms, chemicals, and foreign materials, while it also offers shelf-life extension by modifying package atmospheric gas compositions, generally oxygen percentages, which reduces the respiration and transpiration rate of the product which inhibits microbial growth and subsequently extends shelf life (1, 2, 5, 7, 28). Plastic achieves this shelf-life extension through intentional design, providing differing packaging options with varying oxygen transmission rates (OTR) (7, 19, 29). With reduced oxygen levels, modified atmosphere packaging (MAP) can slow the senescence of the product, inhibit enzymatic activity, and disrupt the growth of aerobic microorganisms, which can lead to spoilage and food safety risks for consumers (7, 16). Various approaches are available in MAP, with some packages being classified as passive or others as active packaging depending on their function (e.g., gas-flushing, gas scavengers/adsorbers, modified permeability) (1, 7, 29). A growing area of interest includes incorporating antimicrobial materials into a packaging system to provide enhanced food safety (28). Examples include time-release of chlorine dioxide, embedded antimicrobial materials such as zinc oxide, green tea extract, and other antimicrobial compounds aimed at further reducing microorganism growth (1, 2, 19, 29, 30).

Plastic packaging also serves as a structural barrier to physical damage which can accelerate tissue destruction, alter respiration rates due to damaged cells, and enhance microbial growth on the damaged plant tissues (spoilage and pathogens), all conditions that lead to reductions in shelf-life (1, 2, 5, 7, 20, 29). As the demand for fresh-cut products has increased, packaging and material science engineers have designed more complex packaging to address the shelf-life and supply chain challenges to support the rapidly growing segment (5, 7, 39). In recent years, the Produce industry has embraced increasing percentages of post-consumer plastics, using materials with greater overall recyclability, and have been active collaborators with packaging companies to help develop post-consumer plastic, biodegradable plastic, and non-plastic alternatives to replace traditional non-renewable plastic materials (26, 29). These collaborative efforts are critical to ensure that the distinguishing material characteristics maintain the key attributes provided by plastic films and containers: thermal properties, tensile strength, moisture permeability, gas porosity, etc. (7, 26, 27, 29). Material alternatives are in development, including those that are biodegradable and from renewable sources; the packaging characteristics required for the diversity of produce items are extensive and no one alternative material has been identified to work for all items (26, 27, 29).

Besides product shelf-life and food safety optimization, primary plastic packaging allows

manufacturers and retailers to address food tampering, cross-contamination, and bioterrorism risks (20, 28). Given the ready-to-eat status of fresh-cut products, packaging serves a critical role in controlling intentional and unintentional manipulation downstream of processing (20). The outer packaging is a means to control access and identify when a product may have been manipulated, potentially posing a risk to the consumer (20). If an alternative material to plastic cannot be identified, and the fresh-cut industry cannot maintain individually packaged units, ready-to-eat fruits and vegetables would be sold at the retail store in bulk with customers having to select their own product. Bulk sale of ready-to-eat fruits and vegetables offers an opportunity for intentional or accidental contamination by customers and retail store employees; human handling and hygiene have been identified as a source of food contamination (9, 20). Studies have shown gaps in consumer food safety handling practices and bulk sale of susceptible ready-to-eat items could create potential opportunities for contamination (23, 31). While retail employees can be trained and assessed over time on optimal food handling and hygiene practices, addressing the risk from customer handling is less straightforward or controllable (9, 23, 31). Food handling within a retail grocery store introduces additional risk variables given the concurrent interaction with other products and tools in the store (e.g., carts, baskets) (25). These interactions may introduce new contamination opportunities and increase the likelihood a customer or employee's hand could harbor pathogenic microorganisms (6, 8, 25). As an example, a 2018 study surveilled 35 retail stores and the surfaces of 105 packaged raw poultry products in Tennessee and found six were positive for shiga-toxigenic *Esherichia coli* (STEC), seven were positive for *Campylobacter*, three were positive for both STEC and *Campylobacter (*8). Since customers move throughout and between areas of the store and interact with objects shared between customers (e.g., shopping carts, other products) and areas of the store, there is an increased opportunity to transfer pathogens during shopping (6, 8, 25, 39).

Bulk sale of ready-to-eat fresh-cut fruit and vegetables will require a container for the product to be held in so a consumer can take it home. If such packaging is provided by customers, as is common with bring-your-own coffee mugs or with the use of reusable bags for shopping, considerations must be made to improve education for consumers on proper cleaning and sanitation of these containers, as well as proper storage of containers as they may present opportunities for pathogen exposure or growth (39). A container provided by a customer could harbor microorganisms, chemical contaminants, etc. based on their handling and storage of the container; current food handling assessments and studies indicate there may be gaps in general food safety handling knowledge (21, 39). If a container is contaminated, it can pose a risk to that customer, additional customers, and store employees should poor handling practices be used. For example, if a customer places product in their reusable container and decides they selected too much product, they may replace the excess back into the bulk container. If their container is contaminated, this represents a cross-contamination opportunity that would endanger other customers.

Temperature control and retailer cleaning and sanitation practices within a bulk display of ready-to-eat produce will be critical to maintaining the cold chain and ensuring that no cross-contamination occurs between lots, suppliers, or products (7, 35). While cold-chain

management is already critical for packaged fresh-cut items, the absence of outer packaging on these items will require that retail stores redesign their display sets to house numerous, open containers of product. Protocols must be in place to ensure that traceability between lots and suppliers is maintained to best facilitate efficient and limited recall in the event of a foodborne illness outbreak; as such, display sets must be depleted prior to a new lot or supplier being added to replenish product (3). Lack of traceability or comingling of multiple lots or suppliers may broaden the exposure of an outbreak, involve suppliers and items unassociated with the risk, and delay regulators and investigators' investigations in the event of an outbreak (3). Numerous efforts over the past decades have focused on improving lot traceability following outbreaks that required broad warnings to avoid all items of a product and all suppliers due to gaps in traceability (3, 33, 36). The 2018 FDA and CDC warning to consumers to not eat any romaine lettuce is an example where all suppliers from an area were impacted during an outbreak, irrespective of whether that supplier's product was associated with the outbreak itself (34). Traceability deficiencies create confusion for consumers and complicate foodborne outbreak investigations.

FRESH PRODUCE PLASTIC PACKAGING CONSIDERATIONS

Fresh commodity fruit and vegetable items such as avocados, potatoes, and oranges use less plastic packaging compared to fresh-cut, and if used, plastic is less critical for product safety and integrity. In many cases, a product's inherent structure serves as a package (e.g., banana peel, cantaloupe rind, citrus peel). Plastic packaging within this segment is often used to create different retail units (e.g., bag of apples, clamshell of grapes, rubber-banded asparagus), and in most cases serves no food safety function. One type of plastic packaging that can be of utility in the event of an outbreak or recall is that of the Produce Look-Up sticker (PLU) (18). PLUs are applied at time of pack and, at a minimum, contain a retail code to facilitate the transaction (18). PLUs generally include a brand or marketer name as well. If a supplier's name is present, this provides a potential linkage to identify the origin of product more quickly. In recent years, efforts have been made to further expand the information captured in a PLU to improve the traceability of fruits and vegetables. Traceability and rapid recalls are extremely important to help identify remaining product in the market and communicate to the public if they have contaminated product (33, 36).

Commodity fruits and vegetables move through the supply chain in bulk in containers that vary in materials ranging from traditional wood crates, polypropylene-based containers, bioplastic-comprised containers, corrugated cardboard, medium-density fiberboard (MDF), and wooden boxes (17, 22). As shipping containers, bulk containers serve many purposes and must be selected based on the purpose and activities they will encounter (22). For example, fiber-based containers may not be appropriate for items that are hydrocooled due to their capacity to adsorb water, grow microorganisms, and become less structural over time (22). Increasingly, the produce industry has been incorporating reusable containers to minimize waste and address sustainability goals and concerns (10, 17, 22). Incorporating reusable containers from a food safety perspective requires critical consideration to ensure that the material can meet the physical characteristics required for the purpose (e.g., rigidity, moisture-resistance, durability, metal-detectable if broken)

while also addressing the hygienic design needed to ensure proper cleaning and sanitation can occur. Studies have shown that transfer of foodborne pathogens is possible between product and containers, and foodborne pathogens may remain present on container surfaces over time (17, 22). With the increasing focus on the removal of primary plastic packaging that may serve as a physical barrier between a product and a reusable container, careful consideration must be made to optimize materials used, account for pathogen transfer opportunities, and address cleaning, sanitation, and storage between uses (22).

CONCLUSION

Concerns for waste production, plastics contamination, and overall environmental stewardship warrant diligent study and efforts to ensure the most effective packaging solutions are identified, developed, and adopted around the world for all items, including those within the complex fresh produce segment (10). Consistent collaboration and alignment between global legislation, agencies, and industries is critical to address and optimize paths forward to maintain and improve access to healthy, safe, and nutritious foods for all global consumers. Packaging materials, including nonrenewable petrochemical plastics, have served varied, but critical functions in the produce industry that have extended the shelf life of perishable products, modified post-harvest metabolic and microbiological activity, controlled post-processing pathogen contamination, established tamper-proof containers, and provided surface areas large enough to capture lot codes and distinguishable traceability elements. Packaging materials, and in many cases nonrenewable plastic, have allowed for the expansion of the fresh produce industry and have ultimately supported the growth of a robust global fresh fruits and vegetable supply chain. Plastic packaging has proven to be a capable material; displaying unique characteristics that make it suitable and efficient for a wide variety of produce packaging types, processing scenarios, and logistics (26, 27). As the produce industry, governments, and societies evolve to incorporate a growing diversity of more sustainable packaging options, careful consideration must be made to ensure the advancements in food safety, quality, and portability are not lost, and that with each new material introduced, we ensure that appropriate research is conducted to assess that non-plastic alternatives provide comparable, if not improved upon, advancements to food safety and public health (2, 10, 28, 29, 32).

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