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Interactions between sanitizers and packaging gas compositions and their effects on the safety and quality of fresh-cut onions (*Allium cepa* L.)

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ABSTRACT

Onions are one of the most widely utilized vegetables worldwide, with demand for fresh-cut onions steadily increasing. Due to heightened safety concerns and consumer demand, the implications of sanitizing and packaging on fresh-cut onion safety and quality need to be better understood. The objective of this study was to investigate the effect of produce sanitizers, in-package atmospheres, and their interactions on the growth of *Salmonella* Typhimurium, mesophilic aerobic bacteria, yeast and mold, and the physico-chemical quality of diced onions to determine the best sanitizer and in-package atmosphere combination for both safety and quality. Diced onions were inoculated or not with *S.* Typhimurium, sanitized in sodium hypochlorite, peroxyacetic acid, or liquid chlorine dioxide, and then packaged in either polylactic acid bags containing superatmospheric O_2, elevated CO_2/reduced O_2, or air, or in polyethylene terephthalate snap-fit containers. Throughout 14 days of storage at 7 °C, packaged diced onions were assessed for their safety (*S.* Typhimurium), and quality (mesophilic aerobic bacteria, yeasts and molds, physico-chemical analyses, and descriptive and consumer acceptance sensory panels). While sanitizer affected ($P < 0.05$) fewer parameters (*S.* Typhimurium, mesophiles, yeasts and molds, headspace CO_2, weight loss, and pH), in-package atmosphere had a significant ($P < 0.05$) effect on all parameters evaluated. Two-way interactions between sanitizer and atmosphere that affected *S.* Typhimurium and pH were identified whereas 3-way interactions (sanitizer, atmosphere and time) were only observed for headspace CO_2. Sodium hypochlorite and elevated CO_2/reduced O_2 was the best sanitizer and in-package atmosphere combination for enhancing the safety and quality of packaged diced onions. In addition, this combination led to diced onions acceptable for purchase after 2 weeks of storage by trained and consumer panels.

1. Introduction

With an annual per capita consumption of nearly 6 kg, onions (*Allium cepa* L.) are one of the highest volume vegetables sold worldwide (National Onion Association, 2011). Due to changes in consumers' lifestyles over the last decade, the demand for ready-to-use (RTU) onions has notably increased with onions among the five most commonly sold RTU vegetables in the USA (Fresh Cut Magazine, 2008). As a RTU product, onions have a very short shelf life. Discoloration, softening, surface and cut-edge dehydration, water loss, ethylene production, glucose and fructose loss, sucrose increase, translucency, aroma loss, off flavor development, and exudate in the package can all occur as a consequence of the wounding associated with the cutting process (Block et al., 1997; Howard et al., 1994; Selman, 1993; Zaulia et al., 2013; Pérez-Gregorio et al., 2011). Moreover, spoilage microorganisms rapidly proliferate due to easy accessibility to nutrients resulting from processing. In addition to spoilage microorganisms, pathogenic microorganisms are an increasing concern in the processed onion industry since they can also be transferred from the outer skin and roots to the flesh during processing. *Salmonella* has been reportedly responsible for 8 confirmed outbreaks and 348 illnesses involving onions during the past ten years (Centers for Disease Control and Prevention, 2015; EFSA Panel on Biological Hazards (BIOHAZ), 2013; Kansas Department of Health and Environment, 2015; Ministry of Health and Long-Term Care, 2010; OzFoodNet Working Group, 2005).

A range of technologies including chemical sanitizer washes (Beerli et al., 2004; Park and Lee, 1995), controlled atmosphere (Blanchard et al., 1996), commercial fermentation products (Yang et al., 2011), UV light (Hadjok et al., 2008), modified atmosphere packaging (MAP) (Farber et al., 1998; Forney et al., 2012; Liu and Li, 2006), and active packaging (Piercey et al., 2012) have been assessed to reduce spoilage and pathogenic microorganisms in RTU onions. The reviewed literature shows that MAP with low O_2 and high CO_2 levels can reduce psychrotrophic bacteria and *Listeria monocytogenes* growth in RTU onions (Farber et al., 1998; Forney et al., 2012; Liu and Li, 2006). Furthermore, this packaging strategy can extend the shelf life of RTU

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fresh onions by reducing respiration and discoloration, maintaining sucrose content, and preserving aroma (Forney et al., 2012; Liu and Li, 2006), with its benefits on shelf life extension also having been shown by sensory panels (Liu and Li, 2006; Selman, 1993). Sanitizer washes can also decrease microbial populations and affect the physico-chemical quality of RTU onions. When stored at 4 °C, lower populations of aerobic mesophilic bacteria, yeasts and molds were found in packaged sliced onions that were previously treated with hydrogen peroxide (H_2O_2) at 40 and 60 g/L as compared to sodium dichloroisocianurate (NaDCC) at 0.05 and 0.1 g/L. These same sanitizers also differentially impacted sliced onion quality, with NaDCC promoting higher pH and H_2O_2 promoting higher firmness (Beerli et al., 2004). Park and Lee (1995) reported that packaged onions treated with chlorine had a reduced initial microbial load compared to non-treated onions, however, no effect of the sanitizer on surface color of the diced onions was observed.

Although the effect of both MAP and sanitizing washes on spoilage and pathogenic microorganisms in RTU onions has been studied, the literature lacks information on the effect of the interactions between chemical sanitizers and in-package gas compositions on the microbiological safety and quality as well as the physico-chemical parameters of RTU onions. In addition, there is no information on the effect of either chemical sanitizers or in-package gas compositions on *Salmonella* Typhimurium growth on RTU onions. Thus, the objective of this study was to investigate the effect of different commercial sanitizers, in-package atmospheres, and their interactions on the growth of *Salmonella* Typhimurium, mesophilic aerobic bacteria, yeast and mold, and the physico-chemical quality of diced onions to determine the best sanitizer and in-package atmosphere combination for both safety and quality.

2. Material and methods

2.1. Onion dicing

Spanish yellow onions (*A. cepa* L.) were purchased from a local distributor (Stan Setas Produce, Lansing, MI, USA), stored under refrigeration, and used within 1 day of delivery. Three different batches of onions were visually inspected, had their ends and outer layers manually removed and finally were diced using an Urschel mechanical dicer model HA (Valparaiso, IN, USA).

2.2. Preparation of inoculum and inoculation of the diced onions

A stock culture of one avirulent strain of *Salmonella enterica* subsp. enterica serovar Typhimurium LT2 (ATCC 700720) (obtained from Dr. Michelle Danyluk, University of Florida, Gainesville, FL, USA) was maintained at −80 °C and subcultured twice (24 h/37 °C) in 9 mL of trypticase soy broth (Difco, Becton Dickinson, Sparks, MD, USA) containing 6 g/L yeast extract (Difco, Becton Dickinson). After diluting the culture in tap water (~2 °C) to contain 5 log CFU/mL, the diced onions (~4 °C) were inoculated by immersion for 2 min to contain 3.87 ± 0.05 log CFU/g and then held for 6 h at 4 °C before further processing.

2.3. Sanitizer treatment of diced onions

Salmonella-inoculated and un-inoculated diced onions (~23 kg per replicate) were placed in a large mesh sack and were then immersed for 2 min at ~2 °C in 60 L of one of the following commercial sanitizers: 80 mg/L free chlorine (Cl) (XY-12, Ecolab, St. Paul, MN, USA) acidified to at pH 6.5 with citric acid, 80 mg/L peroxyacetic acid (PA) at pH 5.9 (Tsunami 100, Ecolab), or 2 mg/L liquid chlorine dioxide (ClO_2) at ~pH 7 (CDG Environmental, Bethlehem, PA, USA). After sanitizer washing, the diced onions were centrifugally dried using a SD50-LT spin drier (Heinzen Manufacturing Intl., Gilroy, CA, USA).

2.4. Packaging of diced onions

Two types of packages were used: polylactic acid (PLA) bags (11 × 12.5-cm, total surface area of 275 cm^2) formed from film (EVLON EV-HS1, BI-AX International Inc., Wingham, ON, Canada) using an impulse sealer (Ceratek, Sencorp Systems Inc., Hyannis, MA, USA) and polyethylene terephthalate (PET) snap-fit containers (Clear Lam, Elk Grove Village, IL, USA) measuring 9.5 × 9.5 × 2.5-cm with a total volume of 210 mL, an external surface of 270 cm^2, and an average thickness of 330 μm.

The sanitizer-treated onions were divided into 100-g aliquots for packaging. The PLA bags to contain diced onions in an active modified atmosphere were filled and sealed in a glovebox chamber (Labconco 50004 Fiberglass Glove Box, Kansas City, MO, USA) at 4 °C that was flushed with the appropriate atmosphere (100 kPa O_2 or 15 kPa CO_2 + 5 kPa O_2 + 80 kPa N_2). Passive modified atmosphere packages were obtained by sealing the bags under air. Snap-fit containers were simply closed before storage. All packages were stored at 7 °C until analysis. For simplicity, throughout this paper 92 kPa O_2 + 8 kPa N_2 in bag is abbreviated as O_2, 14 kPa CO_2 + 4 kPa O_2 + 82 kPa N_2 in bag as CO_2, 21 kPa O_2 + 79 kPa N_2 in bag as Air, and 21 kPa O_2 + 79 kPa N_2 in snap-fit container as SF.

2.4.1. Package permeability

Transmission rates for O_2, CO_2, water vapor, and ethanol were determined for both types of packages at 23 °C (Table 1). Since snap-fit containers are non-hermetically sealed, the whole package transmission rate for O_2 and CO_2 was measured using a static method, adapting the procedure described by González et al. (2008). Water vapor and ethanol transmission rates in the snap-fit containers were measured using a gravimetric method as follows: 12 mL of water or ethanol was placed on the bottom of the packages, the lids were then snapped and their weight losses were measured over time using a precision balance (OHAUS, model Discovery DV314C, Florham Park, NJ, USA). All testing was conducted in triplicate with the results expressed as kg/s·package. For the PLA bags, O_2, CO_2, water vapor, and ethanol transmission rates were estimated using previously calculated PLA film permeability values (González-Buesa et al., 2014), the average thickness of the PLA film, the total area of the bag, and the pressure difference of gases and vapors. The results were expressed as kg/s·package. Diffusion of O_2, CO_2, and ethanol but not water vapor is significantly greater through air in non-hermetic sealed snap-fit containers compared to the sealed PLA bag as shown in Table 1. These diffusion coefficients for O_2 and CO_2 are about 450 and 62 million times greater, respectively, through air as compared to PET film ($0.58 * 10^{-18}$ Kg m m^{-2} s^{-1} Pa^{-1} and $4.59 * 10^{-18}$ Kg m m^{-2} s^{-1} Pa^{-1} for O_2 and CO_2, respectively) The approach of Yasuda (1975) and the diffusion coefficient for O_2 and CO_2 in air provided by Mannapperuma et al. (1989) and Massman (1998), respectively, were used for the calculations. The PET snap-fit container behaved similar to a microperforated package, where microperforations have a greater impact on O_2 than water vapor content inside the package (Fishman et al., 1996).

Table 1
Gas and vapor transmission rates (TRs) for the two packaging systems.

Packaging system	Whole package TR ($\times 10^{-10}$ kg/s·package)			
	O_2	CO_2	WV	Ethanol
PET container[a]	1402 ± 91	1591 ± 117	45 ± 2	81 ± 29
PLA bag[b]	3.6 ± 0.7	19 ± 6	192 ± 28	1.0 ± 0.3

[a] Whole package TR values calculated in this study.
[b] Whole package TR values estimated from film permeability values in González-Buesa et al. (2014).