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Effect of different chemical compounds and ultrasound bath on the sanitization of minimally processed carrots

Efeito de diferentes componentes químicos e banho de ultrassom na sanitização de cenouras minimamente processadas

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Highlights:
Contamination from minimally processed foods negatively affects consumer's health.
Ultrasound and chemical compounds was effective for the decontamination of carrots.
Sanitizing agents tested may be viable option to the use of inorganic chloride.

Abstract

The objective of this study was to evaluate the effect of the use of different chemical compounds combined with ultrasound bath on the sanitization of minimally processed carrots. The sanitizers sodium hypochlorite, peracetic acid, and sodium dichloroisocyanurate were investigated, all of them associated with the ultrasound bath, and the aerobic mesophiles and *E. coli* counts were evaluated. Sodium hypochlorite associated with ultrasound reduced the population of aerobic mesophiles and *E. coli* by 0.23 and 1.88 log cycles, respectively. For sodium dichloroisocyanurate associated with ultrasound, the reduction was 3.06 and 2.76 log cycles, while for the association with peracetic acid, this reduction was 2.72 and 2.35 log cycles. Thus, the effect of the ultrasound bath and sodium dichloroisocyanurate increased the decontamination efficiency of the minimally processed carrots. In addition, there is an alternative to the use of sodium hypochlorite, once they are not involved in reactions with organic compounds and the formation of trihalomethanes, which are harmful to health.
Key words: Peracetic acid. Sodium dichloroisocyanurate. Sodium hypochlorite. Minimally processed. Pathogens. Ultrasound.

Resumo

O objetivo deste estudo foi avaliar o efeito do uso de diferentes compostos químicos combinados ao ultrassom na sanitização de cenouras minimamente processadas. Foram investigados os sanitizantes hipoclorito de sódio, ácido peracético e dicloroisocianurato de sódio, todos associados à técnica de banho de ultrassom, e foram avaliadas as contagens de mesófilos aeróbios e *E. coli*. O hipoclorito de

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sódio associado ao ultrassom reduziu em 0,23 e 1,88 ciclos log a população de mesófilos aeróbios e *E. coli,* respectivamente. Para o dicloroisocianurato de sódio associado ao ultrassom a redução foi de 3,06 e 2,76 ciclos log, enquanto que para a associação com o ácido peracético essa redução foi de 2,72 e 2,35 ciclos log. Assim, o tratamento composto pela técnica de ultrassom e o dicloroisocianurato de sódio aumentou a eficiência de descontaminação das cenouras minimamente processadas. Além disso, considera-se uma alternativa ao uso do hipoclorito de sódio, uma vez que não estão envolvidos em reações com compostos orgânicos e na formação de trihalometanos, prejudiciais à saúde.
Palavras-chave: Ácido peracético. Dicloroisocianurato de sódio. Hipoclorito de sódio. Minimamente processado. Patógenos. Ultrassom.

Introduction

The consumption of fruits and vegetables has increased with modern society seeking healthier lifestyles. Today consumers want fresh foods, with convenience and microbiological, sensory and nutritional quality (São José, 2017).

Thus the fresh-cut industry is expected to continue expanding rapidly and is still in urgent need of improved technologies for shelf life extension. Future studies should aim at improving microbial, organoleptic quality and nutritional value of fresh-cut produce by reasonable combinations of novel technologies (Ma, Zhang, Bhandari, & Gao, 2017).

It is noteworthy that with the growth of the market for fresh and minimally processed products, driven by the convenience provided by these ready-to-eat foods (Glowacz, Mogren, Reade, Cobb, & Monaghan, 2013), the incidence of food poisoning has also increased by eating fruits and vegetables contaminated with pathogenic microorganisms (Kim & Song, 2017).

Foodborne Disease (FDB) is a major international problem, mainly regarding the consumption of vegetables, and is usually related to the contamination of raw materials or the product ready for consumption (Food and Agriculture Organization [FAO]/ World Health Organization [WHO], 2002). The FBD comes from the ingestion of food contaminated by etiological agents with biological, physical, or chemical origin in sufficient quantities to affect the consumers' health, thus constituting a risk to the whole population (Ministério da Saúde [MS], 2005). To measure the global and regional burden of foodborne disease (FBD), the World Health Organization (WHO) established the Foodborne Disease Burden Epidemiology Reference Group (FERG), they find that the global burden of FBD is comparable to those of the major infectious diseases, HIV/AIDS, malaria and tuberculosis. The most frequent causes of foodborne illness were diarrheal disease agents, particularly norovirus and *Campylobacter* spp. Diarrheal disease agents, especially non-typhoidal *Salmonella enterica*, were also responsible for the majority of deaths due to FBD. Other major causes of FBD deaths were *Salmonella* Typhi, *Taenia solium* and hepatitis A virus. (Havelaar et al., 2015).

Outbreaks of contamination can negatively affect the food industry and the production chain. Thus, minimally processed food processing companies have focused on raw materials of excellent sanitary quality, and efforts have been made to ensure the safety of the product to the consumer (Moretti, 2008).

Carrot is considered one of the most important vegetables for its nutritional contribution. It can be consumed *in natura* and used as a raw material for food processing in the minimally processed form (mini carrots, cubes, grated, slices), or processed in the form of vegetable mixtures, infant foods, and instant soups (Vieira, 2008).

Minimally processed fruits and vegetables should be subjected to important sanitization steps, which aims to inactivate the pathogens and reduce the spoilage microorganisms to levels considered safe, thus providing a safe product from the microbiological point of view.

Chlorine is the sanitizer most used by the minimally processed food industry due to the ease of use, low cost, and recognized antimicrobial activity.

However, in minimal processing, under typical fruit and vegetable washing conditions, chlorine efficiency is limited (Park, Alexander, Taylor, Costa, & Kang, 2009). In addition, there is the possibility of hyperchlorination of residual water, which associated with the high content of organic carbon may contribute to the increase in the concentration of trihalomethanes and other disinfection by-products (Selma, Ibañez, Allende, Cantwella, & Suslow, 2008).

For these reasons, the use of chlorine is prohibited or restricted in some European countries, such as the Netherlands, Sweden, Germany, Switzerland, Denmark and Belgium, for the disinfection of the raw materials used for the production of minimally processed vegetables (Gil, Selma, López-Galvez, & Allende, 2009).

In this context, effective alternatives for the surface decontamination of fruits and vegetables have been studied, aimed to increase food safety. Ultrasound (US) has been recommended in food industries due to its ability to inactivate the microbial cells by the cavitation phenomena, consisting of the formation and collapse of bubbles, which generates localized mechanical and chemical energy. Cavitation can also facilitate the breakdown of microorganisms, thus increasing the efficacy of the chemical sanitizers (Gil et al., 2009; Gogate & Kabadi, 2009).

Thus, the present study aimed to evaluate the effect of the use of different chemical compounds combined with the ultrasound bath on the sanitization of minimally processed carrots.

Material and Methods

Obtaining the carrot samples

The carrot samples were purchased from the local market of Uberaba, MG, and transported in isothermal boxes to the Laboratory of Bioprocesses, belonging to the Federal University of Triângulo Mineiro (UFTM), for microbiological characterization. The samples were kept at 5 °C for a maximum of 24 hours prior to analysis.

Production of minimally processed carrots

The minimum processing of carrots for consumption *in natura* consists of several operations to obtain a fresh, healthy and safe product. The first step consisted of the selection of the raw material to eliminate unfit materials and unprocessed parts. Before the processing, the raw materials were kept under refrigerated storage at 5 ºC to reduce metabolism. The raw material was classified with regard to medium size (20 cm) to facilitate handling during the processing, and to standardize the final product. The second step consisted of washing the carrots in potable water for 5 minutes to remove the impurities, insects, and other adhered organisms. After selection and rinsing, the product was subjected to bark removal and cutting. Then, the carrots were cut into cubes using a vegetable manual processor (Vitalex Cm-fp Médio, Catanduva, SP, Brazil)

The material was immersed in water at 5 °C to remove the extravasated cell juice released due to the cell disruption during cutting. The sanitization step consisted of the isolated immersion of approximately 0.2 Kg of minimally processed carrots in 0.5 L of sanitizing solution (Table 1) to analyze the efficiency against natural microbial contamination. After the treatment, the carrots were rinsed in potable water for 5 minutes to remove excess sanitizer. The ultrasound bath (Unique, Usc-1400, 40 KHz and and 70 W, Indaiatuba, SP, Brazil) used in the sanitization stage was from the Laboratory of Fine Films and Plasma Processes of the Institute of Technological and Exact Sciences of the Federal University of Triângulo Mineiro.

Table 1
Treatments used in the sanitization of vegetables

Treatments	Sanitizers Conditions (Concentration / Frequency/ Time, temperature)
Sterilized water + Ultrasound (US)	40 KHz / 10 min/ 20 °C
Sodium hypochlorite (Start, Uberlândia, MG, Brazil) + US	0,1 g.L^{-1} / 40 KHz / 10 min / 20 °C
Sodium dicloisocyanurate (Nippoclor, Indaiatuba, SP, Brazil) + US	0,1 g.L^{-1} / 40 KHz / 10 min / 20 °C
Peracetic acid (Launer, Estrela, RS, Brazil) + US	0,04 g.L^{-1} / 40 KHz / 10 min / 20 °C

After the sanitization step, centrifugation was carried out in a manual vegetable dryer (Plasútil, Bauru, SP, Brazil) for two minutes to remove excess water from washing, sanitizing, and rinsing steps.

In the final step, after weighing, the products were packed in sterilized polyethylene bags and kept under refrigerated storage (5 °C) until analysis.

Natural microbiota of the minimally processed carrots

To evaluate the natural microbiota of the minimally processed carrot, the aerobic mesophiles were determined by depth plating technique using plate counting agar (PCA) and incubation at 35 ºC for 48 hours. The analysis was performed in the product after the sanitization step.

Hydrophobicity of both the minimally processed carrots and bacteria

The hydrophobicity of the minimally processed carrots and bacteria used for the challenge study (*E. coli* ATCC 25922) was evaluated using the contact angle method, as reported by Van Oss (1994). For the different surfaces, the contact angle between the surfaces and distilled water, formamide (Sigma Aldrich, São Paulo, SP, Brazil), and α-bromonaphthalene (Sigma Aldrich, São Paulo, SP, Brazil) were determined using a goniometer (EasyDrop, Krüss, Hamburg, Germany). The contact angle measurement of a drop of 2.0 µL was performed every second for 30 consecutive seconds for all liquids and surfaces. The measurements were performed at 25 °C. Three replicates were made for each liquid on each surface.

To determine the contact angle of the bacterial cell surface, measurements were performed on a layer of vegetative cells, as described by Busscher et al. (1984).

Hydrophobic interaction free energy (ΔG_{sas}^{tot}) and free energy of adhesion ($\Delta G_{adesão}$) (explicar cada sigla)

The hydrophobic interaction free energy (ΔG_{sas}^{TOT}) between the molecules of the surface (s) immersed in water (a) was calculated by the sum of the polar and nonpolar components of the interaction free energy, ΔG_{sas}^{LW}, and ΔG_{sas}^{AB}, respectively (Van Oss, 1994).

$$\Delta G_{sas}^{tot} = \Delta G_{sas}^{LW} + \Delta G_{sas}^{AB} \quad (1)$$

where:

ΔG_{sas}^{LW} interaction energy of Lifshitz–van der Waals

ΔG_{sas}^{AB} acid interaction energy and Lewis base.

The ΔG_{sas}^{tot} or ΔG_{bab}^{tot} values were calculated using the Equations 2 and 3, in relation to the hydrophobicity of a substrate (s) or the cell surface (*b*):

$$\Delta G_{sws}^{LW} = -2\sqrt{\gamma_s^{LW} - \gamma_w^{LW}} \quad (2)$$

$$\Delta G_{sws}^{AB} = -4\left(\sqrt{\gamma_s^+\gamma_s^-} + \sqrt{\gamma_w^+\gamma_w^-} - \sqrt{\gamma_s^+\gamma_w^-} - \sqrt{\gamma_w^+\gamma_s^-}\right) \quad (3)$$

where:

γ_s surface energy

γ^{LW} is the component of the Lifshitz–van der Waals interaction

γ^{+} refers to the Lewis acid interaction componente

γ^{-} is the Lewis base interaction.

The components of the interfacial tension of the surfaces were determined using Equation 4.

$$(1+\cos\theta)\gamma_1 = 2(\sqrt{\gamma_s^{LW}\gamma_l^{LW}} + \sqrt{\gamma_s^{+}\gamma_l^{-}} + \sqrt{\gamma_s^{-}\gamma_l^{+}})\ (4)$$

To determine the three components of the interfacial tension of the surfaces, the contact angle formed by the three liquids of different polarities was used.

The system of equations below was obtained using the values of Table 2 and Equation 4, for each liquid:

a) $\gamma_s^{LW} = 11{,}1(1+\cos\theta_B)^2$ (5)

b) $5{,}049\sqrt{\gamma_S^{+}} + 5{,}049\sqrt{\gamma_S^{-}} = 36{,}4(1+\cos\theta_W) - 15{,}55(1+\cos\theta_B)$ (6)

c) $6{,}293\sqrt{\gamma_S^{+}} + 1{,}510\sqrt{\gamma_S^{-}} = 29(1+\cos\theta_F) - 20{,}806(1+\cos\theta_B)$ (7)

where:

θ_B contact angle formed by α-bromonaphtalene

θ_F contact angle formed by formamide

θ_w contact angle formed by water

Table 2
Components of the interfacial tension of liquids with different polarity at 25 °C

Liquid	Interfacial Voltage (mJ/m²)			
	γ_l^{TOT}	γ_l^{LW}	γ_l^{+}	γ_l^{-}
α-bromonaphthalene	44.40	44.40	0.00	0.00
Water	72.80	21.80	25.50	25.50
Formamide	58.00	39.00	2.28	39.60

γ_l^{TOT} surface tension of the liquid used in the measurement; γ_l^{LW} is the component of the Lifshitz–van der Waals interaction; γ^{+} refers to the Lewis acid interaction componente and γ^{-} is the Lewis base interaction.

By the last three equations, three components of the interfacial tension of the surface were determined and the global interfacial tension of a surface was calculated (s), γ_s^{TOT}.

Inactivation and removal efficiency of Escherichia coli cells intentionally added to minimally processed carrots

This test was performed to evaluate the inactivation/removal capacity of *E. coli* cells intentionally added to the minimally processed carrots.

Samples were washed in sterile distilled water before inoculation with *E. coli* cells. The *E. coli* culture (ATCC 25922) was stored in 1 mL Eppendorf tubes containing BHI at -12 °C and activated by two consecutive BHI replications, and incubated at 37 °C for 24 h until reaching the population of 10^8-10^9 CFU.mL^{-1}.

For that, 0.2 kg of freshly processed carrots were placed in previously sterilized plastic bags, and the inoculum (0.010 L) and 1 L of 0.1% peptone water was added. The plastic bag containing the inoculum and the vegetables was lightly stirred for 5 minutes. The vegetables were kept in contact with the cell suspension for 60 minutes at 25 ± 1 °C.

The cell suspension was drained and the vegetables contaminated with *E. coli* were placed in sterile plastic bags and incubated at 25 °C for 24 h to allow for greater bacteria adhesion.

Subsequently, 0.2 Kg of the contaminated sample was immersed in 0.5 L of the sanitizing solution (Table 1) for 10 minutes at 7 ± 1 °C. The non-sanitized samples and the samples subjected to washing step in sterile distilled water were considered as a control.

After each treatment, 25 g sample was transferred to sterile plastic bags containing 0.225 L of 0.1% peptone water and homogenized in a stomacher (Marconi, MA440; Piracicaba, SP, Brazil) for two minutes. Then, they were plated onto plate count agar, incubated for 18 to 24 h, and the colonies were counted at 37 ºC.

Interfacial tension of the sanitizing solutions

The interfacial tension of the sanitizing solutions was evaluated by the drop method with the use of a goniometer DSA 25 (EasyDrop, Krüss, Hamburg, Germany) (Fialho et al., 2017).

Experimental design

A completely randomized design was used to compare the effect of the different treatments on the natural microbiota, the challenge study, the physicochemical characteristics, and the interfacial tension, for each treatment, with three repetitions. Data were submitted to analysis of variance (ANOVA) and Tukey's test, at 5% of significance, using the Statistica Software, version 8.0.

Results and Discussion

The results of aerobic mesophile counts are shown in Table 3. The application of stelirized water + US was not effective to ensure a decimal reduction of the bacterial population. When we used the ultrasound and the sanitizers: sodium hypochlorite, peracetic acid, and sodium dichloroisocyanurate, no significant difference was observed for the performance of the different antimicrobial agents. The contamination of aerobic mesophiles was reduced to the final population of 1.22 a 4.05 log CFU.g^{-1}.

Table 3
Count of aerobic mesophiles of the minimally processed carrots after the sanitization step 3

Treatments	Log CFU.g^{-1}	Decimal Reduction
Control	$4.28^{a} \pm 0.36$	-
Control + Ultrasound (US)	$4.05^{a} \pm 0.35$	0.23
SH + US	$1.43^{b} \pm 0.35$	2.86
PA + US	$1.56^{b} \pm 0.56$	2.72
SD + US	$1.22^{b} \pm 0.17$	3.06

[a, b]Means followed by the same letter, in the same column, do not differ among them by the Tukey's Test at 5% significance.
Legend: SH – Sodium hypochlorite; PA – peracetic acid; SD – sodium dichloroisocyanurate.

The decimal reduction corresponds to the variation between the initial log (control) and the final log count (treatments and ultrasound). A greater decimal reduction was observed when the sanitization was performed with sodium dichloroisocyanurate combined with ultrasound, with a total reduction of 3.06 log cycles.

According to the United States Environmental Protection Agency, a treatment that reduces the microbial contamination by at least 2 log cycles can be considered as significant (Michaels, Gangar, Schattenberg, Blevins, & Ayers, 2003).

Similar results were found by São José and Vanetti (2012), who found satisfactory results of ultrasound associated with sanitizers. A reduction of 2.1 log cycles of contamination was achieved in minimally processed cherry tomatoes after exposure to sodium dichloroisocyanurate combined with ultrasound, with a reduction of 4.4 log cycles when peracetic acid was used together with ultrasound.

Francisco, Araujo, Ferreira, Rosario and Cunha (2017) studied the decontamination of arugula leaves using the combinations sodium hypochlorite and ultrasound (40 kHz) and sodium dichloroisocyanurate and ultrasound (40 kHz), both for 5 minutes. For the arugula, the treatment with sodium hypochlorite and ultrasound proved to be more efficient, resulting in a decimal reduction of 1.46 log cycles.

The sanitizer efficiency in combination with the ultrasound can be due to the cavitation process consisting of the formation, growth, and collapse of bubbles that generate a localized mechanical and chemical energy (Rastogi, 2011). When ultrasound is associated with chemical agents such as Cl_2, H_2O_2, O_3, suggest that the pressure gradient allows the penetration of these agents by the cell membrane of the microorganisms. In addition, cavitation may facilitate the breakdown of microorganisms also present on surfaces (Gil et al., 2009, Gogate & Kabadi, 2009). Several factors can affect the ultrasound performance, including the type of target microorganism, time of contact, frequency and amplitude of the ultrasound waves, temperature, pH of the medium, and composition and volume of food (Cao et al., 2010; Gani et al., 2016).

The hydrophobicity results showed that the carrot surface is hydrophobic, while the bacterial surface (*E. coli*) is hydrophilic (Table 4). It is known that the surfaces are hydrophobic when the free energy of hydrophobic interaction is negative (Van Oss & Giese, 1995). The water molecules prevented unfavorable interactions (lower adhesion energy between liquid and solid) with the apolar surface (carrot). In these hydrophobic surfaces, the water molecules prefer to interact between them (greater cohesive energy of liquid) to absorb on the hydrophobic interface. Therefore, the water molecules acquired a greater degree of freedom, which caused an increase in entropy of the system and the variation of the Gibbs free energy of negative hydrophobic interaction. It can be said that the removal of the water film from the hydrophobic surface is always spontaneous when the ΔGTOT is less than zero.

Table 4
Values of the apolar (ΔG_{sas}^{LW}) and polar components (ΔG_{sas}^{AB}) of the total free interaction energy (ΔG_{sas}^{TOT}) of both the bacterial surface and the minimally processed carrots

Surfaces	(ΔG_{sas}^{LW}) (mJ.m^{-2})	(ΔG_{sas}^{AB}) (mJ.m^{-2})	(ΔG_{sas}^{TOT}) (mJ.m^{-2})
Carrot	-2.42	-66.73	-69.16
E.coli	-1.01	30.81	29.80

The bacterial cell hydrophilicity can be explained by the predominant electron-donor character (γ-). Biosurfaces are predominantly electron donors due to the presence of oxygen in the Earth's atmosphere and the surface hydration of the microbial cells (Strevett & Chen, 2003).

It is suggested that the hydrophobic interactions between the epidermal layer and the bacterium play an important role in bacterial adhesion (Burnett & Beuchat, 2001).

To evaluate the effect of the hydrophobicity on the microbial adhesion on the surface of minimally processed carrots, the challenge study with *E. coli*, one of the pathogens most involved in outbreaks with vegetables, was carried out. It was observed that a biofilm was formed on the carrot surface, reaching a count of 7.63 log $CFU.g^{-1}$ (Table 5). After the sanitization process, there was no significant difference between the antimicrobial agents evaluated. When the decimal reduction was calculated, a higher value was reached for sodium dichloroisocyanurate combined with ultrasound, which was similar to the results for the aerobic mesophile counts.

Knowledge about the microbial reduction with adherent pathogens is important, once the sanitizer efficiency can be impaired as a function of the surface characteristics (Ruíz-Cruz, Félix, Cinco, Osuna, & Aguilar, 2007). It is known that harvesting and post-harvesting of fruits and vegetables can cause significant tissue damage and promote the growth of pathogenic bacteria. In addition, if the pathogen is internalized in the product, the sanitization procedure becomes inefficient. The chemotaxis and flagellar motile processes allow microorganisms to penetrate the vegetables (Kroupitski et al., 2009).

Table 5
Count of *E. coli* of minimally processed carrots after the challenge study and sanitization

Treatments	Log $CFU.g^{-1}$	Decimal Reduction
Control + Ultrasound (US)	$7.63^{a} \pm 1.16$	-
SH + US	$5.75^{b} \pm 0.69$	1.88
PA + US	$5.28^{b} \pm 1.05$	2.35
SD + US	$4.87^{b} \pm 1.24$	2.76

[a,] Means followed by the same letter, in the same column, do not differ among themselves by the Tukey's Test at 5% significance.
Legend: SH – Sodium hypochlorite; PA – peracetic acid; SD – sodium dichloroisocyanurate.

Lower pathogen counts such as *Y. enterocolitica* and *E. coli* can be found naturally in plants. However, under appropriate conditions and sufficient time, there may be cell multiplication (Velázquez, Barbini, Escudero, Estrada, & de Guzmán, 2009), leading to the formation of biofilms. Bacteria biofilms on plant surfaces exhibit an increase in resistance to sanitizers, due to several properties including reduced diffusion, physiological changes and the production of enzymes that degrade antimicrobial compounds (Ganesh & Anand, 1998).

The interfacial tension was measured to investigate whether the sanitizer interfered with the antimicrobial action. No significant difference was observed in the interfacial tension values between the agents analyzed, with values of 61.49, 63.32, and 70.60 $Mn.m^{-1}$ for sodium hypochlorite, peracetic acid, and sodium dichloroisocyanurate, respectively. Thus, a similar wettability and penetration capacity of the sanitizer on the surface was observed for all treatments.

No significant differences were observed for the efficiency of peracetic acid and sodium dichloroisocyanurate salts when compared to sodium hypochlorite, which is the most common agent for decontamination of fruits and vegetables in food industries. Thus, from these results, we highlight these two alternatives to the use of inorganic chlorates. According to Andrade (2008), an important advantage of sodium dichloroisocyanurate is related to its stability in aqueous solution when compared to the inorganic salts, leading to a slower release of hypochlorous acid, which is the bactericidal agent and, consequently, a more significant efficiency. In addition, it reacts less in the presence of organic matter, reducing the risk of formation of compounds with harmful effects. As for peracetic acid, it is worth mentioning that it is consists of a stabilized mixture of peracetic acid, hydrogen peroxide, and acetic acid, which can be friendly to the environment. This sanitizer also stands out as being less reactive with organic matter.

Conclusion

The present study showed that the effect of ultrasound and the chemical compounds: sodium hypochlorite, sodium dichloroisocyanurate and peracetic acid was effective for the decontamination of minimally processed carrots by reducing aerobic mesophile and previously inoculated *E. coli* counts.

This study also suggests that the sanitizing agents such as peracetic acid and sodium dichloroisocyanurate may be viable and effective alternatives to the use of inorganic chloride for decontamination of food, since they are less reactive with organic matter, with no water hyperchlorination and the formation of trihalomethanes that are considered carcinogenic to humans.

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References

Andrade, N. J. (2008). *Higiene na indústria de alimentos: avaliação e controle da adesão e formação de biofilmes bacterianos*. São Paulo, SP: Varela.

Burnett, S. L., & Beuchat, L. R. (2001). Human pathogens associated with raw produce and unpasteurized juices, and difficulties in decontamination. *Journal of Industrial Microbiology Biotechnology*, *27*(2), 104-110. doi: 10.1038/sj.jim.7000199

Busscher, H. J., Weerkamp, A. H., Van Der, M. H. C., Van Pelt, A. W., De Jong, H. P., & Arends, J. (1984). Measurement of the surface free energy of bacterial cell surface and its relevance for adhesion. *Applied Environmental Microbiology*, *48*(5), 980-983.

Cao, S., Hu, Z., Pang, B., Wang, H., Xie, H., & Wu, F. (2010). Effect of ultrasound treatment on fruit decay and quality maintenance in strawberry after harvest. *Food Control, 21*(4), 529-532. doi: 10.1016/j.foodcont.2009.08.002

Fialho, J. F. Q. Jr., Naves, E. A. A., Bernardes, P. C. B., Ferreira, D. C., Anjos, L. D. dos, Gelamo, R. V.,... Andrade, N. J. (2017). Stainless steel and polyethylene surfaces functionalized with silver nanoparticles. *Food Science and Technololy International*, *24*(1), 87-94. doi: 10.1177/1082013217731414

Food and Agriculture Organization/World Health Organization (2002). *First pan-european conference on food quality and safety.* Foodborne Diseases are on the Rise. In Europe -FAO/WHO Call For Better Consumer Protection. Retrieved from http://www.fao.org/3/a-y3696e.pdf

Francisco, C. A. I., Araujo, E. A., Ferreira, D. C., Rosario, D. K. A., & Cunha, M. F. (2017). Synergistic effect of sodium hypochlorite and ultrasound bath in the decontamination of fresh arugulas. *Journal of Food Safety*, *38*(1), 12391e. doi: 10.1111/jfs.12391

Ganesh, K. C., & Anand, S. K. (1998). Significance of microbial biofilms in food industry: a review. *International Journal of Food Microbiology*, *42*(1-2), 9-27. doi: 10.1016/s0168-1605(98)00060-9

Gani, A., Baba, W. N., Ahmad, M., Shah, U., Khan, A. A., Wani, I. A.,… Gani. A. (2016). Effect of ultrasound treatment on physico-chemical, nutraceutical and microbial quality of strawberry. *LWT - Food Science and Technology*, *66*, 496-502. doi: 10.1016/j.lwt.2015.10.067

Gil, M. I., Selma, M. V., López-Galvez, F., & Allende, A. (2009). Fresh-cut product sanitation and wash water disinfection: problems and solutions. *International Journal of Food Microbiology*, *134*(1-2), 37-45. doi: 10.1016/j.ijfoodmicro.2009.05.021

Glowacz, M., Mogren, L. M., Reade, J. P. H., Cobb, A. H., & Monaghan, J. M. (2013). Can hot water treatments enhance or maintain postharvest quality of spinach leaves? *Postharvest Biology Technology*, *81*, 23-28. doi: 10.1016.j.postharvbio.2013.02.004

Gogate, P. R., & Kabadi, A. M. (2009). A review of application of cavitation in biochemical engineering/ biotechnology. *Biochemical Engineering Journal, 44*(1), 60-72. doi: 10.1016/j.bej.2008. 10.006

Havelaar, A. H., Kirk, M. D., Torgerson, P. R., Gibb, H. J., Hald, T., Lake, R. J.,… Devleesschauwer, B. (2015). World health organization global estimates and regional comparisons of the burden of foodborne disease in 2010. *PLoS Med*icine, *12*(12), e1001923. doi: 10.1371/journal.pmed.1001923

Kim, H., & Song, K. B. (2017). Combined treatment with chlorine dioxide gas, fumaric acid, and ultraviolet-C light for inactivating Escherichia coli 0157:H7 and Listeria monocytogenes inoculated on plums. *Food Control, 71*, 371-375. doi: 10.1016/j. foodcont.2016.07.022

Kroupitski, Y., Golberg, D., Belausov, E., Pinto, R., Swartzberg, D., Granot, D., & Sela, S. (2009). Internalization of Salmonella enterica in leaves is induced by light nd involves chemotaxis and penetration through open stomata. *Applied Environmental Microbiology*, *75*(19), 6076-6086. doi: 10.1128/AEM.01084-09

Ma, L., Zhang, M., Bhandari, B., & Gao, Z. (2017). Recent developments in novel shelf life extension technologies of fresh-cut fruits and vegetables. *Trends in Food Science and Technology*, *64,* 23-38. doi: 10.1016/j.tifs.2017.03.005

Michaels, B., Gangar, V., Schattenberg, H., Blevins, M., & Ayers, T. (2003). Effectiveness of cleaning methodologies used for removal of physical, chemical and microbiological residues from produce. *Food Service Technology*, *3*(1), 9-15. doi: 10.1046/j.1471-5740.2003.00063.x

Ministério da Saúde (2005). *Vigilância epidemiológica das doenças transmitidas por alimentos no Brasi*l, *1999 - 2004.* Brasília: Secretaria de Vigilância em Saúde. (Boletim Eletrônico Epidemiológico, ano 5, 6). Recuperado de http://bvsms.saude.gov.br/bvs/periodicos/boletim_eletronico_epi_ano05_n06.pdf

Moretti, C. V. (2008). *Encontro nacional sobre processamento mínimo de frutas e hortaliças*. Lavras, MG: UFLA.

Park, E. J., Alexander, E., Taylor, G. A., Costa, R., & Kang, D. H. (2009). The decontaminative effects of acidic electrolyzed water for *Escherichia coli* O157:H7, *Salmonella Typhimurium*, and *Listeria monocytogenes* on green onions and tomatoes with differing organic demands. *Food Microbiology*, *26* (4), 386-390. doi: 10.1016/j.fm.2008.10.013

Rastogi, N. (2011). Opportunities and challenges in application of ultrasound in food processing. *Critical Reviews in Food Science and Nutrition, 51*(8), 705-722. doi: 10.1080/10408391003770583

Ruíz-Cruz, S., Félix, E. A., Cinco, M. D., Osuna, M., & Aguilar, G. (2007). Efficacy of sanitizers in reducing *Escherichia coli* O157:H7, *Salmonella* spp. and *Listeria monocytogenes* populations on fresh-cut carrots. *Food Control, 18*(11), 1383-1390. doi: 10.1016/j.foodcont.2006.09.008

São José, J. F. B. (2017). Estratégias alternativas na higienização de frutas e hortaliças. *Revista de Ciências Agrárias*, *40*(3), 630-640. doi: 10.19084/RCA16124

São José, J. F. B., & Vanetti, M. C. D. (2012). Effect of ultrasound and commercial sanitizers on natural microbiota and *Salmonella enterica* Typhimurium on cherry tomatoes. *Food Control, 24*(1-2), 95-99. doi: 10.1016/j.foodcont.2011.09.008

Selma, M. V., Ibañez, A. M., Allende, A., Cantwella, M., & Suslow, T. (2008). Effect of gaseous ozone and hot water on microbial and sensory quality of cantaloupe and potential transference of *Escherichia coli* O157:H7 during cutting. *Food Microbiology*, *25*(1), 162-168. doi: 10.1016/j.fm.2007.06.003

Strevett, K. A., & Chen, G. (2003). Microbial surface thermodynamics and applications. *Research in Microbiology*, *154*(5), 329-335. doi: 10.1016/S0923-2508(03)00038-X

Van Oss, C. J. (1994). *Interfacial forces in aqueous media*. New York, NY: Marcel Dekker, Inc.

Van Oss, C. J., & Giese, R. F. (1995). The hydrophilicity and hydrophobicity of clay minerals. *Clays and Clay Minerals*, 43, (4) 474-477. doi: 10.1346/CCMN.1995.0430411

Velázquez, L. C., Barbini, M. B., Escudero, E., Estrada, C. L., & Guzmán, M. S. de. (2009). Evaluation of chlorine, benzalkonium chloride and lactic acid as sanitizers for reducing *Escherichia coli* O157:H7 and *Yersinia enterocolitica* on fresh vegetables. *Food Control*, *20*(3), 262-268. doi: 10.1016/j.foodcont.2008.05.012

Vieira, J. V. (2008). *Cenoura (Daucus carota). Importância econômica*. Brasília, BR: EMBRAPA Hortaliças, Sistemas de Produção, 5. Recuperado de https://sistemasdeproducao.cnptia.embrapa.br/FontesHTML/ Cenoura/Cenoura_Daucus_Carota/importancia_economica.html