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The Effect of Various Preparation Methods on the Spoilage Rate of Roma Tomatoes *(Solanum lycopersicum)*

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Summary

As levels of food waste continue to rise, it is essential to find improved techniques of prolonging the shelf life of produce. This study aimed to find a simple, yet effective, method of slowing down spoilage in tomatoes. Roma tomatoes were soaked in water, salt water, bleach solution, vinegar solution, or vegetable oil. One half of the tomatoes washed in each solution were dried, while the rest were not. The tomatoes were then stored in individual plastic containers for 14 days and scored each day on a semi-quantitative scale that measured spoilage. While we originally hypothesized that the bleach treatment with drying would perform the best, soaking the tomatoes in salt water and leaving them undried resulted in the least spoilage over time. The salt water undried group had an average spoilage score of 7 out of 20 by the end of the first iteration and 4.3 out of 20 by the end of the second. These scores were both the lowest in their respective rounds of the experiment, demonstrating significantly reduced spoilage compared to the control. Linear regression analysis revealed that the salt water undried tomatoes displayed the lowest correlation between time and spoilage, confirming that this preparation was the most effective. Additionally, bacterial counts from the second iteration revealed that higher bacterial levels did not correlate to more visible spoilage. In conclusion, application of a simple 1% salt water solution to tomatoes could significantly extend their shelf life and thus reduce waste.

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Introduction

Food wastage is becoming an increasingly critical problem in the world today. Around 70 billion pounds of food in the United States are thrown away every year (1). This is especially staggering when taking into account the fact that 1 in 8 Americans experience food insecurity (2). Furthermore, wasted food makes up large portions of U.S. landfills, which in turn emit high levels of methane, one of the strongest greenhouse gases (1). One of the root causes of this problem is spoilage (3). Therefore, finding better methods of extending the shelf life of produce is a vital step in the efforts against global warming as well as hunger.

We conducted an experiment to determine what method of washing tomatoes would result in the least spoilage over time. Spoilage is the process in which food deteriorates and becomes inedible. This often occurs because of the growth of microorganisms, specifically mold and bacteria (4). Tomatoes were chosen because they are a common produce item in households across the U.S. (5) and also have clear indicators of spoilage. As a result of spoiling, tomatoes will often bruise and their skin will turn black or brown. Mold and wrinkles are common visual indicators that a tomato has begun to decay. The goal of this study was to discover a better method of extending the shelf life of tomatoes in efforts to reduce their wastage.

Past studies have shed light on certain preparation methods that may be effective in slowing down produce spoilage. An experiment reported in 2007 by *Cook's Illustrated* examined which methods of cleaning fresh produce eliminated the most bacteria (6). The article compared four different methods of cleaning apples and pears: using antibacterial soap, a vinegar solution, water, and scrubbing. After preparation, the fruits were swabbed with sterile Q-tips, which were then rubbed onto Petri dishes. Following incubation at 80°F for several days, the dishes were examined for bacterial growth. The vinegar solution was ultimately the most effective method of cleaning the fruit, as it eliminated 98% of the bacteria. These results demonstrated the antiseptic properties of vinegar, suggesting that it may also be effective in delaying spoilage.

S. P. Guleriato and R. M. Wijewardane examined the effect of surface coating with various concentrations of neem oil and marigold flower on the quality of freshly harvested Royal Delicious apples in 2013 (7). In addition, these surface coatings were coupled with pre-cooling—the rapid removal of heat from freshly harvested produce—and the spoilage rates of the apples were measured. The results showed that the combination of

Figure 1. Representative tomatoes from Day 14 of the first iteration. (A) The salt water undried tomato showed very minimal signs of spoilage, with a total score of 7. (B) The oil dried tomato showed mild signs of spoilage, as it had a total score of 12, with 3 points in each of the four categories. (C) The control tomato was significantly spoiled, as it had a score of 20, the maximum that could be attained.

a 1.5–2% concentration of neem oil with pre-cooling was the most successful treatment. Collectively, this data suggested that oil coatings could be effective in retarding the spoilage of produce.

The hypothesis in our study was that soaking the tomatoes in the mild bleach solution and then drying them would be the most effective method to slow down spoilage. This is because bleach is known as a universal disinfectant and was likely more antiseptic than the other solutions (8). In addition, the dried tomatoes were expected to spoil more slowly than the undried tomatoes due to the fact that excess moisture can boost microbial growth, accelerating spoilage (9).

Results

Two iterations of this experiment were performed. In the first iteration, tomatoes were divided into five groups of six tomatoes each based on the solution that they were soaked in: either water, salt water, vinegar, bleach, or vegetable oil. Half of the tomatoes in each group were dried after being washed, while the other three tomatoes were left undried. The control group consisted of three tomatoes that were not soaked in any solution. The tomatoes were stored and examined for two weeks total. Starting on the sixth day, they were scored based on a semi-quantitative spoilage scale (**Table 1**) in order to determine which method of preparation was the most effective. The maximum total score that a tomato could achieve was 20. A score of 16 or above was considered "spoiled" (**Figure 1**). All other factors in the experiment, including temperature, humidity, and light were kept constant.

The salt water undried preparation was the most successful in retarding spoilage. At Day 14, the salt water undried tomatoes had the lowest average spoilage score (**Figure 2**). Linear regression analysis confirmed the effectiveness of the salt water undried preparation. The spoilage score of the control tomatoes increased with the number of days in a highly correlated manner (**Figure 3A**). This confirmed that for a tomato left alone under the experimental conditions, spoilage does increase with time. There was less correlation between spoilage and time for the salt water undried tomatoes compared to the control (**Figure 3B**). Instead of steadily increasing in a linear fashion, the data points on the salt water plot remain at the same spoilage score for several days. This result indicates that the salt water undried preparation allowed the tomatoes to spoil at a much slower rate than they otherwise would.

	1	2	3	4	5
Mold	**None**	**Minimal** (just around stem; less visible)	**Mild** (around or slightly past stem; more intense)	**Moderate** (well past stem; bushy)	**Severe** (well past stem or in multiple parts of the tomato; extremely severe)
Damage to Skin	**None**	**Minimal** (stem is barely damaged; skin peeling back)	**Mild** (more intense scratches or bruises; just around stem)	**Moderate** (scratches or bruises around tomato or past stem)	**Severe** (many bruises or scratches all over tomato)
Discoloration	**None**	**Minimal** (whiteness around stem)	**Mild** (patches of grey, black, or white around stem)	**Moderate** (patches of grey, black or white around the tomato or past stem)	**Severe** (patches of grey, black or white all over tomato)
Wrinkles	**None**	**Minimal** (some around stem; barely visible)	**Mild** (around stem; more visible)	**Moderate** (visible and located around tomato or well past stem)	**Severe** (completely wrinkled and soft)

Table 1. Scoring parameters for tomato spoilage.

The water undried, salt water dried, and bleach dried groups also had relatively low spoilage scores, while oil dried and the control were the highest scoring groups.

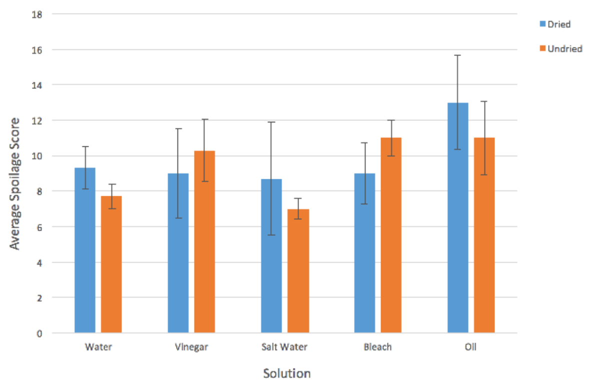

Figure 2. Effect of post-wash drying on each group's average spoilage score by Day 14 of the first experimental iteration. Error bars represent the standard error of mean within each group.

Furthermore, not drying the tomatoes after soaking them resulted in less spoilage for three out of the five solutions used (**Figure 2**). The average spoilage score of all dried groups was 9.8, while it was 9.4 for the undried groups. Overall, the difference between the dried and undried groups was not statistically significant ($P = 0.74$, t-test). In both dried and undried conditions, salt water was the most effective solution for reducing spoilage over time. Tomatoes soaked in water, vinegar solution, and bleach solution were less spoiled than controls (**Table 2**). On the other hand, oil was the only solution that seemed to accelerate spoilage (**Table 2**). Over the course of the two weeks, the tomatoes soaked in oil spoiled at a significantly more rapid rate than those from the salt water group (**Figure 4**). To verify this observation, both the salt water and oil tomatoes were plotted in a power regression graph, as both groups had a higher correlation in this type of model than in a linear or exponential model. The line of best fit for the salt water power regression plot was $y=5.468(x^{0.142})$, while the line of best fit for the oil plot was $y=4.639(x^{0.444})$. These

Solution	Average Spoilage Score
Control	11.0
Water	8.5
Vinegar	9.7
Salt water	7.8
Bleach	10.0
Oil	12.0

Table 2. Effect of various solutions on each group's average spoilage score by Day 14 of the first iteration. The scores of the dried and undried components of each solution are averaged.

equations demonstrate that the salt water tomatoes, with a growth factor of 0.142, spoiled at a significantly slower rate than the oil tomatoes, which had a growth factor of 0.444.

We performed a second iteration of the experiment to verify our conclusions from the first iteration regarding the most effective methods of preparation. In the second iteration, only three experimental groups were used: salt water undried, bleach undried, and water undried. The salt water undried and water undried groups were chosen because of their success in the first round. Meanwhile, the bleach solution was used again to confirm its limited effect on spoilage. The oil preparation was not included due to the fact that it was the only preparation that, on average, accelerated spoilage in the first iteration. Furthermore, only undried groups were tested for two reasons. First, the two most successful groups in the first iteration were undried. Second, the results from the first iteration demonstrated that soaking

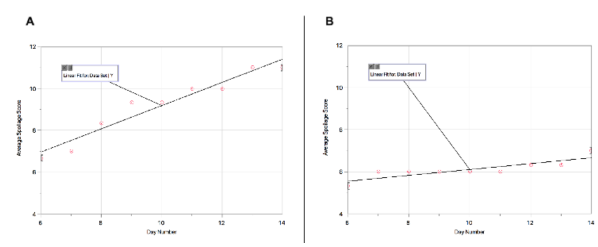

Figure 3. (A) Linear regression plot for control tomatoes from the first iteration. This plot had a slope of 0.56 and a correlation of 0.97. (B) Linear regression plot for salt water undried tomatoes from the first iteration. This plot had a slope of 0.14 and a correlation of 0.86. Therefore, there was less of a correlation between spoilage and time for the salt water undried tomatoes compared to the control tomatoes.

the tomatoes in different solutions had a greater impact on their spoilage than whether or not they were dried. Therefore, using three undried groups in the second iteration allowed us to focus only on how different solutions affected spoilage. Unlike the first round of the experiment, we used PetriFilms on Day 14 of the second iteration to determine the bacterial counts on the stems of the tomatoes.

The salt water undried preparation was once again the most effective in slowing down spoilage. Tomatoes in the salt water undried group showed less spoilage than both the control and the other experimental groups. Meanwhile, bleach undried was the second most successful preparation, while water undried was the least successful (**Table 3**). This contrasted from the results of the previous iteration in which the water undried tomatoes had the second-lowest spoilage

Group	Average Spoilage Score
Control	6
Water undried	6.3
Salt water undried	4.3
Bleach undried	5.3

Table 3. Effect of various preparation methods on each group's average spoilage score by Day 14 of the second iteration.

score (**Figure 2**). All in all, however, the tomatoes in this iteration demonstrated much less spoilage across the board than those in the first iteration.

Bacterial counts on the PetriFilms revealed that the salt water undried tomatoes had by far the most bacterial colonies on average of all the groups. On the other hand, the control group actually had the fewest colonies: only around 21 colonies compared to the salt water group's 82 colonies (**Figure 5**).

Discussion

This experiment was performed in order to determine the most effective method of slowing down spoilage in tomatoes. We originally hypothesized that the bleach dried group would be the most successful due to bleach's antiseptic properties, and because drying would remove excess moisture. The results, however, negated this hypothesis. Instead, they demonstrated that the salt water undried preparation was the most effective inhibitor of spoilage. In both iterations, the salt water undried group had the lowest average spoilage score. The bleach dried group performed better than the majority of the other groups, but was still not the most successful. Bleach was less effective than salt water and vinegar (**Table 2**), suggesting that antiseptic properties alone might not be sufficient to significantly retard spoilage. An alternative explanation could be that the concentration of bleach used – 2% – was too low to be effective. This may especially be true because bleach can easily be neutralized by organic material (8). Therefore, a higher concentration such as 20% likely would have been more successful in eliminating microbial growth and retarding the spoilage of the tomatoes. However, a low concentration was ultimately used because it was important for the tomatoes to be consumable afterwards. Another significant finding was that the effects of drying or not drying the tomatoes after soaking were not conclusive enough to recommend one method over the other, as seen from iteration 1 of the experiment.

The salt water undried preparation did the best job of inhibiting spoilage, possibly because salt water dehydrated the tomatoes slightly, creating conditions unfavorable for the growth of mold. Because the tomatoes were not dried after soaking, their skin may have better absorbed the salt. Salt water, being hypertonic to the tomatoes, likely caused them to lose water through osmosis (10). This resulted in a reduction of the tomatoes' water activity (a_w), or the amount of free water molecules inside of them (10). Most produce items have high a_w levels of around 0.97-1.00, which is the ideal condition for many microbes and molds to thrive in (9). As a result, the salt water solution may have been successful in limiting spoilage by decreasing the tomatoes' a_w levels, making them less suitable for the growth of mold. On the other hand, the bleach and vinegar solutions, as well as plain water, were likely unable to have the same effect because they caused little to no moisture loss in the tomatoes.

With reduced levels of mold on the surface of the salt water undried tomatoes, more bacteria may have been able to thrive on them instead. Competition between bacteria and fungi often occurs in a variety of environments (11). While the salt water concentration used — 1% — seemed to be high enough to eliminate most mold, certain species of bacteria may have been able to survive in lower a_w levels. With mold unable to thrive on the tomatoes, these bacteria may have been able to dominate instead, which would explain why the most bacterial colonies were found on the salt water undried PetriFilms. Furthermore, while it was initially thought that more bacteria would correspond to a shorter shelf life, it is possible that mold or other factors had to first compromise the skin of the tomatoes before bacteria could actually begin to boost spoilage. This could be why, despite the high levels of bacteria, the salt water undried tomatoes experienced significantly reduced levels of spoilage.

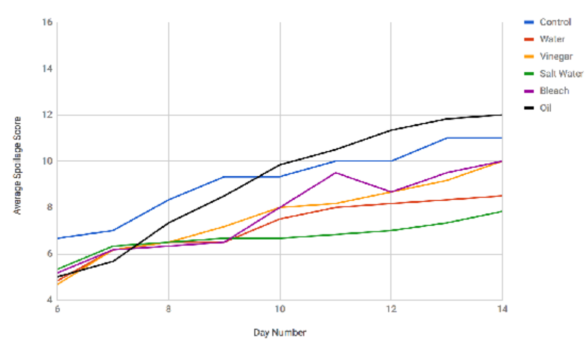

Figure 4. Spoilage over time for tomatoes washed in each solution from the first iteration. Quantitative data was collected starting on the sixth day, as minimal spoilage was observed up until that point.

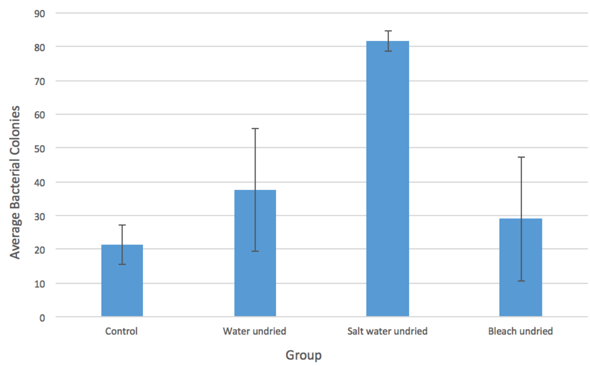

Figure 5. Average number of bacterial colonies present on the stems of the tomatoes on Day 14 of the second iteration. Error bars represent the standard error of mean within each group.

In the second iteration, the control, bleach undried, and water undried groups all spoiled more rapidly than the salt water undried group; however, they also had much lower bacterial counts. The control tomatoes may have had fewer bacterial colonies because their pesticides were not removed or washed off. Likewise, the plain water may have been effective in destroying bacteria because of its chlorine, which was at a concentration of approximately 4 mg/L (12). Chlorine kills a significant number of pathogens in tap water (13) and thus may have been responsible for Water undried tomatoes having the lowest bacterial levels in the second iteration. In future experiments, chlorine concentrations in the water could be controlled to demonstrate how chlorine's antiseptic properties affect spoilage. Another possible explanation for the reduced levels of bacteria on the Water undried tomatoes could be that increased moisture from the water promoted the growth of mold. Although most bacteria also thrive in high a_w levels (9), it is possible that in the presence of mold, fewer bacteria were able to survive due to competition between the two. Finally, bleach was the second most successful solution in this round and also had low bacterial counts, most likely because it was effective in killing both bacteria and mold. However, the 2% bleach solution may not have been concentrated enough, which could explain why it still fared worse than the salt water.

There were several possible sources of error that could have influenced the outcome of this experiment. First, there was difficulty in standardizing the contact of the PetriFilms with the tomatoes. The duration of this contact and the pressure with which the films were held to the tomatoes likely differed, perhaps resulting in variability in bacterial counts within the groups. Another source of error could have occurred while counting the bacterial colonies on the PetriFilms. Some of the bacterial colonies were extremely small and bunched together, making it difficult to identify and differentiate between them. As a result, this likely caused the number of bacterial colonies that were counted to differ from the actual number. Finally, the scale that was used to score the spoilage of the tomatoes was only semi-quantitative and was largely based on judgment. This was an inherent flaw of the experiment; however, there was no viable alternative due to the fact that spoilage cannot be fully quantified.

This experiment raised multiple questions for further investigation. One of these questions was how varying concentrations of salt water will affect the spoilage of tomatoes. Although it is clear that salt water was the most effective solution for slowing down spoilage, only a 1% concentration was used. It would be interesting to see how a higher concentration, such as 10%, would perform, especially in terms of eliminating bacteria. Additionally, in future experiments, a more consistent bacterial count could be achieved by homogenizing all three tomatoes from each group separately in a blender and adding 1 mL of the resulting mixture to each PetriFilm. The bacteria on each individual tomato could then be counted to determine variation between the groups. Finally, another area that could be examined more deeply is the relationship between bacteria and mold in facilitating spoilage. The results showed that it is possible to have high bacterial counts but low levels of mold and spoilage, however there is no definitive answer for why this was the case.

All in all, this experiment demonstrated that there is a simple and chemical-free method of extending the shelf life of tomatoes: soaking them in a 1% salt water solution for about five minutes and leaving them undried. This is a simple process that can easily be performed and it significantly reduces the spoilage rate of tomatoes, thereby reducing waste, as well. In addition, a salt water bath may even be preferable to refrigeration, which, despite being a popular method of preserving tomatoes, alters their taste and texture, making it less preferable than alternatives.

Materials and Methods

Nine small holes were poked into the lids of thirty-three 16 oz plastic containers. Small nails were heated over a stove flame on medium heat, and were then used to pierce the container lids. The nail was re-heated when it cooled off. For each lid, eight holes were poked evenly in a circle around the edge and one was poked in the center. The containers were stored in a basement with a temperature of around 21°C and a humidity of 28%.

Three non-organic Roma tomatoes were placed individually into the control group containers. Plastic gloves were used whenever handling the tomatoes.

Because these tomatoes were not washed in any of the solutions, they were used as the control. The remaining tomatoes belonging to the experimental groups were washed in various solutions. For the water, vinegar, salt water, and bleach solutions, six tomatoes were soaked in a basin filled with the respective solution for a total of five minutes. During the last two minutes of this period, the tomatoes were gently swished around and rubbed. After soaking, three of the six tomatoes were completely dried with paper towels and placed into their respective containers. The other three were directly placed into their containers without any drying. This process was carried out for each solution. All of the solutions were prepared in a large basin, which was rinsed after each use. The vinegar solution was composed of distilled white vinegar mixed with tap water in a 1:4 ratio. The salt water solution was composed of three teaspoons of iodized salt mixed with six cups of water. The bleach solution was made up of 40 mL of Clorox bleach mixed with 1,960 mL of water, creating a 2% bleach concentration.

Finally, a small amount of vegetable oil was used to fill the bottom of the basin. The tomatoes were rolled around in the oil one-by-one. After they were thoroughly coated, three of the tomatoes were placed directly into their containers, while the other three were lightly dried so that the oil formed only a thin coating. After all 33 tomatoes were in their containers, the lids were securely closed. The tomatoes would remain in their containers for a duration of 14 days. During this period, the lights of the basement were turned on every day at about 7 am and turned off around 7 pm.

The tomatoes were observed and data was collected over the duration of 14 days. For the first six days, data was collected qualitatively. The general appearance and smell of the tomatoes were noted. Quantitative data was not yet collected because the majority of the tomatoes showed almost no signs of spoilage during this period. After Day 5, however, a scale was created that semi-quantitatively measured the spoilage of the tomatoes in terms of mold, skin damage, discoloration, and wrinkles. For each of these categories, the tomatoes were evaluated on a scale of one to five. Each day starting on Day 6, the tomatoes were examined and scored based on this scale. If the sum of a tomato's scores in all of these categories was 16 or above, it was considered "spoiled."

The experiment was concluded on Day 14. To better analyze the effect of each solution, an average group score was calculated. On the last day of the second iteration, the bacterial counts of the tomatoes were collected using 3M PetriFilms. Around 1 mL of purified water was applied to the PetriFilms before they were pressed onto the stem of each tomato for several seconds. The PetriFilms were left in the basement to incubate for two days, after which the bacterial colonies were counted.

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References

1. "Fighting Food Waste With Food Rescue." Feeding America, 2017, www.feedingamerica.org/about-us/how-we-work/securing-meals/reducing-food-waste.html. Accessed 28 Mar. 2017.
2. Feeding America, 2017, http://www.feedingamerica.org. Accessed 13 Feb. 2017.
3. Flick L. "America's $165 billion food-waste problem." CNBC, 22 April 2015, http://www.cnbc.com/2015/04/22/americas-165-billion-food-waste-problem.html. Accessed 21 Feb. 2017.
4. Rawat S. "Food Spoilage: Microorganisms and their prevention." Asian Journal of Plant Science and Research, 5.4 (2015) 47-56.
5. Lucier G, Lin BH, Allshouse J, Kantor LS. "Factors Affecting Tomato Consumption in the United States." Economic Research Service/USDA (2000), http://usda.mannlib.cornell.edu/usda/ers/VGS//2000s/2000/VGS-11-16-2000.pdf.
6. Allison A. "What Does it Take to Clean Fresh Food?" NPR Morning Edition (2007), http://www.npr.org/templates/story/story.php?storyId=14540742.
7. Wijewardane RM, Anuruddika N, Guleria SPS. "Effect of Pre-Cooling, Fruit Coating and Packaging on Postharvest Quality of Apple." Journal of Food Science and Technology 50.2 (2013): 325–31.
8. World Health Organization. "Annex G, Use of disinfectants: alcohol and bleach." Infection Prevention and Control of Epidemic- and Pandemic-Prone Acute Respiratory Infections in Health Care. Geneva: WHO Press, 2014. www.ncbi.nlm.nih.gov/books/NBK214356/.
9. he Institute of Food Technology and the Food and Drug Administration of the United States Department of Health and Human Services. "Evaluation and Definition of Potentially Hazardous Foods." Comprehensive Reviews in Food Science and Food Safety, (2003) 50: 21-2.
10. Parish M. "How Do Salt and Sugar Prevent Microbial Spoilage?" Scientific American, 2006. www.scientificamerican.com/article/how-do-salt-and-sugar-pre/.

11. Frey-Klett P, et al. "Bacterial-Fungal Interactions: Hyphens between Agricultural, Clinical, Environmental, and Food Microbiologists." American Society for Microbiology 75.4 (2011) 583:609. mmbr.asm.org/content/75/4/583.full.
12. Environmental Protection Agency. "What Are EPA's Drinking Water Regulations for Disinfectants like Chlorine?" EPA, safewater.zendesk.com/hc/en-us/articles/211403178-2-What-are-EPA-s-drinking-water-regulations-for-disinfectants-like-chlorine-.
13. Calomiris JJ and Christman KA. "How Does Chlorine Added to Drinking Water Kill Bacteria and Other Harmful Organisms? Why Doesn't It Harm Us?" Scientific American, 1998. www.scientificamerican.com/article/how-does-chlorine-added-t/#.