The Role of Crop Production Practices and Weather Conditions in Microbiological Safety of Tomatoes and Peppers[1]

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Over the last decade, fruits, vegetables, and nuts were among the foods often linked to gastroenteritis outbreaks caused by enterovirulent strains of *E. coli* and non-typhoidal *Salmonella*, resulting in thousands of hospitalizations and multi-million dollar losses to the food-crop industry. Since 2006, at least sixteen salmonellosis outbreaks have been linked to the consumption of tomatoes, cantaloupes, sprouts, cucumbers, mangoes, pine nuts, pistachios, peanut butter, papayas, and peppers as well as mixed, frozen, and processed foods containing plant products. This fact sheet was produced to provide up-to-date information about tomato production practices and their relationships with *Salmonella*. This information should be useful for county UF/IFAS Extension agents in their vegetable education programs.

Salmonella and other human pathogens can contaminate produce at any stage of the production cycle, "farm to fork." The interpretation of data on persistence of human pathogens, such as *Salmonella* and pathogenic *E. coli*, under the field conditions remains controversial. Human pathogens, such as non-typhoidal *Salmonella*, have been isolated rarely but consistently from fields and field-grown plants (Greene et al. 2008). Once deposited in the field with animal excretions or improperly processed manure, for example, they can persist for extended periods of time in the root zone or even within plant tissues. However, when avirulent (i.e., not disease-inducing) *Salmonella* or *E. coli* surrogates were artificially introduced onto crops in large-scale field studies, recovery of culturable pathogens declined over time (Gutierrez-Rodriguez et al. 2012; Islam et al. 2004; Lopez-Velasco et al. 2012). Collectively, these observations suggest that under some environmental conditions ("perfect storm"), human pathogens can persist in the crop production environment and contaminate crops. It is unclear to what extent the environmental and crop production factors contribute to the "perfect storm." A better understanding of the role of production practices in susceptibility of crops to human pathogens pre- and post-harvest could eventually result in a significant reduction of the number and/or severity of the produce-associated outbreaks.

Figure 1. Tomato plants in the field at the UF/IFAS Research and Education Center in Citra, Florida, are subjected to different irrigation and fertilization regimens.
Credits: Max Teplitski, UF/IFAS

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To that end, several recent studies focused on the impact of crop production practices (nitrogen [N] fertilization, potassium [K] fertilization, and irrigation levels) on post-harvest susceptibility of tomatoes to infections with *Salmonella* (Marvasi, George, et al. 2014; Marvasi, Hochmuth et al. 2013). The rationale for these studies was based on the published reports indicating that plant nitrogen status and levels of irrigation affect susceptibility of crops to phytopathogens (i.e., pathogens harmful to plants). Even though *Salmonella* is not considered to be a plant pathogen, it is reasonable to consider the possibility that varying levels of irrigation and N and/or K fertilization would affect how this bacterium interacts with plants. Furthermore, over-irrigation can lead to fruit water congestion (i.e., an excess of water inside the fruit that can result in a tendency to bruise more easily) or lead to the development of fruit surface cracking. Both water congestion and cracks can favor proliferation of *Salmonella* in tomatoes. Water stress is known to alter plant defenses, including those that limit human pathogens in plants. Over-irrigation can also promote growth of phytophathogens, and this indirectly may favor an increase in growth of human pathogens (Brandl, Cox, and Teplitski 2013).

In studies conducted over three production seasons in north and central Florida, irrigation regimes (soil moisture targets were 6%, 10%, and 12% volumetric water content) did not have an overall significant effect on the susceptibility of mature or immature tomatoes to post-harvest proliferation of *Salmonella*. However, some tomato varieties displayed increased post-harvest susceptibility to *Salmonella* as a result of differences in the irrigation regime, and these differences were even more pronounced under different harvest conditions (Marvasi, Hochmuth, et al. 2013). However, when tomatoes were water-congested artificially, an increase in proliferation of *Salmonella* was observed. Even though none of the field-tested irrigation regimes led to fruit water congestion, production conditions or post-harvest treatments that cause water congestion could increase the proliferation of the pathogen within tomatoes (Marvasi, Hochmuth, et al. 2013).

In the fertilization study, levels of N and K were 168, 224, and 280 kg/ha N and total-season K treatments were 168, 252, and 336 kg/ha as K_2O. Varying levels of N or K fertilization (either alone or combined) did not affect overall susceptibility of tomatoes to *Salmonella* (Marvasi, George, et al. 2014). However, different tomato varieties responded differently to varying levels of fertilization and displayed varying levels of susceptibility to *Salmonella*, especially when harvested at different maturity stages (Marvasi, George, et al. 2014). A correlation between tissue levels of N and susceptibility to *Salmonella* were observed for partially ripened tomatoes of tomato cultivar (cv.) Solar Fire, but not cv. Sebring, even though both varieties accumulated more N in their vegetative tissues in response to the increase in N supplied with the fertilizer treatment (Marvasi, George, et al. 2014). The mechanism behind this observation is not yet known; however, it has been reported that tomato varieties responded to varying levels of N nutrition by producing different levels of flavonoids and related phenolics (compounds with functions in responses to plant pathogens) (Larbat et al. 2012).

Season-to-season variability in the susceptibility of crops to colonization by *Salmonella* and enterohemorrhagic *E. coli* pre- and post-harvest appear to be the strongest (Gutierrez-Rodriguez et al. 2012; Marvasi, George, et al. 2014; Marvasi, Hochmuth, et al. 2013). Weather conditions within a month prior to tomato harvests appear to have an important effect on post-harvest susceptibility of tomatoes to *Salmonella* (Marvasi, George, et al. 2014; Marvasi, Hochmuth, et al. 2013). Tomatoes harvested in the sunniest, driest seasons were most susceptible to *Salmonella* post-harvest (Marvasi, George, et al. 2014; Marvasi, Hochmuth, et al. 2013). Cold stress within a day of harvest (drop in temperature to 1.6°C) also appears to have increased post-harvest susceptibility to *Salmonella*.

Previous studies have clearly demonstrated that *Salmonella* proliferates to significantly higher numbers in the presence of plant pathogens or plant lesions (Brandl, Cox, and Teplitski 2013). However, tomatoes with obvious signs of plant disease lesions are likely to be discarded prior to reaching the consumers. Curiously, in our studies, there was a statistically significant trend suggesting that blemish-free tomatoes harvested from plants with the most severe disease (bacterial leaf spot) symptoms were less conducive to the proliferation of *Salmonella*. The severity of viral symptoms did not correlate strongly with the increased susceptibility of the fruit to *Salmonella*.

The mechanism responsible for this observed effect is not yet clear. There are at least two possibilities: (1) blemish-free fruits from otherwise diseased plants may contain elevated levels of plant defense compounds, which may reduce proliferation of *Salmonella*; and (2) asymptomatic fruits may contain microorganisms that are hostile to the proliferation of this pathogen. The synergistic and antagonistic effects of these potentially beneficial, normally occurring microbes on proliferation of human pathogens are well documented (Brandl, Cox, and Teplitski 2013; Poza-Carrion, Suslow, and Lindow 2013).

Conclusions

None of the tested production practices (varying levels of irrigation or N and K fertilization) had a strong overall effect on post-harvest susceptibility of tomatoes to *Salmonella* contamination; however, individual tomato cultivars varied in susceptibility to *Salmonella* depending on these production conditions. Environmental conditions (dry, sunny) within a month prior to harvest and/or cold stress at harvest may predispose tomatoes to post-harvest susceptibility to *Salmonella*.

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