DEVELOPMENT AND VALIDATION OF A MATHEMATICAL MODEL FOR GROWTH OF SALMONELLA IN CANTALOUPE

by

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ABSTRACT OF THE THESIS

Development and Validation of a Mathematical Model for Growth of *Salmonella* in Cantaloupe

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The United States is the largest importer of cantaloupes worldwide and domestic consumption of cantaloupe has been increasing steadily. Many salmonellosis outbreaks associated with the consumption of fresh-cut melons have also been reported. Cut melon pieces were most often contaminated due to poor hygienic practices and suffered temperature abuse.

The objective of our research was to develop and validate a mathematical model that predicts the growth rate of *Salmonella* on fresh-cut cantaloupe over a range of storage temperatures. Bacterial growth experiments were conducted, and growth curves were constructed for five temperatures from 4 to 25°C. Exponential growth rates of *Salmonella* were calculated using DMFit software. The Ratkowsky or square root model was used to describe *Salmonella* growth rate as a function of storage temperature.

Our results show that the levels of *Salmonella* on fresh-cut cantaloupe with an initial load of ~10^3 CFU/g can reach over 7 log CFU/g at 25°C within 24h. No growth was

observed at 4°C. A linear correlation was observed between *Salmonella* growth rate vs. temperature: $\sqrt{Growth\ Rate} = 0.026 \times (T - 5.613)$, R^2= 0.9779. The model was validated with data collected from experiments conducted with other melon and pathogen combinations and compared with existing models. Our model is consistent with predictions from the ComBase Predictor model. Our research confirms that *Salmonella* can grow quickly and reach high concentrations when cut cantaloupe is stored at ambient temperatures without visual signs of spoilage.

Our model provides a faster and more cost-effective alternative to laboratory studies to estimate the effects of storage temperature on cantaloupe safety and can also be used in subsequent quantitative microbial risk assessments.

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1. INTRODUCTION

Fruit and vegetable consumption has increased in recent years because of the nutritional value and health benefits of such foods. Foodborne illness outbreaks associated with the consumption of contaminated fresh produce has also been reported over the same time period (*34*). Cantaloupe is one of the most popular melons consumed in the United States. The per capita consumption of cantaloupe increased more than doubled from 5.5lb to 11.1lb between 1976 and 2002 (*16*). Pre-packaged, ready to eat produce has also become more popular due to its convenience, time and labor saving benefits. Fresh-cut fruits are widely served in the food service industry and pre-cut fruit and fruit salads can be easily found in retail stores and food courts. Kaufman and colleagues (*22*) reported that the share of total sales of fresh-cut produce and packaged salads increased from a 1% share of sales in 1987 to 15% in 1997.

Many foodborne illness outbreaks associated with fresh-cut cantaloupes have been documented since the 1990s, often caused by *Salmonella*. The produce associated *Salmonella* serotypes include *S.* Chester, *S.* Poona, *S.* Saphra, *S.* Oranienburg, *S.* Newport, *S.* Muenchen, *S.* Entertidis, *S.* Litchfield, and *S.* Javiana. Cantaloupe-related outbreaks linked to *Eschericha coli* O157:H7 and norovirus have also been reported (*14*, *21*). Other melons like honeydew and watermelon have also been linked to *Salmonella* and *E coli* outbreaks. Common themes in many of these outbreaks include contaminated melon surfaces, poor hygienic practices, and temperature abuse (*10*, *11*, *26*). Contamination can occur pre-harvest: from soil, irrigation water, or animals, or post-harvest from wash water (*7*, *17*, *19*). Cross contamination could also take place during packaging (from a few contaminated melons to many in the lot), transportation (from transport vehicles or

storage facilities to melons), handling (from contaminated melon surfaces or food contact surfaces to melon flesh) and serving (from contaminated human hands to melons).

The rough rind of the cantaloupe provides an irregular and hydrophobic surface where bacteria can attach strongly (*33*, *38*). Studies have shown that bacteria on melon surfaces can be transferred into melon flesh (*10*, *11*). If contaminated melon pieces are kept under abused temperatures, bacteria such as *Salmonella* and *E. coli* O157:H7 can growth very fast and reach high levels, from ~ 3 log CFU/g to ~ 8 log CFU/g without visual signs of spoilage within 24 h (*14*, *20*).

With the increased number of foodborne illness outbreaks caused by consumption of fresh-cut cantaloupe, it is important to understand the factors that can influence or contribute to the risk. The purpose of our study was to develop a mathematical model capable of predicting the growth of *Salmonella* in fresh-cut cantaloupes as a function of temperature, to validate the model with different melon and pathogen combinations, and also to compare our developed model with existing *Salmonella* growth models.

2. LITERATURE REVIEW

2.1 Cantaloupe Production

Cantaloupe, also known as muskmelon (*Cucumis melo* L. var. reticulatus), is a nutrient-rich fruit that contains various vitamins, minerals and dietary fiber. It is low-calorie, fat- and cholesterol-free. Cantaloupe is one of the most popular melons consumed in the United States and accounts for 30 to 40 percent of per capita melon consumption (*16*). Since 1970s, both domestic production as well as imports of cantaloupes has been increasing steadily. Per capita consumption increased more than doubled from 1976 to 2002 (*16*). In 2009, the value of U.S. cantaloupe production was $359.1 million (*27*).

Cantaloupes grow best in well-drained, warm, silt sandy or silt loam soils with a pH between 6.0 and 6.5 and a growing temperature of 24 to 35 °C (75 - 95 °F). In the United States, cantaloupes are better adapted to the southern region of the country including Arizona, California, Georgia, Texas, and South Carolina, which usually provide a long, warm, frost-free growing season. Cantaloupes have also been grown successfully in the warm interior valleys of Colorado, Indiana, Maryland, and Pennsylvania. Cantaloupes are usually planted no earlier than two weeks before the last expected frost date of the spring when the soil temperature has reached approximately 21°C (70 °F); the peak season is from June through September. However, as production flexibility and imports have increased availability, cantaloupe is available year round and the fruit has gained in popularity. The United States is the world largest importer of cantaloupes. Cantaloupes are imported mainly from Mexico and other countries in Central and South America such as Guatemala, Costa Rica, and Honduras. The USDA Economic Research Service reported (*16*) that about 1045 million pounds of cantaloupes were imported in 2009.

2.2 Cantaloupe Contamination and Outbreaks

Cantaloupes are grown in close contact with the ground, either directly on the soil or on top of thin plastic mulch (*8*). The rind of the melon can occasionally be contaminated by bacteria, or damaged by insects from soil, water, animals and waste both during and after harvest. The rough microstructure of the netting surface of a cantaloupe can increase bacterial adherence and reduce the ability to remove bacteria cells (*1*). During cutting, microorganisms on the melon surface can be easily transferred into the cantaloupe flesh (*5*). If not properly stored, pathogens may proliferate rapidly, increasing consumers' risk.

Salmonellae are a group of gram-negative, rod-shaped bacteria belonging to the family Enterobacteriaceae and are the most frequently reported cause of bacterial foodborne illness (*31*). *Salmonella* can grow at a wide range of temperatures, under conditions of low pH, and survive well in low-water-activity foods. They live in the intestinal tracts of humans and animals and can cause acute gastroenteritis. Common symptoms include diarrhea, cramps, vomiting and fever. According to the Centers for Disease Control and Prevention (CDC), each year *Salmonella* causes an estimated 1.4 million cases of foodborne illness and more than 400 deaths in the United States (*31*). Poultry, egg and dairy products are the most common vehicles for foodborne salmonellosis. In recent years, many foodborne illness outbreaks associated with the consumption of cantaloupe have been documented (*5*, *26*) and *Salmonella* has been found to be the pathogen most frequently implicated. Outbreaks caused by *E. coli* O157:H7 (*14*) and norovirus have also been reported (*21*).The latest multistate outbreak caused by cantaloupe was traced back to cantaloupes from Jensen Farms, Colorado contaminated with *Listeria monocytogenes*. The epidemiology investigation indicated that a total of 146

persons from 28 states were infected (*12*). In the most recent US cantaloupe-related *o*utbreak due to *Salmonella* (March 2011), a total of 13 cases were reported in five states, primarily in the west, and the causative agent was the strain *Salmonella* Panama. A single farm in Guatemala was indicated from the subsequent trace back investigation of cantaloupe products (*12*). In 1990, 245 confirmed cases were reported during a multi-state outbreak in the US due to the consumption of contaminated cantaloupe and *S.* Chester was implicated as the causative pathogen. One year later, another multi-state outbreak caused more than 400 illnesses in 23 states and four Canadian provinces in June 1991. The suspect cantaloupes were contaminated with *S.* Poona (*11*). In 1997, twenty-five people who consumed cantaloupes imported from Mexico were infected with *S.* Saphra (*26*). Between 2000 and 2002, four multi-state salmonellosis outbreaks were linked to contaminated cantaloupes imported from Mexico. *S.* Poona was identified in three of the outbreaks and *S.* Anatum in the other (*35*).

Five percent of cantaloupe samples imported from Mexico in 1999 tested by the US Food and Drug Administration (FDA) were positive for *Salmonella* contamination (*37*). As a result of outbreaks caused by imported cantaloupe, an import alert was issued by FDA in October 2002 and recommended that both whole and pre-cut cantaloupes from all Mexican growers should be subject to detention without physical examination before entering the United States (*35*), however, Castillo and colleagues (*9*) found no differences in the levels of *Salmonella* contamination on melons grown in Texas or Mexico. Although FDA has been working with experts to provide recommendations to assist domestic and foreign firms on minimizing the microbial food safety hazards of melons,

seven salmonellosis outbreaks associated with the consumption of cantaloupe were documented between 2003 and 2008.

2.3 Hygiene Practices

Poor hygiene practices are one of the suspected causes associated with outbreaks of foodborne illness. Among 28 recorded outbreaks associated with cantaloupe consumption, seventeen (75%) were traced back to melons prepared by a caterer, in a restaurant, or a grocery store. Most often, the pathogens were apparently spread through soiled equipment, utensils and sick food handlers (*6*). According to a 2,000-person survey study (*23*) focusing on consumer handling of fresh fruits and vegetables, more than 35% of home preparers do not wash melons before preparation and about half of the survey population does not always wash their hands before handling fresh produce. Another onsite study from twenty-nine catering operations showed that food handlers performed hand washing in compliance with FDA Food Code only 14 percent of the time (*13*).

Good hygienic practices can reduce the risk of food poisoning and infections from melons. Washing melons and hands properly prior to fresh-cut produce preparation can reduce the probability of exposure to pathogens and keeping cut melons refrigerated inhibits the growth of bacteria. FDA has provided guidance for the melon supply chain and recommended that melons with visible signs of decay or damaged rinds should be discarded. FDA also advises that before cutting, the preparer should wash both the hands thoroughly with soap, and then wash the melon rind under running tap water, scrubbing with a clean produce brush. The food contact surfaces and utensils must be clean and gloves can be used to reduce cross contamination. Once cut, melons should not be held

out of refrigeration for more than four hours. If held out of refrigeration they should be discarded after four hours (*36*).

2.4 Predictive Food Microbiology

Predictive food microbiology assumes that microbial responses to environmental variables are reproducible and can be predicted from previous observations (*30*). A predictive model is a mathematical expression that describes the growth, survival, and/or inactivation of a foodborne microorganism under specified environmental conditions. Models use existing data to predict bacterial behavior under different situations, and can be used for quick evaluation and decision-making. Once predictive models have been developed, they can be cost-effective and less time consuming than traditional methods challenge studies (*24*). The origin of predictive microbiology can be traced back to 1922, when Esty and Meyer described the thermal death of *Clostridium botulinum* type A spores using a log-linear model and showed that the relative death rate of the bacteria is constant with time at a given temperature (*18*, *25*). In 1953, Scott established the correlation between water activity and the growth of bacteria (*32*), which can be viewed as a major step forward in predictive microbiology.

The classical development of predictive models includes two steps. The first step is to establish the growth or death model under certain constant environmental conditions, and this is known as primary model development. The second step is to determine how the parameters of the primary model are affected by various environmental factors (*40*). However, limited knowledge on “lag” and “stationary” phase in growth curves and “shoulder” and “tailing” effect in death curves prior to the exponential/death phase were obstacles to modeling these transition periods. The model of Baranyi and Roberts (*2*)

provided a solid mathematical basis for mechanistic modeling of the lag phase and has been widely used as a primary growth model since then. An Excel add-in program called DMFit was developed by Baranyi, based on the model described by Baranyi and Roberts (*2*) and DMFit provides an easy to use tool for fitting microbial growth curves. The square root model (*29*), which can be used to describe the effect of temperature on the specific growth rate, is widely used as a secondary model (*3*).

Predictive microbiology has been widely recognized and several freely available computer programs describing the growth and death of bacterial pathogens have been developed. The development Food MicroModel was initiated by the UK Ministry of Agriculture Fisheries and Food in 1988. The UK Food Standards Agency (FSA) then took it over and has been supporting its development ever since. In the United States, the Department of Agricultural Research Service (ARS), Eastern Regional Research Center (ERRC) produced a similar program called the Pathogen Modeling Program (PMP) that can be used to predict the growth, survival, and inactivation of foodborne bacteria, primarily pathogens, under various environmental conditions. In May 2003, the UK-FSA and USDA-ARS committed to work together, and a combined database of microbial responses to food environments, called ComBase were released, which contains quantified microbial responses to the food environment with more than 50,000 records from Food MicroModel, PMP, related publications, as well as data submitted from supporting institutes, universities, companies. ComBase is systematically formatted, and provides basis of predictive models which can be used for predicting the growth of many foodborne pathogens, provide information for setting up new guidelines in food production and food service industries, and assessing microbial risk in foods through a

web-based interface. ComBase Predictor is one of the predictive model programs associated with the ComBase database. It is focused on predicting the response (growth and survival) of foodborne microorganisms to environmental factors such as temperature, pH, water activity, and gas composition, etc. and can be used to analyze specific environmental conditions.

3. MATERIALS AND METHODS

3.1 Strain and Media Preparation

Salmonella spp. and *Escherichia coli* O157:H7 strains used in our study were provided by Dr. Danyluk of the University of Florida. All strains were adapted by the Danyluk lab to grow in the presence of 100 ug/ml of rifampicin. The strains and their sources are as follows: *S.* Agona (alfalfa sprouts), *S.* Enteritidis PT 30 (raw almonds), *S.* Gaminara (orange juice), *S.* Michigan (cantaloupe), and *S.* Montevideo (tomatoes). Five *E. coli* O157:H7 serotypes were originally isolated from patients in outbreaks associated with the following foods: 1) spinach, 2) cantaloupe, 3) lettuce, 4) alfalfa sprouts, and 5) apple juice. Pathogen strains were preserved both frozen at -70 °C in tryptic soy broth (TSB; Bacto) with 15% glycerol (Fisher, Pittsburgh, P.A.) and on tryptic soy agar (TSA; Difco) supplemented with 100ug of rifampicin (Fisher, Fair Lawn, N.J.) per ml (TSAR) slants at 4 ºC until use. Before each experiment, each antibiotic-resistant strain of *Salmonella* and *E. coli* O157:H7 was cultured to stationary phase in TSB supplemented 100ug/ml of rifampicin (TSBR), and incubated at 37 °C for 24 h. Overnight cultures were harvested by centrifugation at 3000rpm for 10 minutes. The broth was decanted and the cell pellets were washed three times and resuspended in 1 ml of sterile 0.1% peptone water (Difco). Equal volumes of cell suspensions of five strains of each pathogen were combined to generate a cocktail of *Salmonella* spp. or *E. coli* O157:H7. The cell density (CFU per milliliter) was determined by serially diluting suspensions in sterile 0.1% peptone water and surface plating samples (0.1 ml) in duplicate on TSAR and incubating at 37 °C for 24 h. The cocktail (~ 9 log CFU/ml) was diluted to a final concentration of 10^6 CFU/ml using 0.1% peptone water. A final inoculum level of 10^3 CFU/g was targeted.

3.2 Sample Preparation

Fresh, ripe cantaloupe and honeydew melons were purchased from local grocery stores. Melons with visible bruises, cracks, or other physical defects were excluded. Melons were stored in the refrigerator (4 °C) and brought to room temperature (24±2 °C) approximately one hour prior to being used in the experiments. To prepare fresh-cut pieces, whole cantaloupe and honeydew melons were first washed, dried and then cut into halves, the melon seeds were removed and each half was sliced into 4-6 crescent-shaped wedges using a flame-sterilized knife and the rinds were carefully removed. The interior flesh was cut into cubes of approximately 25g weight and $3cm^3$ in size.

3.3 Inoculation Procedure

The fresh-cut melon cubes were spot-inoculated by depositing 10 μl of the prepared inoculum (10^6 CFU/ml) on the cut surface to achieve an initial population of 10^3 CFU/g, and the control samples were spot-inoculated with 10 μl 0.1% peptone water. Samples were then held in a laminar flow biosafety cabinet for 10 minutes to facilitate bacterial cell attachment. Each inoculated melon cube was placed in a sterile bag (18 x 30cm, Fisher, Pittsburgh, P.A.) and transferred to a temperature-controlled water bath or refrigerator set at the designated temperature. At least two replicate experiments were conducted at temperatures of 4, 10, 15, 20, and 25 ºC. Inoculated samples and the control treatments were examined at the time of inoculation and growth was monitored periodically with a frequency dependent on the holding temperature. Both selective and non-selective media were used to enumerate pathogens on melon pieces. TSAR was used as the non-selective recovery medium for both *Salmonella* spp. and *E. coli* O157:H7. Bismuth sulfate agar (BSA; Difco) supplemented with 100 ug/ml of rifampicin (BSAR)

was the selective medium used for recovering *Salmonella* and Sorbitol MacConkey agar (SMA; BBL) supplemented with 100 ug/ml of rifampicin (SMAR) was used for enumerating *E. coli* O157:H7 selectively. A sample bag containing a 25 g melon piece was taken from the water bath, mixed with 10 ml of Dey-Engley neutralizing broth (DE; Difco), and pummeled at high speed for 2 minutes (Stomacher 400, Tekmar Inc., Cincinnati, O.H.) at each time point. After blending, further decimal dilutions of the sample were made with 0.1% peptone water where appropriate, and viable counts of *Salmonella* spp. and *E. coli* O157:H7 were obtained by plating 0.1 ml portions in duplicate onto selective and nonselective media. Colonies were counted after incubation at 37 ºC for 24-hour. No bacterial colonies were evident in control (uninoculated) samples plated on selective media.

3.4 Model Development

A model was developed using experimental data collected from *Salmonella* spp. grown on fresh-cut cantaloupe cubes. DMFit (Institute of Food Research, Norwich, UK) was used to model the growth from experimental observations, fitting data to the Baranyi and Robert model (*2*) and the growth of *Salmonella* was expressed as a function of time. Growth curves were obtained for each temperature. Exponential growth rates of *Salmonella* were calculated. The square root or Ratkowsky equation:

$$\sqrt{Growth\ Rate} = b\ (T\ -\ T_0)$$

was used to describe *Salmonella* growth rate as a function of temperature, where b is the regression coefficient and T_0 represents the theoretical minimum growth temperature for the microorganism.

3.5 Model Validation

Experiments on the growth of *Salmonella* spp. on honeydew and *E. coli* O157:H7 on both cantaloupe and honeydew melons were conducted at temperatures of 4, 15, and 25 ºC. Two to three replicates were carried out for each treatment. Growth rates were obtained using DMFit and used for model validation.

3.6 Model Comparison

Growth curves of *Salmonella* under conditions (pH, Aw) similar to the fresh-cut cantaloupe used in our lab experiments were generated for multiple temperatures using Pathogen Modeling Program 7.0 (PMP) (http://ars.usda.gov/Services/docs.htm?docid=6788) and ComBase Modeling toolbox (http://modelling.combase.cc/). Growth rates were calculated and square root models were constructed for comparison purposes. The *Salmonella* spp. growth models on poultry and tomatoes previously developed in our lab (*15*, *28*) were also compared with the model developed in this study. Besides comparison with existing models, data from related studies were also collected for comparison.

4. RESULTS

4.1 Model Development

The growth rates of *Salmonella* spp. on fresh-cut cantaloupe at 4, 10, 15, 20, and 25 ºC are shown in Table 1. No growth of *Salmonella* was observed during refrigerated storage (4 ºC) and a very short or non-existent lag time was observed at and above 15 ºC. The growth rate of *Salmonella* increases as the storage temperature goes up. The square root of growth rate verses storage temperature was plotted in Figure 1 and fitted to the Ratkowsky equation: $\sqrt{Growth\ Rate} = 0.026 \times (T - 5.613)$. The linear relationship is very clear and the correlation between the model and the collected data is good (R^2= 0.9779).

Table 1. Growth rate of *Salmonella* spp. on fresh-cut cantaloupe at five different storage temperatures

Temperature (ºC)	Average Growth Rate (log CFU/g/min)
4	0
4	0
10	0.0069
10	0.0244
15	0.0607
15	0.0527
15	0.0551
20	0.1445
20	0.1459
25	0.2354
25	0.2750

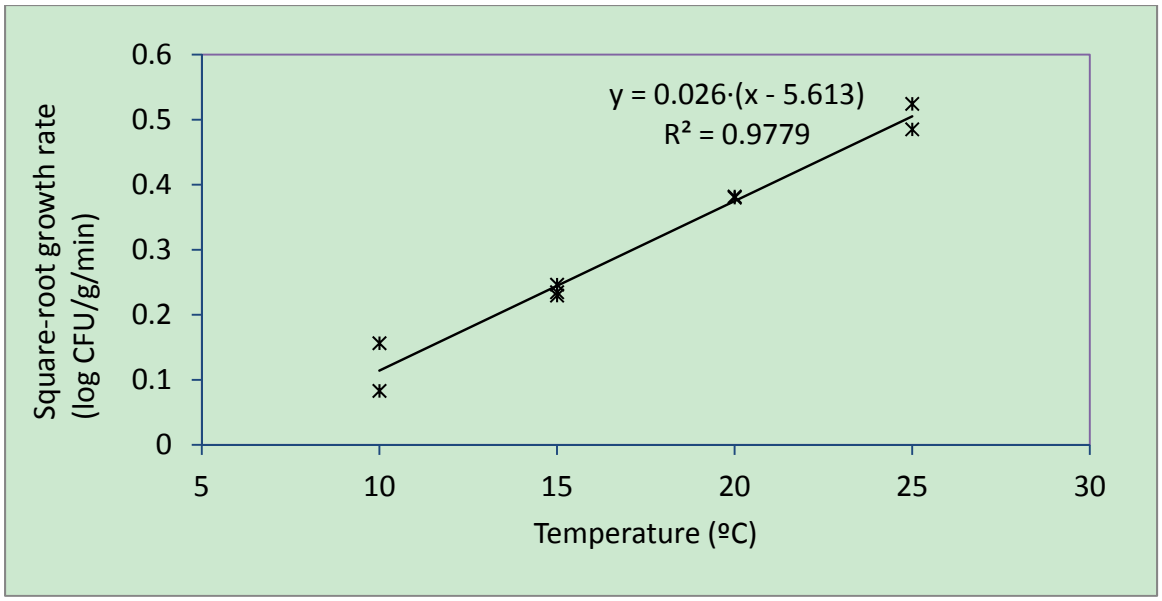

Figure 1. The square root model describes a linear relationship between the growth rate of *Salmonella* spp. on fresh-cut cantaloupe and storage temperature. Ratkowsky equation:$\sqrt{Growth\ Rate} = 0.026 \times (T - 5.613)$, R^2= 0.9779.

4.2 Model Validation

Growth rates of *Salmonella* on fresh-cut honeydew and *E. coli* on both cantaloupe and honeydew melons are shown in Table 2. No growth was detected at refrigerated (4 ºC) temperatures. At 15 ºC, the growth rates of *Salmonella* were very similar to what was observed on fresh-cut cantaloupe. At 25 ºC, there was more variation. *E. coli* grew faster on both cantaloupe and honeydew than *Salmonella* and the growth rate of both pathogens on honeydew melon is slightly lower than on cantaloupe. The square root of growth rates versus temperatures were plotted in Figure 2.

Table 2. The growth rate of *Salmonella* spp. on fresh-cut honeydew melon and *E. coli* on both cantaloupe and honeydew melons under different storage temperatures

Fresh-cut Melon	Organism	Temperature (ºC)	Growth Rate (log CFU/g/min)
Cantaloupe	*E. coli*	4	0
		4	0
		15	0.0899
		15	0.0727
		25	0.3457
		25	0.4413
Honeydew	*Salmonella*	4	0
		4	0
		15	0.0508
		15	0.1009
		25	0.1821
		25	0.1978
Honeydew	*E. coli*	4	0
		4	0
		15	0.0641
		15	0.0670
		25	0.2693
		25	0.2914

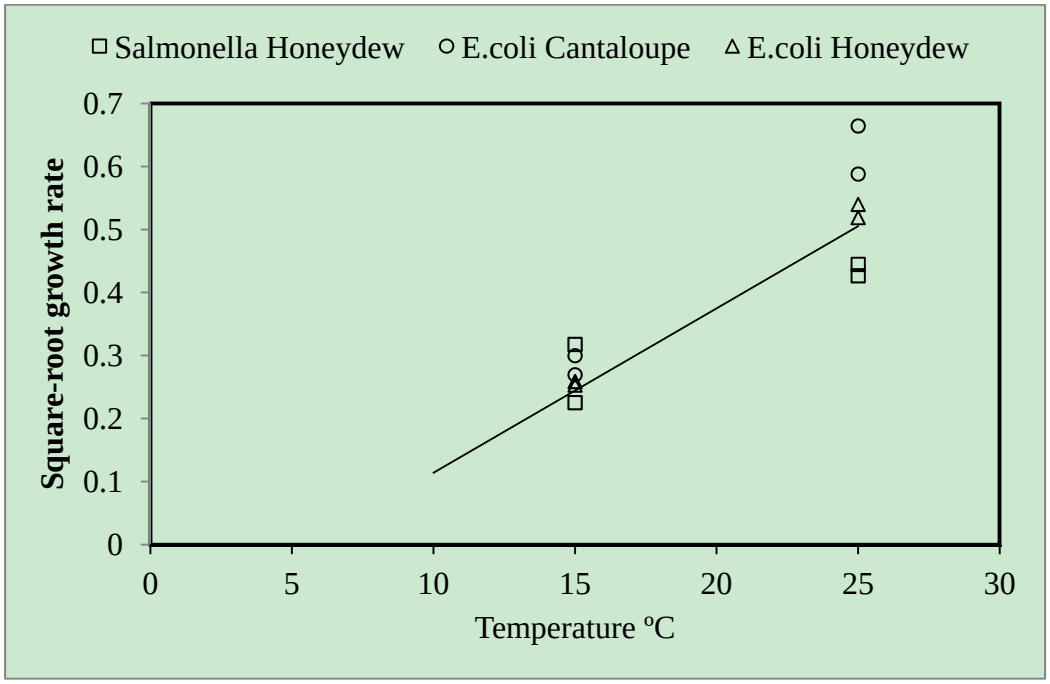

Figure 2. Model validation using data collected from the growth of *Salmonella* on honeydew and *E. coli* on honeydew and cantaloupes at 15 and 25 ºC. No growth was observed at 4 ºC, thus is not shown in this figure. The solid line represents the growth model.

4.3 Model Comparison

The pH of the fresh-cut cantaloupe used in this study ranged from 6.4 – 6.6, and its water activity ranged from 0.970 to 0.971. Figure 3 shows *Salmonella* growth models generated using Pathogen Modeling Program and ComBase predictor for these pH and water activity conditions, as well as *Salmonella* growth models for poultry and tomatoes from previous studies conducted in our laboratory. The slopes of all five regression lines are similar, but the value for T_0 from the raw chicken and cut tomato models is lower (i.e. growth is predicted down to a lower theoretical minimum). The predictive model generated from ComBase predictor almost overlaps with our model. Data collected from published studies on cantaloupe or honeydew melons were also plotted along with our

model (Figure 4). These studies were conducted on cantaloupe or honeydew melon with either *E. coli* or *Salmonella*. Most of the data points lie close to our model, with the exception of two points at 22 ºC from Ukuku and Sapers (*39*).

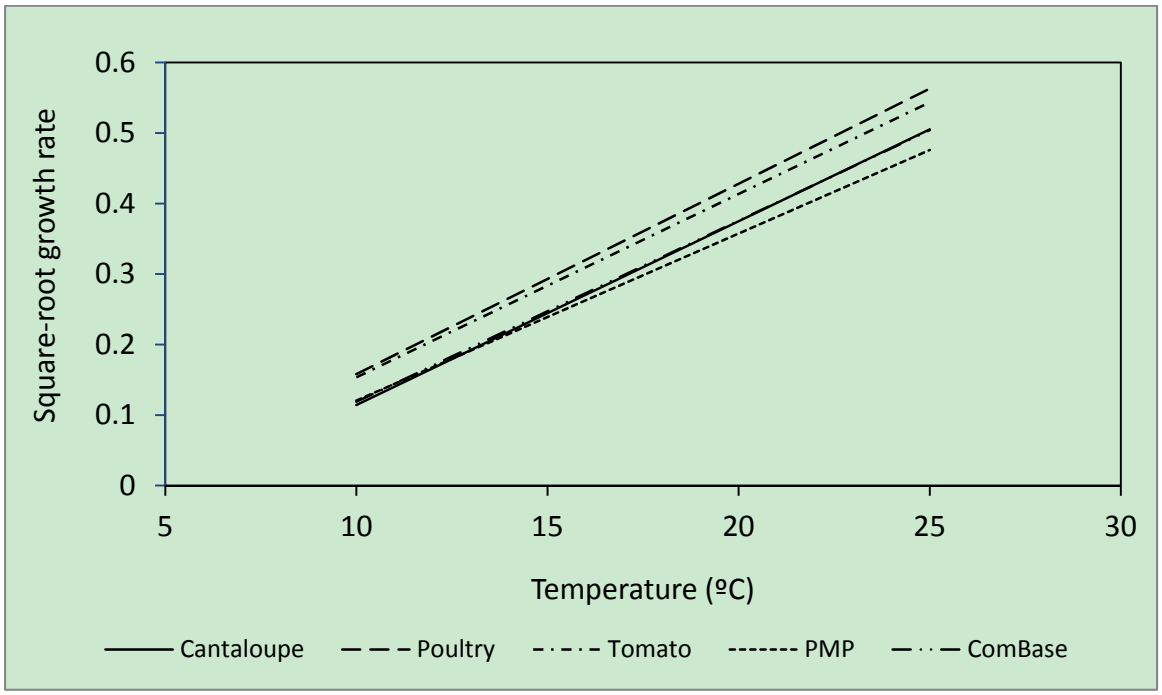

Figure 3. A comparison of the *Salmonella*-cantaloupe model with previously developed *Salmonella* growth models in poultry and cut tomatoes and regression models developed using PMP, ComBase program under similar environmental conditions

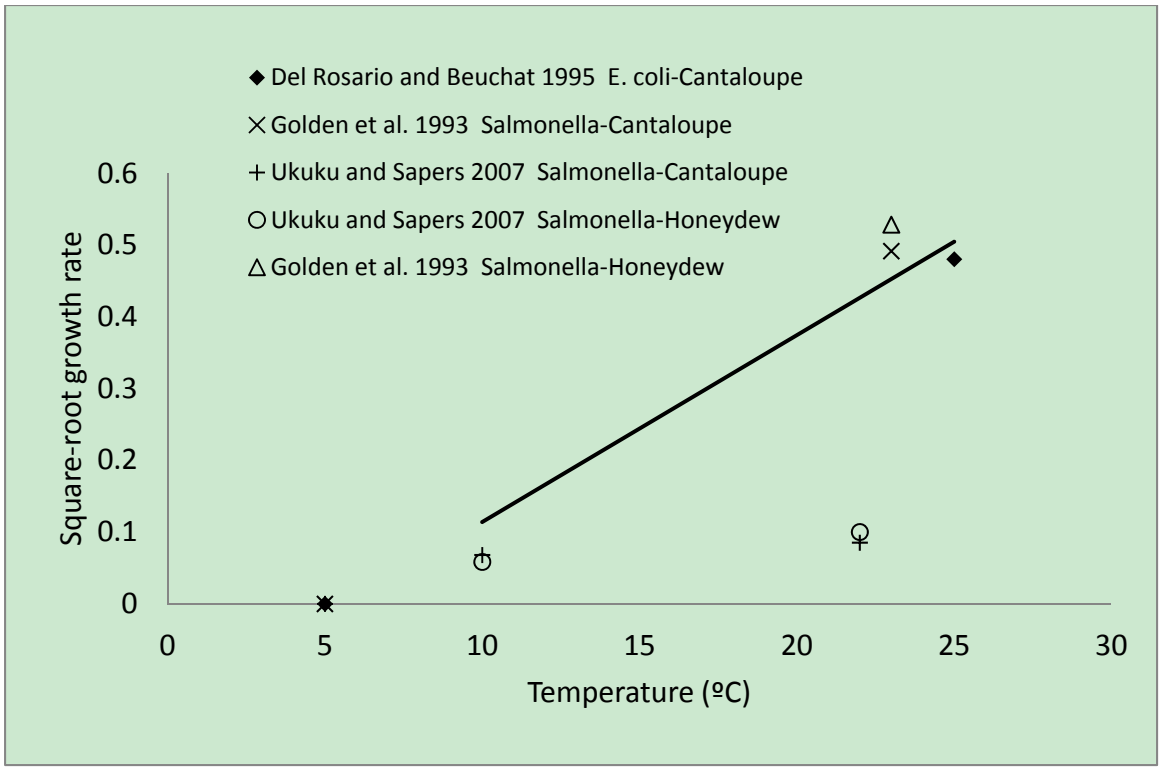

Figure 4. A comparison of the *Salmonella*-cantaloupe model (solid line) with published data from related studies.

5. DISCUSSION

The simple linear regression model developed in our study describes the influence of storage temperature on the growth rate of *Salmonella* on fresh-cut cantaloupe. No growth was observed at refrigeration temperature and *Salmonella* growth rate increases rapidly at elevated temperatures, which can increase risks associated with food safety. This is consistent with FDA recommendations that cut melons should be stored at 0 - 5 ºC to prevent the potential rapid and prolific growth of human pathogens (*36*). We observed very short or non-existent lag times at or above 15 ºC (data not shown), consistent with previous studies in our lab on *Salmonella* growth in raw chicken and cut tomatoes (*15, 28*). Cantaloupe and honeydew melons may have provided an environment that is more favorable to *E. coli* than *Salmonella,* and *E. coli* tends to grow slightly faster. The growth rates of both pathogens in fresh-cut cantaloupe are slightly higher than that on honeydew, which might due to its slightly higher pH, which is close to neutral. Although pH could be a growth-limiting factor, Beuchat (*4*) showed that growth rates in different types of tomatoes were not significantly different despite differences in tomato pH.

The predictive model generated from ComBase predictor is most similar to our model and both poultry and tomatoes models are parallel to our cantaloupe model but with a lower T_0 (temperature where predicted growth rate is zero). The discrepancy may be caused by the different strains used in this study as well as a difference in the initial inoculum level used. In the current study the initial inoculation level was 10^3 CFU/g while a concentration of about 10^2 CFU/g were used in the poultry and tomato studies. The lower inoculation level may have led to higher growth rates. The growth rate of *Salmonella* on cantaloupe at 22 ºC in Ukuku and Sapers (*39*) study is much lower than

predicted by our model. This is probably caused by the long intervals between sampling times used by Ukuku and Sapers, as their studies were not conducted specifically for the purpose of estimating growth rates, and long intervals between sampling times can lead to underestimation of growth rates.

6. CONCLUSION

Salmonella and *E. coli* can grow quickly and reach high concentrations (> 7 log10 CFU/g) without visual signs of spoilage on fresh-cut melons at ambient temperatures. Many foodborne illness outbreaks linked to cantaloupe were due to the initial contamination on the melon surface or by cross contamination from food handlers or dirty utensils and were then kept under less than ideal refrigeration temperatures. Thus, it is important to wash melons, hands, and contact surfaces following FDA guidelines and to refrigerate cut melons properly.

We developed, validated, and compared a mathematical model that describes the square root of the growth rate of *Salmonella* spp. on fresh-cut cantaloupe as a function of temperature. The model matches the one developed using ComBase predictor under similar pH and a_w. This model provides a faster and more cost-effective alternative to laboratory studies to estimate the effects of storage temperature on cantaloupe safety. The model allows the end user to estimate the effect of storage temperature on *Salmonella* concentration in fresh-cut cantaloupes held over temperatures from 4 to 25°C, and can also be used in subsequent quantitative microbial risk assessments for the fresh produce industry to improve the safety of their products.

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