Research Note

Evaluation of the Inactivation Kinetics of Cronobacter Sakazakii in Infant Formula Treated by Radio Frequency Dielectric Heating and UVC Light

Yuwei Wu1,2, Yuanrong Zheng1, Danfeng Wang2, Zhenmin Liu1, and Yun Deng2,*

1State Key Laboratory of Dairy Biotechnology, Dairy Research Institute, Bright Dairy & Food Co., Ltd, Shanghai 200436, China
2Department of Food Science & Technology, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai 200240, China

*Author for Correspondence; email: Y_deng@sjtu.edu.cn; Phone: +86-21-34204137; Fax: +86-21-34204137

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We studied the inactivation kinetics of Cronobacter sakazakii (CS) in infant formula subjected to radio frequency dielectric heating (RF) alone or sequential RF-UVC irradiation for 30 min. We used one linear model and two nonlinear models to fit the data and compared the results. Our findings revealed that CS was more susceptible to the combined treatment than to RF alone at the same temperature and that inactivation rate increased with increasing temperature. The sequential RF (90°C, 5 min) - UVC (25 min) treatment was the most effective at inactivating CS. The survival curves of CS were non-linear. The modified log-logistic model ($R^2 = 0.9783$–$0.9904$, RMSE = 0.02–0.05, $A_i =1.04$–$1.07$, $B_i = 0.99$–$1.03$) generated a better fit than the Weibull ($R^2 = 0.9111–0.9863$, RMSE = 0.02–0.10, $A_i = 1.04$–$1.16$, $B_i =1.00$–$1.09$) or first-order kinetics models ($R^2 = 0.6514–0.7937$, RMSE = 0.07–0.30, $A_i = 1.12$–$1.77$, $B_i = 0.93$–$1.38$). Overall, the survival curves of CS in infant formula subjected to RF alone or sequential RF - UV light were nonlinear. The modified log-logistic model may be a useful tool to describe the inactivation patterns for CS in infant formula, and our results also demonstrated the high color stability of samples after sequential RF - UVC treatments.

Keywords: radio frequency dielectric heating; Cronobacter sakazakii; infant formula

Abbreviations: CS—Cronobacter sakazakii, RF—radio frequency dielectric heating, RMSE—root mean square error, $A_i$—accuracy factor, $B_i$—bias factor, LSD—least significant difference.

INTRODUCTION

Cronobacter sakazakii (CS) is a Gram-negative, non-spore forming, rod-shaped bacterium that is fairly resistant to osmotic, high heat, and dry conditions and can grow at $< 4^\circ$C (Iversen et al. 2004, Hunter et al. 2008). It has been reported that CS has a prevalence rate of 40% in dry samples from infant formula factories (Iversen et al. 2004). CS may exhibit long-term persistence in dried infant formula milk and has been reported to be the only organism isolated after a 2.5-y storage period (Hunter et al. 2008). CS infections have brought life-threatening diseases to newborn and premature infants including neonatal meningitis, sepsis and necrotizing enterocolitis (Pina-Pérez et al. 2016). To improve the nutritional quality and guarantee food safety of powdered infant formula milk to meet the specific requirements of the neonatal and premature population, efforts have been made to develop or integrate novel thermal and non-thermal technologies for the control of CS.

Radio frequency dielectric heating (RF) achieves rapid and uniform heating patterns in food products due to friction generated by spinning polar dielectric molecules and moving ions (Wang and Tang 2001). RF is effective in inactivating foodborne microbes in milk products and other food (Awuah et al. 2005, Chen et al. 2013, Michael et al. 2014, Liu et al. 2018, Ozturk et al. 2019, 2020, Lin et al. 2020). It has also been reported that long RF treatments reduce whey protein nitrogen index and contribute to browning in nonfat dried milk, thereby affecting foaming, emulsifying, and sensory properties (Chen et al. 2013). RF treatment alone has several drawbacks including heat sink effects, uneven distribution of radio frequency energy, and quality damage (Wang and Tang 2001). Therefore, RF should be coupled with other techniques.
UVC (200–280 nm) irradiation, which exhibits biocidal effects by degrading bacterial and viral DNA, is currently being investigated as an alternative to thermal treatment of milk (Liu et al. 2012, Hu et al. 2015, Fang 2016). One disadvantage of UV light as a microbial inactivation method is that organisms must be directly exposed to UVC to absorb UV photons (Koutchma at al. 2009). The combined effects of UVC with other treatment factors, such as heat treatment and ultrasound for inactivation of spoilage and pathogenic microorganisms, have been investigated (Liu et al. 2012, Ha and Kang 2014). The feasibility of combined RF and UVC for controlling CS in dehydrated infant formula has not yet been evaluated, which is one of the purposes of the current study.

Mathematical models that accurately estimate the survival of microorganisms allow a thorough understanding of the kinetics of the inactivation and assist in the successful adaptation of different technologies for industrial applications (Cole et al. 1993, Anderson et al. 1996, Buzrul and Alpas 2004, Pina-Pérez et al. 2016). However, the kinetics of microbial inactivation in foods by RF alone or sequential RF-UVC irradiation is still unclear.

The aim of this study was to evaluate the response of CS to the single and combined effects of RF and UVC in infant formula. Three models were selected to describe the survival rate of CS, and their predicting capacities were compared based on their accuracy factor, bias factor, and mean square error.

MATERIALS AND METHODS

CS Inoculum Preparation

Commercial infant formula milk (Wyeth, S-26 SMA GOLD, stage 1) was obtained from Auchan (China) Investment Co. Ltd. (Shanghai, China). CS strain ATCC 29544 was acquired from the American Type Culture Collection (ATCC, Manassas, VA, USA). All other reagents were laboratory-grade chemicals obtained from Sinopharm Chemical Reagent Co., Ltd (Shanghai, China). Inoculum preparation and the inoculation procedure were performed as previously reported (Iversen et al. 2004), with minor modifications. Briefly, a loopful of each strain was inoculated into 40 mL of tryptone soya broth and incubated at 37°C for 24 h. Strains were subsequently centrifuged at 5,520 × g for 15 min at -4°C. The resulting supernatant was discarded, and the pellets were reconstituted in 40 mL of 0.1% peptone water (Difco) and transferred into 100 mL of sanitized spray bottle. Infant formula was evenly spread on the sanitized plastic plate (sample of approximately 3 mm in height) and incubated with CS strain by evenly spraying 8 mL per 150 g of sample. Inoculated milk sample containing 1.55% moisture content (w.b.) was dried with open lids at 37°C for 24 h and ground in a food processor for 1 min to homogenize the inoculum. The inoculated powders with 10⁷-10⁷ CFU/g powder were weighted for following treatments.

RF Alone Treatment

A 12-kW, 27.12-MHz parallel electrodes, pilot-scale free-running RF unit (GJD-6A-27-JY, Huashi Jiyuan Co. Ltd., Hebei, China) was used. Heating treatments for the samples conducted as previously described (Hu et al., 2018), with some changes. A big polyethylene plastic container (18.5 cm × 11.5 cm × 5.8 cm) was used to hold non-inoculated sample, and a small rounded polypropylene plastic box (6.7 cm diameter × 4.3 cm height) located in the middle of it was used to contain inoculated samples (Fig. 1 A). According to our preliminary experiments, the gap between the top and bottom electrode was fixed at 10.5 cm in order to obtain an appropriate heating rate (Fig. 1 B). The samples within the container were placed on the center of the bottom electrode, and they were heated until target temperatures of 80°C, 85°C, or 90°C for 30 min, namely, A [RF (80°C, 30 min)], B [RF (85°C, 30 min)], and C [RF (90°C, 30 min)], respectively. Fiber optic sensors (ThermAgile RD Optsensor, Xi’an Heqiguangdian Co. Ltd., Shanxi, China) connected with a computer were applied to monitor the real-time temperature changes during RF treatment. More information of this system can be found in the study conducted by Hu et al (2018).

Sequential RF-UVC Irradiation Treatment

After RF treatment with 5-min holding, samples were then subjected to UVC irradiation for 25 min in a UVH30DC instrument (Shanghai Guoda UV Equipment Co., Ltd., Shanghai, China) at 254 nm with a radiation dose of 11.8 Wm⁻² (Hu et al. 2015), namely, D [RF (80°C, 5 min)]-UVC(25 min)], E [RF (85°C, 5 min)-UVC(25 min)], and F [RF (90°C, 5 min)-UVC(25 min)] respectively.

Analysis of Basic Composition

The protein, fat, ash, and moisture contents were determined according to the Chinese standard methods of GB5009.5-2016, 5009.6-2016, GB5009.4-2016, and GB5009.3-2016, respectively (Standardization Administration of the People’s Republic of China (SAC) 2016).

Color Characteristics

The sample colors were measured using a Color Difference Meter (LabScan XE, HunterLab, USA). CIE
(Commission International de l’Eclairage) color values of L (lightness), a (redness), and b (yellowness) were obtained from the reflection spectra of the samples using a D65 illuminant and the observer at 10°.

Microbial Enumeration

Microbial enumeration was performed as previously reported (Iversen et al. 2004). The microbial enumerations were conducted at 5 min intervals during 30 min of treatment.

Inactivation Models

To establish the relationship between microbial inactivation and the different treatments, first-order kinetics, Weibull distribution, and log-logistics models were selected for their ease of use (Cole et al. 1993, Anderson et al. 1996, Buzrul and Alpas 2004, Pina-Pérez et al. 2016).

The first-order kinetics model presents a linear relationship between the logarithmic number of microorganisms and treatment time,

$$\log \frac{N}{N_0} = -t/K$$

where N and N₀ are the concentrations (CFU/g) at time t and zero, respectively; t is the treatment time (min); and K is the decimal reduction time (min) or time required to achieve one log reduction of the microbial population.

The Weibull model, a two-parameter model, is suitable for the analysis of microbial inactivation based on the assumption that cells within a population have different resistance. Resistance to stress follows a Weibull distribution,

$$\log \frac{N}{N_0} = -bt^\gamma$$

where b and γ are the scale parameters. Parameter γ determines the direction of the concavity, i.e., indicates whether the death rate is increasing, constant, or decreasing with treatment time. Parameters γ < 1 and γ > 1 correspond to concave-upward and concave-downward, respectively, survival curves. At γ = 1, the Weibull model reduces to the first-order model.

The log-logistic model was originally developed by Cole et al. (1993) to characterize the non-linear thermal inactivation of microorganisms and later was modified by Chen and Hoover (2003) to avoid the direct use of different initial numbers and to reduce the number parameters in the equation:

$$\log \frac{N}{N_0} = \frac{G}{1 + e^{4\sigma (t - \log t_0)/G}} - \frac{G}{1 + e^{4\sigma (t - \log t_0)/G}}$$

where G is the upper asymptote-lower asymptote (log₁₀ CFU/g), σ is the maximum inactivation rate (log₁₀
results have been reported with observed a rapid initial drop in bacterial counts followed RF alone or sequential RF Fig. 1C shows the CS inactivation curves obtained from RF Alone or Sequential RF.

RESULTS AND DISCUSSION

RF Alone or Sequential RF-UVC

Fig. 1C shows the CS inactivation curves obtained from RF alone or sequential RF-UVC. In both treatments, we observed a rapid initial drop in bacterial counts followed by tailing caused by a decreasing inactivation rate. Similar results have been reported with *E. sakazakii* in infant formula (Buzrul and Alpas 2004). The RF alone or sequential RF-UVC treatments resulted in about 1-3 log reductions of CS with initial inoculated populations of 7-8 log CFU/g, and higher sterilization temperature and longer treatment time resulted in more log reduction of CS. Throughout the whole RF alone process, survivors of CS in the powders were reduced by 0.7 log CFU/g, 0.8 log CFU/g and 1.9 log CFU/g at 80°C, 85°C, and 90°C, respectively. After 30 min of RF alone at 90°C, we obtained a reduction of 1.5 log CFU/g compared with 0.7 log CFU/g at 80°C (p ≤ 0.05). During RF, the destruction of microorganisms is mainly due to the thermal effect (Michael et al. 2014) The log survivors of CS in the powders could be reduced by 0.8 log CFU/g for RF (80°C, 5 min) -UVC (25 min), 1.2 log CFU/g for RF (85°C, 5 min) -UVC (25 min) and 2.6 log CFU/g for RF (90°C, 5 min) -UVC (25 min), which was due to synergistic effects of RF and UVC.

After 5 min of treatment, the sequential RF-UVC led to more log reductions of CS compared with the RF alone at the same temperature and treatment time (except for 10 min at 80°C) (p ≤ 0.05) (Fig. 1C), which showed that CS was more susceptible to UVC irradiation than to RF alone at the same temperature and treatment time. It is common knowledge that UV technology applied on solid particles has an inherent bactericidal effect on non-shadowed surfaces and a potentially additional thermal inactivation effect derived from energy dissipation (heating effect) (Koutchma et al. 2009), which would explain the differences for microorganism inactivation between UVC and RF alone. Similar results have been reported with heat-treated *E. sakazakii* (Breeuwer et al. 2003).

As shown in Fig. 1C, the sequential RF (90°C, 5 min) -UVC (25 min) treatment was the most effective at inactivating CS in infant formula (p ≤ 0.05). The log-cycle reduction after 5 min RF + 5 min UVC (2.1 log CFU/g) was similar to that of 30 min RF alone treatment (1.9 log CFU/g) at 90°C, and the CS log reduction after 5 min RF + 25 min UVC treatment was 2.6 log CFU/g, respectively (p ≤ 0.05), which revealed that the sequential RF-UVC treatment required less time to reach a desired lethality. Michael et al. (2014) observed that the log reduction of CS in high heat-treated and low heat-treated nonfat dry milk subjected to RF alone at 90°C for 5.57 min and 5.37 min was approximately 2.0 and 3.0 log CFU/g, respectively. The resistance of bacteria to RF varies significantly depending on the species, treatment method, experimental conditions, and media (Wang and Tang 2001, Chen et al. 2013, Hu et al. 2018).

Our study findings showed that the log reduction of CS after sequential RF (90°C, 5 min) -UVC (20 min)
treatment was approximately 1.76 log CFU/g. Liu et al. (2012) reported that UVC (72.8 kJ/m², 25 min) inactivated up to 1.38 log cycles of CS in dry infant formula. Fang observed that CS on utensil surface in dairy plant was fully inactivated after 10 min UVC irradiation with the power of 40 W (Fang 2016). Reductions of 2.7 log10 CFU/mL APC and 24 MPN/100 mL CC were achieved following UVC (11.8 W/m²) for 5 min (Hu et al. 2015). The differences in the results might be attributed to the UVC dose, UV equipment design, bacterial species and strains, processing conditions, and media (Kouchma et al. 2009).

**Inactivation Models**

Table 1 shows the values of $R^2$, RMSE, $A_t$, and $B_t$. The $R^2$, $A_t$, and $B_t$ values closer to 1, and lower RMSE value would indicate better prediction of each model. The $R^2$, RMSE, $A_t$, and $B_t$ values of the Weibull $(R^2 = 0.9111 – 0.9863$, RMSE $= 0.02 – 0.10$, $A_t = 1.04 – 1.16$, $B_t = 1.00 – 1.09)$ and modified log-logistic models $(R^2 = 0.9783 – 0.9904$, RMSE $= 0.02 – 0.05$, $A_t = 1.04 – 1.07$, $B_t = 0.99 – 1.03)$ revealed that these models fitted the observed data better than the first-order kinetics model $(R^2 = 0.6514 – 0.7937$, RMSE $= 0.07 – 0.30$, $A_t = 1.12 – 1.77$, $B_t = 0.93 – 1.38)$ in present study. Moreover, the origin first-order kinetics could well model the loglinear part of the inactivation curve, but could not effectively reflect the tailing effect (Geeraerd et al. 2000). At similar conditions, the $R^2$, RMSE, and $A_t$ of Weibull and modified log-logistic models were comparable; however, on average, $R^2$ was higher for the log-logistic model (except at 80°C). RMSE, $A_t$, and $B_t$ of the modified log-logistic model were less than or similar to those of the Weibull model. It is noteworthy that the Weibull model was less accurate in

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Temperature</th>
<th>Kinetic Parameters</th>
<th>$R^2$</th>
<th>RMSE</th>
<th>$A_t$</th>
<th>$B_t$</th>
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<tr>
<td><strong>First-order kinetics</strong></td>
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<tr>
<td>A</td>
<td>80°C</td>
<td>$K=50.58\pm0.00$</td>
<td>0.7558</td>
<td>0.07</td>
<td>1.16</td>
<td>0.97</td>
</tr>
<tr>
<td>B</td>
<td>85°C</td>
<td>$K=41.30\pm0.01$</td>
<td>0.7786</td>
<td>0.12</td>
<td>1.28</td>
<td>0.93</td>
</tr>
<tr>
<td>C</td>
<td>90°C</td>
<td>$K=26.02\pm0.01$</td>
<td>0.8514</td>
<td>0.26</td>
<td>1.69</td>
<td>0.99</td>
</tr>
<tr>
<td>D</td>
<td>80°C</td>
<td>$K=23.51\pm0.01$</td>
<td>0.7937</td>
<td>0.09</td>
<td>1.12</td>
<td>0.97</td>
</tr>
<tr>
<td>E</td>
<td>85°C</td>
<td>$K=16.96\pm0.01$</td>
<td>0.7194</td>
<td>0.14</td>
<td>1.58</td>
<td>0.91</td>
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<tr>
<td>F</td>
<td>90°C</td>
<td>$K=12.11\pm0.02$</td>
<td>0.7442</td>
<td>0.3</td>
<td>1.77</td>
<td>1.38</td>
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<tr>
<td><strong>Weibull model</strong></td>
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<tr>
<td>A</td>
<td>80°C</td>
<td>$b=0.21\pm0.02$</td>
<td>0.9863</td>
<td>0.02</td>
<td>1.04</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>85°C</td>
<td>$b=0.37\pm0.04$</td>
<td>0.9749</td>
<td>0.06</td>
<td>1.12</td>
<td>1.04</td>
</tr>
<tr>
<td>C</td>
<td>90°C</td>
<td>$b=0.51\pm0.11$</td>
<td>0.9745</td>
<td>0.09</td>
<td>1.13</td>
<td>1.09</td>
</tr>
<tr>
<td>D</td>
<td>80°C</td>
<td>$r=0.01\pm0.07$</td>
<td>0.9805</td>
<td>0.06</td>
<td>1.09</td>
<td>1.04</td>
</tr>
<tr>
<td>E</td>
<td>85°C</td>
<td>$r=0.43\pm0.04$</td>
<td>0.9396</td>
<td>0.06</td>
<td>1.12</td>
<td>1.02</td>
</tr>
<tr>
<td>F</td>
<td>90°C</td>
<td>$r=0.48\pm0.07$</td>
<td>0.9111</td>
<td>0.1</td>
<td>1.16</td>
<td>1.05</td>
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<tr>
<td><strong>Log-logistic equation</strong></td>
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<tr>
<td>A</td>
<td>80°C</td>
<td>$\sigma=0.56\pm0.06$</td>
<td>0.9829</td>
<td>0.02</td>
<td>1.04</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>85°C</td>
<td>$\sigma=0.57\pm0.10$</td>
<td>0.9826</td>
<td>0.03</td>
<td>1.04</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>90°C</td>
<td>$\sigma=3.17\pm0.18$</td>
<td>0.9832</td>
<td>0.03</td>
<td>1.05</td>
<td>1.03</td>
</tr>
<tr>
<td>D</td>
<td>80°C</td>
<td>$\sigma=0.56\pm0.06$</td>
<td>0.9783</td>
<td>0.03</td>
<td>1.06</td>
<td>1</td>
</tr>
<tr>
<td>E</td>
<td>85°C</td>
<td>$\sigma=1.04\pm0.07$</td>
<td>0.9868</td>
<td>0.03</td>
<td>1.05</td>
<td>1</td>
</tr>
<tr>
<td>F</td>
<td>90°C</td>
<td>$\sigma=3.18\pm0.38$</td>
<td>0.9904</td>
<td>0.05</td>
<td>1.07</td>
<td>0.99</td>
</tr>
</tbody>
</table>

RF: Radio frequency dielectric heating; RMSE: root mean square error; $A_t$: accuracy factor; $B_t$: bias factor.; A: RF (80°C, 30 min); B: RF (85°C, 30 min); C: RF (90°C, 30 min); D: RF (80°C, 5 min) + UVC (25 min); E: RF (85°C, 5 min) + UVC (25 min); F: RF (90°C, 5 min) + UVC (25 min).
predicting the data (accuracy factor of 1.13 for RF alone at 90°C for 30 min and 1.16 for sequential RF (90°C, 5 min) UVC (25 min), which implies the presence of 13% and 16% error in microbial inactivation prediction. However, at the same temperature, the accuracy factor for the log-logistic model was 1.05 with an error of 5% and 1.07 with an error of 7%. Furthermore, the Bi value of the log-logistic model was closer to 1 than that of the Weibull model at 90°C. Therefore, the modified log-logistic model was a better fit for the CS inactivation curve than the Weibull model. Table 1 also shows the values of the log-logistic model kinetic parameter. The τ parameter, the position of maximum shape, has been used to study the effect of treatment variables (e.g., temperature) on microbial inactivation (Anderson et al. 1996). In the temperature range studied, we observed a decrease in τ with increasing treatment temperature. Cole et al. (1993) observed that τ moved linearly with temperature for *Listeria monocytogenes*. However, Anderson et al. (1996) found a linear movement of τ resulted in a systematic bias in the model, and the description by a quadratic response improved the goodness of fit over the tested temperature range. Even though our findings revealed that the τ value decreased with increasing temperature, a clear relationship between τ and treatment temperature was not determined due to lack of experiment data. Although the log-logistics model, same as the other models, has inherent limitation (Geeraerd et al. 2000), there are practical implications which promotes its use in food industry. The log-logistic model changes the concept of equivalence; i.e. where a process at a different temperature other than the reference temperature is deemed to have an identical effect on the reduction of Cl. botulinum. Moreover, the lower the process temperature the greater the deviation of equivalence as predicted by the log-linear and log-logistic models (Anderson et al. 1996). Generally speaking, the log-logistics model may generally be a useful tool to describe the inactivation patterns for pathogenic microorganisms.

**Basic Composition and Color Characteristic**

It can be seen from the above results showed that the sequential RF (90°C, 5 min) - UVC (25 min) treatment was the most effective at inactivating CS. Therefore, the basic compositions and color characteristics of the samples treated at RF (90°C, 5 min), RF (90°C, 30 min) and RF (90°C, 5 min) - UVC (25 min) were determined and compared with the control. The concentrations of protein and ash did not vary significantly among all samples (p > 0.05) (Table 2). After 5 min RF treatment alone, the contents of moisture and fat decreased from 1.55 % to 1.11%, from 31.80% to 29.01%, respectively. The reductions of fat and moisture in RF (90°C, 30 min) treated samples was the highest among all samples (p < 0.05). Color attributes are of prime importance because they directly affect consumer acceptability. The effects of different treatments on L, a and b values of all samples were compared (Table 2). In relation to the nontreated samples, the treated samples became darker as shown by the decreases in L values (except for 5-min RF alone), agreed with previous report on RF-treated high-heat nonfat dry milk samples (Chen et al. 2013) and on UVC-treated milk samples (Hu et al. 2015). The a values increased after different treatments, moreover, the 30 min RF alone-treated samples showed the reddest color (p < 0.05). The b values increased were noted in the treated samples compared with the nontreated ones, indicating a more yellow color. The samples treated at RF alone for 30 min were darker, redder and yellower than the samples treated at RF alone (5 min)-UVC (25 min). The color parameter values reflect color changes toward yellow and brown, suggesting that browning (Maillard reaction) might have been initiated during the RF treatment (Chen et al. 2013, Fang 2016). Changes in the color parameters of the UVC - treated samples may be ascribed to the Maillard reaction and/or to lipid oxidation (Ochoa-Velasco et al. 2014, Hu et al. 2015). Taken together, these results demonstrated the high color stability of samples after sequential RF-UVC treatments.

**CONCLUSIONS**

In summary, RF in combination with UVC is a promising technology for the inactivation of microorganisms in milk products. The modified log-logistic model adequately described the inactivation kinetics of CS in infant formula under all tested conditions. Several factors should be taken into account to precisely

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**Table 2. Basic composition and color changes of infant formula treated with RF alone or sequential RF-UVC treatment at 90°C.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Moisture Content (g/100g)</th>
<th>Fat Content (g/100g)</th>
<th>Protein Content (g/100g)</th>
<th>Ash Content (g/100g)</th>
<th>L</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nontreated</td>
<td>1.55±0.07</td>
<td>31.80±0.85</td>
<td>9.96±0.14</td>
<td>2.21±0.10</td>
<td>90.73±0.02</td>
<td>1.76±0.08</td>
<td>24.07±0.21</td>
</tr>
<tr>
<td>RF alone (5 min)</td>
<td>1.11±0.03</td>
<td>29.01±0.85</td>
<td>9.92±0.01</td>
<td>2.18±0.01</td>
<td>89.38±0.07</td>
<td>-1.43±0.02</td>
<td>25.77±0.07</td>
</tr>
<tr>
<td>RF alone (30 min)</td>
<td>0.65±0.14</td>
<td>26.53±0.28</td>
<td>9.91±0.01</td>
<td>2.22±0.00</td>
<td>87.92±0.07</td>
<td>0.16±0.04</td>
<td>25.78±0.03</td>
</tr>
<tr>
<td>RF alone (5 min) + UVC (25 min)</td>
<td>1.13±0.01</td>
<td>29.61±0.71</td>
<td>9.96±0.02</td>
<td>2.20±0.01</td>
<td>89.63±0.11</td>
<td>-1.24±0.03</td>
<td>25.29±0.04</td>
</tr>
</tbody>
</table>
determine microbial inactivation and quality changes. In future studies, we will assess the effect of RF frequency, light intensity, surface characteristics, and food composition on treatment efficacy and inactivation patterns. Additionally, it would be important to assess the effect of RF in combination with UVC on nutrient composition and functional properties of foods.

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REFERENCES CITED


Evaluation of *Cronobacter Sakazakii* in Infant Formula


