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5aPA6. Microbial inactivation by ultrasound for enhanced food safety
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Inactivation of foodborne pathogens by power ultrasound provides an alternative to traditional thermal processing modalities with potential for minimizing food-quality degradation. To enhance the efficacy of an ultrasonic treatment, it is often combined with other physical or chemical lethal factors which help to shorten the treatment time and improve quality retention. The inactivation mechanisms, thermodynamic aspects, and kinetic modeling of ultrasonic microbial inactivation will be discussed. The critical issue of how to achieve a relatively uniform acoustic field distribution in a treatment chamber will be investigated by computer simulation and verified with microbial inactivation tests. Inactivation of foodborne pathogens in liquid foods and surface decontamination of fresh produce and nuts will be used as examples to show the potential of ultrasound-assisted processes. Lastly, the effect of sonication on the quality of the treated food products will be examined.

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Inactivation of foodborne pathogens by power ultrasound provides an alternative to traditional thermal processing modalities, with potential for minimizing food-quality degradation. To enhance efficacy, ultrasonic treatment is often combined with other physical or chemical lethal factors which serve to shorten treatment time and improve quality retention. Examples for ultrasound-assisted inactivation of foodborne pathogens in a liquid food or on food surfaces are given in FIG 1 & FIG 2. In FIG 1, apple cider was treated with an ultrasound probe unit in a sono-reactor for up to 4 minutes. The ultrasound treatment was conducted at an elevated temperature of 59°C (TS) at atmospheric pressure, or at 59°C with a static pressure of 200 kPa (MTS), or at a lower and nonlethal temperature of 55°C at 200 kPa (MS). The number of inoculated *Escherichia coli* K12 was reduced by 5 log cycles (99.999%), as required by USFDA for liquid food pasteurization, in all three treatments. The times used to achieve the 5-log reduction were 1.4, 2.5, and 3.8 minutes for the MTS, MS and TS treatments, respectively. The ultrasound treatment at lethal temperature (59°C) and elevated static pressure, a process known as mano-thermo-sonication, was the most effective in microbial count reduction.

**FIGURE 1.** Inactivation of *E. coli* K12 with ultrasound in apple cider (Lee et al., 2013).

Surface decontamination of raw vegetables with ultrasound in combination with selected sanitizers was conducted in a pilot-scale continuous-flow washer, as shown in FIG 2a and 2b. The acoustic field distribution in the ultrasonic channel was relatively uniform, as shown in a test with aluminum foil (data not shown).

**FIGURE 2.** Pilot-scale continuous-flow ultrasonic washer (A) and (B). Reduction of survival count of *E. coli* O157:H7 inoculated on spinach leaves in single-leaf test (C) and batch-leaf tests (D) when treated with chlorine alone (Cl2) or chlorine in combination with ultrasound (Cl2/Ultrasound) (Zhou et al., 2012).

The microbial inactivation tests were conducted with either single spinach leaves, or with a batch of spinach leaves. Single-leaf washing was conducted to examine the maximum inactivation capacity of the washer when there are no other leaves in the tank to block ultrasound waves. The batch-leaf test presents a scenario where spinach leaves can block transmission of
ultrasound that would otherwise be absorbed by other leaves. Therefore, in batch-leaf washing, it is essential to provide good mixing to allow each side of each leaf to receive equal ultrasound exposure. The continuous-flow ultrasonic washing tank was specially designed to facilitate such mixing of produce leaves during washing. In single-leaf wash experiments, each leaf was spot-inoculated with \textit{E. coli} O157:H7 on its upper (smooth) surface with 100 μL of the inoculum and air-dried for 60 min in a laminar-flow biological hood before treatment. In batch-wash tests, about 10% of the leaves in a one-pound sample were spot-inoculated. Each washed sample was placed in a sterile stomacher bag and was 10-fold diluted for cell enumeration. Survival counts of \textit{E. coli} O157:H7 on spinach leaves after treatment were determined by TSA enriched with 50 mg/L nalidixic acid. Compared to treatment with chlorine alone, combined treatment with chlorine and ultrasound in the continuous-flow system achieved additional log reductions of 1.0 and 0.5 CFU/g for \textit{E. coli} O157:H7 cells inoculated on spinach, for washing in single-leaf and batch-leaf modes, respectively. The total microbial count reduction for single-leaf and batch-leaf washing was 4.15 and 3.35 log CFU/g, respectively (Zhou et al., 2012).

The inactivation of a microorganism with ultrasound normally follows first-order kinetics if ultrasound is the sole lethal agent. The killing rate at certain temperature and pressure can thus be determined with D value, which is the time used to achieve 90% or 1 log unit reduction in the survival count of an organism. The resistance of microorganisms to an ultrasound treatment varies. As can be seen from FIG 3, when temperature and pressure are fixed, the resistance of the five types of microorganisms as expressed in D-values is in the sequence of spores > fungi > yeasts > Gram-positive > Gram-negative cells. As a result, the inactivation rate (log CFU/min) is in the order of Gram-negative cells > Gram-positive cells > yeasts > fungi > spores (Feng 2011). The inactivation with multiple lethal factors has been reported to follow a nonlinear kinetic. In that case, nonlinear inactivation models, such as Weibull, log-logistic, and biphasic linear models can be used to describe the inactivation data (Lee et al., 2009).

The quality of food products treated by ultrasound in a disinfection operation is determined by the treatment conditions and the nature of the products. For liquid food processing that requires relatively high acoustic power densities (APD), a high intensity short time (HIST) treatment is desirable. In surface decontamination treatments, the APD has to be carefully selected to avoid damaging the product.

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**References**


