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Mechanisms for improving mass transfer in food with ultrasound technology: Describing the phenomena in two model cases

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ABSTRACT

The aim of this work was to demonstrate how ultrasound mechanisms (direct and indirect effects) improve the mass transfer phenomena in food processing, and which part of the process they are more effective in. Two model cases were evaluated: the hydration of sorghum grain (with two water activities) and the influx of a pigment into melon cylinders. Different treatments enabled us to evaluate and discriminate both direct (inertial flow and "sponge effect") and indirect effects (micro channel formation), alternating pre-treatments and treatments using an ultrasonic bath (20 kHz of frequency and 28 W/L of volumetric power) and a traditional water-bath. It was demonstrated that both the effects of ultrasound technology are more effective in food with higher water activity, the micro channels only forming in moist food. Moreover, micro channel formation could also be observed using agar gel cylinders, verifying the random formation of these due to cavitation. The direct effects were shown to be important in mass transfer enhancement not only in moist food, but also in dry food, this being improved by the micro channels formed and the porosity of the food. In conclusion, the improvement in mass transfer due to direct and indirect effects was firstly discriminated and described. It was proven that both phenomena are important for mass transfer in moist foods, while only the direct effects are important for dry foods. Based on these results, better processing using ultrasound technology can be obtained.

1. Introduction

Ultrasound technology has been widely studied as an alternative for improving food processing in such operations as defoaming, freezing, extraction, emulsification, hydration, drying and others [1]. In mass transfer unit operations, the ultrasound technology has been successfully used in different processes, such as extraction [2], drying [3–5], osmotic dehydration [6], hydration [7,8], and desalting [9].

The enhancement of the mass transfer unit operation by ultrasound technology has been attributed to different mechanisms. These are considered to be direct and indirect effects of ultrasound. The direct effects are related to the "sponge effect" and inertial flux. When ultrasonic waves travel through the product, they cause a rapid alternating compression and expansion of the tissue matrix, which is compared to a sponge squeezed and released repeatedly [10–12]. This phenomenon can keep micro channels and pores unobstructed, facilitating mass transfer [12]. Further, it can promote mass flow due to pumping. However, although it is frequently attributed with these direct effects on the mass flow [4,9,13–15], these have not been demonstrated during food processing yet.

The indirect effect is related to micro channel formation due to the acoustic cavitation [16]. When ultrasound waves travel through the product, the phenomenon of cavitation takes place in the water inside or outside the product cells, resulting in cell and tissue disruption and the consequent formation of cavities and micro channels. In fact, micro-channel formation due to ultrasound has been shown in various moist foods, such as melons, potatoes, strawberries, apples and cod [3,9,14,17,18]. In addition, the presence of these micro-channels is believed to be the main effect of the ultrasound technology in enhancing the mass transfer phenomena in food processing [6,8,9,19]. However, the formation of micro channels and its importance for mass flow has not been studied for dry foods, such as grain. As the water activity of these products is low, the lower water vapor pressure can limit cavitation, reinforcing the need for evaluation.

Consequently, this work aimed to demonstrate how these mechanisms improve the mass transfer phenomena in food pro-

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cessing, and which part of the process they are more effective in. Therefore, two model cases were evaluated: the hydration of sorghum grain and the influx of a pigment into melon cylinders.

2. Materials and methods

The mechanisms of ultrasound enhancement during mass transfer processes were studied in two kind of food: sorghum grain (representing dry foods, with low water activity) and yellow melon cylinders (representing moist foods, with high water activity). Moreover, these two foods have already shown good results when treated with ultrasound during osmotic dehydration [14] and hydration [8].

During the experiments, an ultrasonic bath with a frequency of 40 kHz and a volumetric power of 28 W/L (USC-1400, Unique Brazil) was used. This bath had its piezoelectric elements arranged below the tub. These generated the mechanical waves that are transmitted through the water (or solution), reaching the product. The volumetric power was determined following the method described by Tiwari, Muthukumarappan, O'Donnell and Cullen [20], and it was the same or very close to that used in previous works [8,15]. The temperature of the water was controlled using a stainless steel heat exchanger coupled to an external water bath, which was placed at the top of the solution inside the ultrasonic water bath.

2.1. Ultrasound mass transfer enhancement on grain

For sorghum grain, the hydration process was chosen as the evaluated mass transfer processing.

Sorghum grains (*Sorghum bicolor*) with water activity of 0.653 ± 0.001 and a moisture content of 12.46 ± 0.17% d.b. (g water/100 g of dry matter) were used. Furthermore, in order to prepare a sample with higher water activity (0.985 ± 0.003) the grains were hydrated for 3 h at 25 °C. Then, these grains were superficially dried and put into sealed containers for two days at 5 °C in order to homogenize the moisture. Consequently, the evaluation was carried out using two different conditions of water activity.

Different treatments were performed in order to identify the mechanism of mass transfer enhancement caused by the ultrasound technology (Fig. 1). These treatments helped to differentiate the indirect effects (micro-channel formation) with the direct effects (the sponge effect, inertial flow), as well as the moment these acted during processing.

Three treatments were performed for the low water activity grains:

- Treatment 1 (TS1: H) consisted of hydrating the grains (15 g of grains in a beaker with 2 L of distilled water) without the application of ultrasound at 25 °C throughout the process (2 h).
- Treatment 2 (TS2: PUS/H) consisted of vacuum packing one layer of sorghum grains in order to treat the grain with ultrasound without it becoming hydrated. This pack was placed at the bottom of the water bath to receive the sound waves better. After 3 h of pretreatment, the grains were unpacked and hydrated (beaker with 2 L of distilled water) without ultrasound application at 25 °C for 2 h.
- Treatment 3 (TS3: H + US) consisted of hydrating the grains (15 g of grains in the ultrasonic bath with 2 L of distilled water) with the application of ultrasound at 25 °C throughout the process (2 h).

Four treatments were performed for the high water activity grains. Treatments 1, 2 and 3 were the same as those applied to the low water activity grains. The other was:

- Treatment 4 (TS4: PUS/H + U) consisted of pretreating the grains, as in treatment 2, but, after that, hydrating them (15 g of grains in the ultrasonic bath with 2 L of distilled water) with the application of ultrasound at 25 °C for 2 h.

During the hydration process, the samples were periodically drained, superficially dried and their moisture content was obtained by mass balance. The sampling was carried out each 15 min for 2 h. All the treatments described above were performed in triplicate. The results were presented as the mean and the standard deviation.

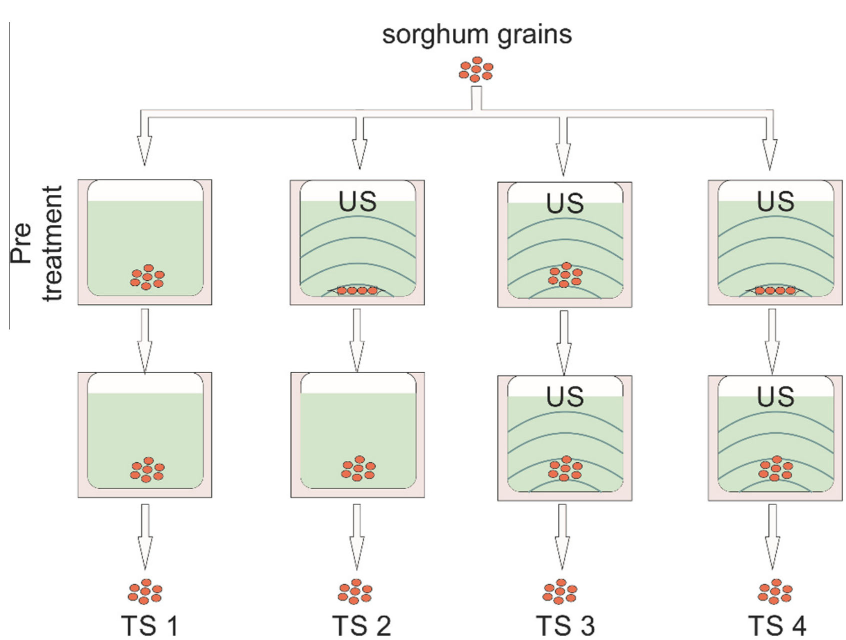

Fig. 1. Treatments to differentiate the ultrasound mechanisms (direct and indirect effects) that enhance mass transfer on the sorghum grains.