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THE EFFECT OF ULTRASOUND ON THE QUALITY OF DRIED FOOD

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ABSTRACT

Drying is the oldest technology used for food preservation that improves sustainability by removing water. Today, drying is employed to prevent microbial spoilage, delay the process of spontaneous spoilage, and restrict damage to food and agricultural products resulted from a wide range of macro-organic or mechanical factors. It has been observed that the quality of products is affected by the lengthy process required for drying. Also, due to the high heat capacities of water and energy consumption, it is necessary to examine the usage of new drying methods such as ultrasound. Despite the well-conducted studies on the use of this technology, its operational position in drying industry has not been clarified sufficiently. Therefore, the present study has aimed to investigate the use of ultrasound in this industry. Method: The method has been explained in the paper under the related heading. The results show that although using ultrasound and electric as well as magnetic pulses for food storage is still in its early stages of development, such methods have interesting applications especially in the case of liquid foods. In addition to drying, ultrasound enhances product quality and is economical in terms of money, energy, and time for the food industry and technology, and packaging.

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Introduction

Exploiting processing techniques is an important advantage in today's advanced industry. One of the most important issues in the development of food products is expert knowledge required for establishing an appropriate balance between a product and its processing equipment [1, 2, 3 و 4]. Thermal processing through modern industrial methods of food preservation is one of the most common techniques of ascertaining the sustainability of agricultural products. Drying contributes to the reduction of weight, volume, and cost of maintenance and transportation of food; it also helps control spoilage, prevent secondary infections, and combat malnutrition and various diseases associated with food. Reducing water activity (aw) to improve food preservation has been traditionally used from the dawn of history. There is no branch of food industry that does not take advantage of the principle of drying (in its modern form, though) in a variety of methods in order to preserve products. Moreover, the increased cost of energy and product quality, and the need to protect the environment have led to the reconsideration of drying mechanism in the light of modern technologies [5,6, 7]. Push technology is a facilitative method originally developed for other applications. Using ultrasound in the drying process is just one of the examples of push technology. The first studies on the use of ultrasound for drying were conducted in 1985 [8]. The results of these studies revealed that ultrasound is conductive to processing, without affecting the temperature rise. Consequently, this method began to be used to enhance the drying operation in the case of temperature-sensitive materials such as food. Initially, due to the low energy efficiency and high noise, investigation on ultrasonic drying was suspended [9]. However, the growth of new high-power ultrasonic generators has recently increased the use of this technology in drying industry [10]. Research has demonstrated that ultrasound, along with other equipollent methods, can speed up drying. Besides, compared with other processing techniques such as microwave, gamma ray, or pulsed electric field, ultrasound is a safe technique to be used. Accordingly, this technology can be employed in the food industry [11]. However, the actual interactions between ultrasound and drying products have not yet been thoroughly investigated. Furthermore, relatively few studies have been carried out on those industrial applications of ultrasound generators that would be of interest in terms of drying processes.

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Meanwhile, there are still a lot of ultrasonic applications in food processing that are in their experimental stage [10]. Modern drying technology that uses ultrasound is able to overcome this gap in drying industry [12, 13]. The aim of this study is to evaluate the effect of ultrasound on the quality of drying food.

Method

This systematic review is based on 40 studies done from 1985 to 2017, reference books on the subject of research, as well as searching of electronic data available at ISI Medline, SID, Pubmed, Science Direct, ProQuest, IranMedex, Scopus, PubMed, web science, ISC, and Google Scholar without any time limitation in both English and Persian. All of these studies conducted in that interval have been reviewed. For searching in the electronic sources, we have used the keywords of ultrasound, modern preservation technologies, shelf life of food, and dehydration. At first, 2563 articles on this topic appeared in the abovementioned databases; of these, 32 papers were chosen based on the inclusion criteria.

Research Background in the World of Science

Sound is the vibration of a material that is propagated in the form of a mechanical wave. In equilibrium, particles fluctuate around their balanced positions. When a mechanical wave passes through the material, the equilibrium is disturbed through the medium. Eventually, balance is restored to the system. Whereas mechanical waves that are propagated in solids are elastic, those propagated in fluids are acoustic [14]. Elastic waves can be transmitted either in a longitudinal (expansion stress - intermittent compression) or transverse (intermittent shear stress) manner. On the other hand, acoustic waves are only longitudinal (intermittent fluid pressure). Frequency range of mechanical waves is below 16 Hz and greater than a GHz, and it allows sound to be divided into four basic groups: infrasound (1 -16 Hz), acoustic (audible sounds, 16-20 kHz), ultrasound (20 kHz - 1 GHz), and ultrasonic sounds (above 1 GHz). A middle-aged person has a hearing range of approximately 16 kHz. However, this ability changes as one gets older. Thus, a young person hears in the range of 20 kHz, while older people only hear up to 15 kHz. It is generally accepted that waves ranging between 20 KHz and 1 GHz are ultrasonic/ultrasound [15]. Ultrasound is produced using mechanical (aerodynamic- hydrodynamic), thermal (electric discharge), optical (shot with a high-power laser), and reversible electrical and magnetic (piezoelectric, electrostriction, magnetostriction) methods. Only two of these methods are used for drying in food processing. Earlier, ultrasound would be produced using aerodynamic method (e.g., Galton and Hartmann whistle). Piezoelectricity was discovered at the end of the 19th century by Pierre and Jacques Curie. When high-quality piezoelectric materials were developed, their practical application became clearer after World War II when they became publicly available. Piezoelectric transducer produces acoustic waves as a result of the generated currents and the magnetic field. The efficiency of this device (i.e. the ratio of power supplied to the audio production powers) is not always the same and depends on the type of transducer. The most important classification of using ultrasound is that which divides it to high-intensity and low-intensity (high and low energy or power). The basic difference between the two groups of ultrasound results from the behavior of waves in each case. In the case of ultrasound with low intensity, after the passage of waves, the material restores its initial balance; however, permanent changes occur at high-intensity radiations whereby the material reaches a new balance. The primary reason for using low intensity is to transmit energy through a medium that eventually remains unchanged. Low intensity refers to using frequencies greater than 100 kHz in intensities below 10 kW / m2. Low-intensity ultrasound is usually used for non-destructive characterization of materials (NDT), measuring fundamental properties of materials, monitoring and control of industrial processes, medical diagnosis, submarine detection, acoustic and microscopic spectroscopy, and so on [14]. In the food industry, low-intensity waves are mainly used to describe food properties (composition, structure, and physical state) and control a process like detecting a foreign body [16-20]. On the other hand, the purpose of using high-intensity ultrasound is to change an environment in which waves are propagated. These waves occur at frequencies between 18 and 100 kHz with an intensity higher than 10 kW /m2. Examples of using high-intensity ultrasound waves are to be found in welding, machining brittle materials, sorting and moving particles in fluids, cleaning surfaces, atomizing liquids, forming and processing nanomaterials, as well as medical treatment [15]. Other applications of high-intensity ultrasound waves include food processing, changing viscosity, emulsification, cell disruption, polymerization, degassing of liquid foods, extraction of enzymes and proteins, disabling microorganisms, cutting, improving the process of freezing and unfreezing, crystallization, filtration, pasteurization, and sterilization [16,13, 21, 12]. In addition, high-intensity ultrasound can be used to expedite drying processes, in particular food drying [8. 9, 13, 22]. The majority of articles examined in this study have employed high-power ultrasound using piezoelectric transducer. The main parameters used for describing the sound wave or the source have been frequency, wavelength, and amplitude, velocity of propagation, phase transitions, and intensity. The most significant parameter in foods that undergo drying is their quality. Yet what determines this quality is the method used for processing (drying).

The study carried out by Kowalski et al. revealed that ultrasound causes a slight reduction in the water activity (aw) of dehydrated apple [23,24]. In a study on the effect of ultrasound on water activity (aw), Kroehnke et al. reported that ultrasound does not affect the water activity (aw) of dehydrated potato [25]. In two other studies, similar results were observed regarding the effect of convective drying using ultrasound and microwave on drying carrot [26] and apple [27]. In another research, the positive impact of using ultrasound has been shown for water activity (aw) in the case of drying green pepper through convection and microwave-convection [28].

Bantle and Eikevik did not report the effect of ultrasound on the color of dried green peas [29]. Schössler et al. also expressed that ultrasound does not affect frozen dried chili [30]. However, another similar study [27] that used ultrasound revealed a reduction in the overall color change of dried apple. In that same research, it was found that ultrasound alters the color of dried samples to various shades of red [27]. On the other hand, another study reported that using ultrasound causes a significant decrease in the overall color change of dried potato [25]. Furthermore, Ozuna et al. reported the effects of ultrasound on cod fish dried in low temperature [31].

Sabarez et al. conducted a study on food tissue and observed the stiffness of an apple which had been dried using convective method; it was suggested that the sample dried without using ultrasound was a little stiffer than the sample processed using ultrasound. Nevertheless, the difference between their results was not significant with regard to standard deviation [32].

The stiffness level of dried cod fish in low temperature was investigated in the study by Ozuna et al. It turned out that ultrasound had reduced stiffness in both dried and rehydrated samples [31]. Santacatalina et al., using simple compression test, studied the stiffness of dried apple in low temperature and observed a reduction in stiffness in the case of applying ultrasound at 10 °C; in contrast, the stiffness of the dried apple was not affected by applying ultrasound at -10 °C [33]. Banaszzak & Pawlowski studied the effect of ultrasound on elasticity, mechanical resistance, fragility, and transparency. They conducted tests on dried apple slices and observed acoustic emissions during the tests. Their results indicated that ultrasound increased both resistance and elasticity of the drying material. Ultrasound helped make dried slices crispier than those slices which had been dried using only the convective method [34].

Gamboa-Santos et al. carried out a study on rehydration compliance and proposed it as another physical parameter for describing dried food. They observed that there is no difference in the ratio of rehydration when either ultrasound or pure convection methods are used to dry strawberry [35].

Another study conducted by Schössler reported that ultrasound does not affect rehydration in frozen dried chili [30]. In contrast, a different study proved that ultrasound increases the ratio and amount of rehydration in dried potato [25]. Other similar results have reported an improvement in the ratio and amount of rehydration in drying green pepper using microwave-convection [29], drying salted cod fish at low temperature [31], and drying apple [33]. Gamboa-Santos investigated the sustainability of Vitamin C by applying convective drying to strawberry, and observed that the total amount of ascorbic acid is very high; however, using ultrasound reduced this compound [35]. Moreno et al. drew similar results from studying apples dried at normal temperature, yet ultrasound, they observed, destroyed a significant amount of ascorbic acid [36]. In a different vein, the study of Schössler et al. proposed that ultrasound does not destroy Vitamin C in frozen dried chili [30]. Szadzińska et al., addressing advanced processing using ultrasound, suggested that Vitamin C retention increased in green pepper [28]. Fernandes et al. reported an increase in the retention of Vitamins A, B_1, B_2, B_3, B_5, B_6, D, and E in the case of applying convective drying to an apple, and they suggested that convective drying increases Vitamins B_1, B_2, B_3, and B_6 but reduces Vitamins E and B_5; nevertheless, it did not have a significant effect on Vitamins D and A [37]. The results of aforementioned studies cannot explain the relationship between using ultrasound and Vitamin retention. The impact of ultrasound can be either positive (mainly at low-temperature drying) or negative (chiefly at high-temperature drying), but there is no direct dependency between the analyzed parameters. Natural pigments such as carotenoids and anthocyanins are another important nutritional group. Kroehnke et al. conducted a study on pigments whereby they studied maintaining carotenoids after applying convective and microwave-convection drying methods to carrot with and without ultrasound. Their findings implied that using ultrasound in a positive manner maintained some materials in a convective-dried carrot and improved the retention of carotenoids in microwave-convection-dried carrot [26]. Konopacka et al. reported that ultrasound does not influence the ultimate content of anthocyanins in dried berry [38]. The extensive study of Kroehnke et al. dealt with other chemical parameters (such as antioxidants activity and the content of total polyphenols) and suggested that the antioxidants activity of carrot samples improved because of applying ultrasound in both the convective drying process and microwave convection method; however, the results did not indicate such improvements for polyphenols [26]. In addition, Rodríguez et al. proposed that ultrasound reduces the content of total polyphenols [39]. Rodríguez et al. similarly studied the loss of antioxidants capacity, total polyphenols, and the total content of flavonoid while drying apple via the convective method. It turned out that losing the antioxidants capacity is related to drying temperature at the time of applying ultrasound. The use of the drying factor and ultrasound at lower temperatures helped reduce the Antioxidant capacity. On the other hand, this parameter was increased in the case of higher temperatures. It has been observed that applying ultrasound, independent from drying temperature, reduces total polyphenols and the content of flavonoid [40]. Santacatalina et al., also, studied the process of drying apple at low temperature [41, 33]. These studies concluded that ultrasound lessens all of the investigated parameters such as antioxidantes, total polyphenols, and the content of flavonoid [41, 43]. Méndez et al. came to the conclusion that applying ultrasound in drying mango and banana reduces both antioxidants activity and the content of total polyphenols of these fruits [42]. Finally, Moreno observed a slight reduction in antioxidants capacity in the case of applying ultrasound to naturally frozen dried apple [36].

Results

1. A highly important physical parameter of dried food is the level of water activity. Regarding the availability of water as solvent, reagent, or as a favorable environment for the growth of microorganisms (including pathogenic ones), there is sufficient evidence suggesting the usefulness of water activity in all oxidation processes, enzymatic browning reactions, and non-enzymatic Millard reaction [46-49], besides its positive effects in the growth of bacteria, fungi, mold, yeasts, etc.
2. The color of products is a very important parameter indicating a key factor (even the determining factor) in judging the quality of that product. Next to smell, color is one of the first stimulants that can affect human mind even from far distances. Customers will be persuaded to buy or reject the presented product at first glance. In addition, given the absence of special equipment or time, color, smell, and touch are usually the only judging tools available for evaluating the quality of such products as fruits, vegetables, bakery products etc.
3. Tissue is another physical quality factor in food. The parameters of a product's appropriate tissue can be assessed by touching or tasting it.
4. Ultrasound can inactivate enzymes and microbes. In the case of food, quality and safety are the major factors determining the suitability of the product as well as its marketability. Enzymes and microorganisms alike are responsible for many deteriorating processes; therefore, it is crucial to slow down their activities. As previously mentioned, almost all negative biochemical conversions and the activity of pathogenic microorganisms may be due to reduced water activity. On the other hand, it has been found that one might inactivate enzymes and microbes using ultrasound [16, 45]. Gamboa-Santos examined the microbiological quality of strawberry immediately after drying and after six months of storage. All of the aerobic bacteria, enterobacters, aerobic and anaerobic thermosaccharolyticum, mold, and finally the yeast were studied. Yet, the results indicated no significant difference between various types of drying (convective drying with or without ultrasound) [44].
5. The results of studies on chemical parameters suggest that many researchers concur on the need to maintain nutrients, vitamins, and antioxidants.
6. Most of the quality parameters either are not affected by acoustic waves (including water activity and the content of vitamins) or have not shown positive changes (in terms of color, size of antioxidants, and stiffness). Inactivation of enzymes and microbes is the chief positive effect of using ultrasound. Such a phenomenon leads to increased durability and reliability, as it slows down the process of decay. At the end of this section, it should be stated that there is a long debate over the appropriateness of using ultrasound in food processing (especially for drying).

Conclusion

The use of ultrasound has demonstrated significantly positive effects on drying. However, the results are greatly dependent on the method of drying (microwave, convection, freezing, etc.), drying conditions (temperature, speed, and relative humidity of the drying material), and the type of materials (texture, structure, etc.). Choosing appropriate methods and processing parameters can accelerate drying significantly. This, in turn, improves the efficiency of processing and eventually reduces energy consumption. In addition, based on the findings of this study, it could be said that the use of ultrasound does not affect the quality of products, and this method will over time become more effective.

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