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Review

# Microwave processing techniques and their recent applications in the food industry

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## ABSTRACT

*Background:* Microwave processing techniques have been extensively used in the food industry due to its significant reduction in cooking time and energy consumption. Microwave processing technologies such as microwave drying, heating and sterilizing play a significant role in food quality and safety control. However, few reviews have been published in recent years summarizing the latest developments in the application of microwave technology in the food industry.

*Scope and approach:* This review focuses on recent applications of microwave processing technologies including microwave drying, heating, and sterilizing in fruit (banana, apple, olive, sour cherries, pomegranate arils, blueberries, kiwifruit, aronia, strawberry, and grape tomato), vegetables (potato, bamboo shoot, purslane leaves, onion, green bean, pumpkin, eggplant, edamame, sea tangle, garlic, kale, red cabbage, tomato, cassava, lentils, chickpea, broccoli, Brussels sprouts, cauliflower, jalapeño peppers, and coriander foliage), and meat products (sardine fish, restructured silver carp slices, sea cucumber, beef semitendinosus muscle, bovine supraspinatus muscle, camel longissimus dorsi muscle, foal meat, bovine gluteus medium muscle, chicken steak, mature cows semimembranosus and semitendinosus muscles, kavurma (a ready-to-eat meat product), salmon, cod, drumettes, and beef slices), changes in product quality as affected with microwave processing are discussed in details, and future directions of research are presented.

*Key findings and conclusions:* Microwave drying has the advantages of low energy consumption and high efficiency as compared to conventional drying, while producing more porous structure of foods. Microwave drying usually combines with other conventional drying to enhance the quality of a food product. Compared with the traditional method, microwave heating or cooking can generally retain higher levels of bioactive components, antioxidant activity and attractive color of vegetables, while microwave cooking with water can cause a serious drop in nutrients due to leaching and thermal liability. Microwave sterilization has the capacity to completely inactivate microorganisms and effectively destroy enzyme activity, and less effect on antioxidant activity, texture and color of food products compared with conventional pasteurization.

## 1. Introduction

Microwaves are electromagnetic waves with the frequency varies from 300 MHz to 300 GHz (Chandrasekaran, Ramanathan, & Basak, 2013). The frequency of the microwave oven is defined to avoid interference with communications. The lower the microwave frequency, the better the penetration. Generally speaking, to balance efficiency and cost, home microwave frequency is 2.45 GHz,

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**Nomenclature**

| | |
|---|---|
| *L* | Lightness (CIELab tristimulus color values) |
| *a* | Redness (CIELab tristimulus color values) |
| *b* | Yellowness (CIELab tristimulus color values) |
| Deff | Effective moisture diffusivity |
| $R^2$ | Determination coefficient |
| RMSE | Root mean square error |

while industrial microwave frequency is 915 MHz or 2.45 GHz. The microwave field is an alternating magnetic field, in which, polarity molecules from the original random thermal motion changes according to the orientation of the electric field direction (2.45 billion times per second) (Menéndez et al., 2010). The ability of food material to convert microwave energy into heat can be understood by its dielectric properties (Franco, Yamamoto, Tadini, & Gut, 2015; Curet, Rouaud, & Boillereaux, 2014). Dielectric properties show the nature of electrostatic energy saving and loss in the electric field, usually expressed as dielectric constant and dielectric loss. Non-uniformity is a characteristic of microwave processing. The microwave pattern is responsible for creating a hot spot and cold spot, and the hot spot is concentrated in a region where the electromagnetic field intensity is higher (Kumar, Saha, Sauret, Karim, & Gu, 2016). Therefore, it is important to improve the uniformity during microwaving. Microwaving has been enormously applied in the field of food processing such as drying, heating or cooking, pasteurization and preservation of foods (Chandrasekaran et al., 2013).

Like cooling (Sun & Hu, 2003; Wang & Sun, 2002a, 2002b; Sun & Wang, 2000; Sun, 1997; McDonald, Sun, & Kenny, 2000; Sun, & Brosnan, 1999; Zheng, & Sun, 2004; Wang & Sun, 2004) and freezing (Kiani, Zhang, Delgado, & Sun, 2011; Ma et al., 2015; Xie, Sun, Xu, & Zhu, 2015; Cheng, Sun, & Pu 2016; Pu, Sun, Ma, & Cheng, 2015; Cheng, Sun, Zhu, & Zhang, 2017, Xie, Sun, Zhu, & Pu, 2016), drying (Cui, Sun, Chen, & Sun, 2008; Yang, Sun, & Cheng, 2017; Pu, & Sun, 2016a) is a common processing method used in the food industry. In particular, microwave drying has many advantages, including lower shrinkage, lower bulk density, and higher rehydration ratio, dehydration rate and energy saving than traditional drying (Aydogdu, Sumnu, & Sahin, 2015; Duan, Zhang, Mujumdar, & Wang, 2010; Horuz & Maskan, 2015). However, more porous structure of foods caused by microwave drying occurs due to faster drying rate when compared with traditional drying (Aydogdu et al., 2015; Horuz & Maskan, 2015). In addition, overheating normally results in scorching and the production of off-flavors especially during the final stage of microwave drying (Horuz, Bozkurt, Karataş, & Maskan, 2017). Usually, in order to improve the drying rate and enhancing the quality of products, the microwave drying method and other traditional drying methods are employed in combination.

Microwave heating or cooking (Półtorak et al., 2015) can retain high levels of bioactive components, antioxidant activity and attractive color of vegetables, when cooking without water or with a small amount of water (Akdaş & Bakkalbaşı, 2016; Pellegrini et al., 2010; Tian et al., 2016; Xu et al., 2014). It can also decrease the antinutritional factors, meanwhile increase in in-vitro protein digestibility (Hefnawy, 2011; Xu et al., 2016; Yang, Hsu, & Yang, 2014). However, microwave cooking with massive water can cause a great drop in nutrients due to leaching and thermal liability (Dolinsky et al., 2015; de Lima et al., 2017).

Microwave sterilization can not only effectively reduce the potential microorganisms in food to ensure food safety, but can also inactivate the enzyme to maintain the nutrition of food (Chen et al., 2016; Marszałek, Mitek, & Skąpska, 2015). Increase in microwave power and time increases the effectiveness (Valero, Cejudo, & García-Gimeno, 2014). In addition, the non-uniformity of microwave sterilization can influence the quality of the product and shorten the shelf life.

Due to the above advantages, microwave processing techniques have been extensively used in the food industry. However, few reviews have been published in recent years summarizing the latest developments. Therefore, this review focuses on the applications of microwave processing technologies in the last few years. The technologies covered include microwave drying, heating or cooking, and sterilizing in vegetable, fruit and meat processing. Attentions are paid to the quality changes of food product after microwave processing and future research directions.

## 2. Microwave drying

### 2.1. Mechanism of microwave drying

Microwave drying, such as vacuum-microwave drying, hot air-microwave drying, microwave-far infrared combination drying, microwave-convective drying and microwave-freeze drying, is a complex process involving heat and mass transfer, which is based on the volumetric heating (Pu & Sun, 2015, 2016b, 2017; Cui, Xu, Sun, & Chen, 2005; Cui, Xu, & Sun, 2003, 2004a, 2004b). Vapor is generated inside a food item and then spread through internal pressure gradient. Because of the strong penetrability of microwave, food inside and outside are heated at the same time and the temperature of food rises simultaneously.

Microwave drying translates the high frequency electromagnetic energy into heat, thus liquid moisture is intensively evaporated and transported toward the food material surface (Li, Wang, & Kudra, 2011). In the process of microwave drying, two successive stages should be considered: liquid evaporation (Arballo, Campañone, & Mascheroni, 2010), and drying consisting of three stages including heating up, constant rate drying and falling rate drying (Bal, Kar, Satya, & Naik, 2010).

### 2.2. Moisture migration and distribution during drying process

During constant and falling rate-drying periods, effective moisture diffusion phenomenon shows an overall mass transport property of water in the food material, including liquid and vapor diffusion, vaporization-condensation, hydrodynamic flow and other possible mass transfer processes. The effective moisture diffusion coefficient is affected by many factors such as composition, moisture content, temperature, and the porosity of food material, which can be explained by the Fick's diffusion equation, and it is the only physical mechanism to transfer the water to surface.

In order to understand the moisture migration and distribution, Jiang, Zhang, Mujumdar, and Lim (2012) employed a nuclear magnetic resonance (NMR) spectroscopy to study banana dried by microwave-freeze drying, as the spin-spin relaxation time, which is the time of revocation of transverse magnetization, and peak area can reflect the nature and content of water. With spin-spin relaxation time increasing, the three peaks represent strongly bound water, bound water, and free water components, respectively. From Fig. 1, it can be seen that as the drying process continues, the area of the three peaks is smaller, which means that the moisture content of food is falling. At the same time, the relaxation time of the three peaks is close to 0, which means that the structure of water and food are closer. During banana chips dried by microwave-freeze drying, from the moisture content and drying rate curves, drying