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# Effect of ultrasound and microwave assisted vacuum frying on mushroom (*Agaricus bisporus*) chips quality

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ABSTRACT

The effect of ultrasound on frying rate and product quality of fried mushroom chips (FMC) was investigated using microwave assisted vacuum frying (MVF). To determine the effectiveness of ultrasound during frying at different microwave power levels (800, 900 and 1000 W) and different frying temperature (80, 85 and 90 °C), quality parameters (moisture loss rate, oil uptake rate, texture, color and microstructure) of the FMC obtained from vacuum frying (VF), MVF and ultrasound assisted microwave vacuum frying (UMVF) were analyzed and compared. It was found that UMVF accounts for the highest moisture loss rate with the increase of microwave power and frying temperature. Considering the oil uptake rate, UMVF could reduce oil content by 16–20% compared to VF and MVF. UMVF chips also had better texture and the most acceptable color characteristics among the frying techniques studied. The optimum condition of 1000 W and 90 °C achieved a higher moisture evaporation rate and lower oil content. Microstructure observations showed that the surface structures of UMVF fried samples were the smoothest and also showed less distorted cells. Based on the parameters evaluated, UMVF mushroom chips had the best-fried matrices as well as accelerated frying rate, lower oil uptake, improved texture and color.

## 1. Introduction

Button mushrooms are the most consumed mushroom throughout the world. Because of their short shelf life, they cannot be stored for more than 24 h at room temperature (Mohapatra, Bira, Kerry, Frías, & Rodrigues, 2010). In view of their highly perishable nature, the fresh mushrooms have to be processed to extend their shelf life for off-season use. Among the various methods employed for preservation, canning is the most frequent method adopted on a commercial scale (Walde, Velu, Jyothirmayi, & Math, 2006). Mushrooms can be processed in many other ways to extend their shelf life such as frying, drying, pickling, etc. Fried mushroom chips (FMC) could be a better way to preserve them in the shortest possible time. There is a growing interest in producing healthier snack food and mushroom chips with lower oil content is a good option and it has been of great interest to many product development specialists.

Fried foods are popular due to their taste, distinctive flavor, aroma and crunchy texture (Fellows, 2017; Saguy & Dana, 2003). During frying, water is removed from the product and the heated oil acts as a heat transfer medium. As the frying proceeds, moisture evaporates which in turn changes the cellular structure of the product. Pores are formed and oil penetrates into the product. In conventional deep fat frying, the oil temperature is high, ranging from 160 to 180 °C which may cause deterioration of some nutrients and the exposure to the air, it causes oxidation of the oil. The main obstacle to satisfy consumer acceptance of fried food product is its high oil uptake during frying. A report on vacuum frying of high-quality fruit and vegetable snack by Silva and Moreira (2008), showed that the vacuum fried products could retain their natural color and flavor better. In general, a frying process done using at vacuum prevents deterioration of quality such as browning and fading of the fried product (Fan, Zhang, & Mujumdar, 2005; García-Segovia, Urbano-Ramos, Fiszman, & Martínez-Monzó, 2016). As such, vacuum frying is a viable option to produce high quality dried fruit and vegetable with a far shorter processing time than conventional frying. Although, vacuum frying is used to produce low oil content fried food products it still has some difficulties to meet the final product quality attributes. Because of depressurization during vacuum frying, the rapid change in pressure (vacuum to atmospheric) the

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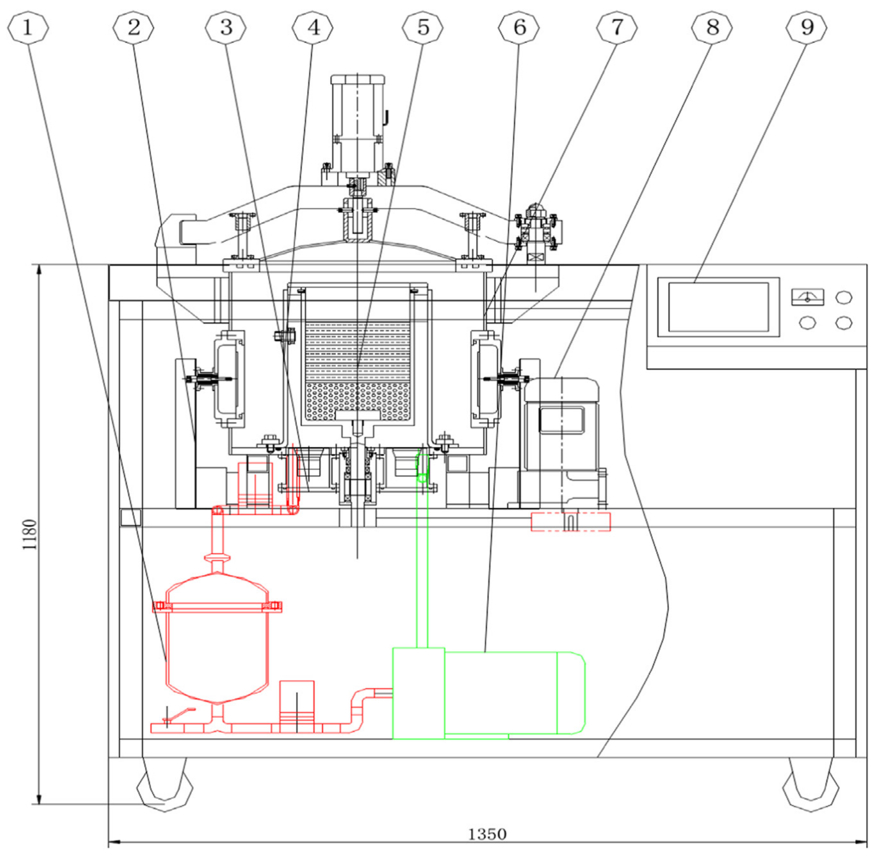


**Fig. 1.** Schematic diagram of the ultrasound and microwave-assisted vacuum frying instrument. 1. Oil tank, 2. Microwave source and heating system, 3. Ultrasound source and vacuum pressure balance system, 4. Vacuum chamber, 5. Frying chamber, 6. Circulation pump, 7. Electric cabin door system, 8. Bending and centrifugation system, 9. Controller and operation panel.

vacuum fried chips have high oil content (Basuny, Arafat, & Ahmed, 2012). Considering these problems hybrid methods are recommended to overcome these limitations of vacuum frying (Szadzińska, Łechtańska, Kowalski, & Stasiak, 2017).

Conventional vacuum fryers rely on conduction heat transfer from hot plates which is a slow process, difficult to control and requires a large surface area. Therefore, conventional vacuum frying has high operating and installation cost. To prevent significant quality loss and to achieve fast and effective dehydration, microwave heating provides an alternative. Microwave heating is one of the rapid heating systems that uses electromagnetic waves in the range of 300 MHz-300 GHz, it significantly shortens the processing time for vacuum frying. Because of its rapid heating ability, it has many applications in the field of food processing such as cooking, drying, thawing, pasteurization and preservation of food materials. It helps to produce high-quality products and reduces the cooking time which saves energy (Zhang et al., 2017). The application of microwave during vacuum frying helps to lower the oil content (Quan, Zhang, Zhang, & Adhikari, 2014; Su, Zhang, Zhang, Adhikari, & Yang, 2016). An alternative microwave and convective hot air application were analyzed by Das and Arora (2018) for rapid mushroom drying. They suggested that their hybrid drying process increased the drying rate and improved the color and other quality parameters.

Ultrasound is a traditional technology in the food industry but its uses have been increasing for drying. The mechanical waves of ultrasound range from 20 kHz to 10 MHz. Commonly low frequency, high energy, power ultrasound in the kHz range is used to assist the dehydration process (Ercan & Soysal, 2013; Fan, Zhang, & Mujumdar, 2017). Research suggests that applying ultrasound to drying resulted in a shorter drying time and could reduce the total energy consumption (Çakmak, Tekeoğlu, Bozkır, Ergün, & Baysal, 2016; do Nascimento, Mulet, Ascheri, de Carvalho, & Cárcel, 2016; Su, Zhang, Zhang, Liu, & Adhikari, 2018; Szadzińska, Kowalski, & Stasiak, 2016). Moreover, due to the small "temperature effect", the quality of the products obtained were noticeably better as compared to the controls without ultrasound treatment (Musielak, Mierzwa, & Kroehnke, 2016). Szadzińska et al. (2016) used a microwave and ultrasound-enhanced hybrid drying system to dry strawberries, where they concluded that both of the energy sources acted together and accelerated the drying rate due to "synergistic effect" which helped to reduce the drying time. The drying rate of mushrooms that were pretreated with electro plasmolysis (EP) (100 V/40 s) and ultrasound (35 kHz/30 min) increased by 37% and ultrasound also preserved the phenolic content and better color compared to EP (Çakmak et al., 2016). A combination of ultrasound and microwave in vacuum frying system was investigated by (Su, Zhang, Bhandari, & Zhang 2018) who found that the UMVF increased the moisture evaporation kinetics, the oil uptake of potato chips was reduced and the chips became crispier. Recent studies suggested that application of ultrasound during drying and frying of potato chips, sweet potatoes, strawberries, apples and green peppers led to higher quality products (Su, Zhang, Zhang, et al., 2018; Su, Zhang, Bhandari, et al., 2018; Szadzińska et al., 2016; Szadzińska et al., 2017).

The aim of this study was to investigate the impact of vacuum frying technology that combined both ultrasound and microwave on quality parameters (moisture removal, oil uptake, texture and color) of fried mushrooms and compare the above-mentioned impact with that of vacuum frying and microwave combined vacuum frying technology.

## 2. Materials and methods

### 2.1. Raw materials

Fresh white button mushrooms (*Agaricus bisporus*) of uniform size, whole, healthy, free of any debris (mold, rots or deterioration) and without unpleasant odor were purchased from a local market in Wuxi, China. They were stored at 4 °C (for a maximum of 72 h) before use. Soybean oil (Fulinmen Zhongliang Co., Shanghai, China) was used as the frying medium and it was also purchased from a local market.