A study on decompresses heat pump dryer for drying of shiitake mushrooms at medium temperature

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Abstract. This study developed a drying method and a dryer that are optimized for shiitake mushrooms. They are mainly being cultivated and consumed as food and medicine in Korea, Japan, China, and Southeast Asia. They generally contain lots of moisture. For this reason, the use of a dryer causes problems such as decomposition and spoilage, and natural dry processing is preferred. To resolve these problems, various drying methods have been proposed (e.g. hot air drying, heat pump vacuum drying) but there has been a difficulty in maintaining a medium-temperature range of 30 to 40°C, the optimal temperature environments for retaining their main components. The study developed a 2-stage decompresses resistive heat pump dryer that can operate also in medium-temperature environments - existing decompresses heat pump dryers have been able to operate only in high-temperature environments. A dryer optimized for shiitake mushrooms that are being produced and distributed in large quantities was proposed, and the utility of the machine was proved through experiments.

1. Introduction
Shiitake mushrooms are edible mushrooms belonging to Lentinus, Pleurotaceae, Agaricales, Agaricomycetes. They are being cultivated and consumed mainly in Korea, China, Japan, and Southeast Asia. The food of nutritional value that has unique fragrance and flavor contains nutrients (e.g. carbohydrates, protein, minerals, vitamins), and therefore is effectively used as food and medicine[1,2]. Notably, in [3] reported them as having anti-cancer effect and then there was a sharp rise in consumption. They contain around 90% moisture, have the most vitamin C contents among mushrooms, and are considered as an excellent alkaline food.

But because of difficulty in storage (e.g. decomposition, spoilage) caused by their high moisture contents, processing operation methods have been proposed (e.g. bottling, a method where they are salted and then dried by sea breeze)[4]. As for drying, sun-drying has been mostly performed; but there is a problem - it is difficult to obtain products of uniform quality, since they are damaged by spore dispersion and insects and easily spoil due to microbial contamination, etc[5]. To resolve this problem, various methods (e.g. high temperature hot air drying, high temperature heat pump vacuum drying, drying with infrared rays) have been proposed, the methods helping to retain the nutrients and colors for a long period of time when storing them after drying[6].

Incidentally, dryers for agricultural and marine products are important pieces of equipment that facilitate maintaining the long-term freshness of them and storing them for a long period of time by removing the moisture inside them - studies of various drying methods with the use of the machines are being performed and the methods are being widely used in the agriculture and fisheries industry. Dryers can be categorized into grain dryers and dryers for agricultural products, marine products, and...
forest products according to what is dried; into small and large ones according to capacity; and into ones powered by oil, gas, electricity, hot-air, and heat pump and ones powered by two or more sources (that is, hybrid) according to energy sources for dryers[7].

Hot-air dryers are generally used. They take shorter drying time than sun-drying, but are exposed to high-temperature air for a long time. For this reason, they have these disadvantages - quality deterioration caused by loss of amino acids, surface color change, etc.; high energy consumption while drying[8]. Heat pump vacuum dryers are known to have better energy conservation effect than hot-air dryers, since they can recover the heat used thanks to the nature of their cycle - the difference in energy efficiency between them is more than double[9,10]. Heat pump vacuum dryers are categorized into pressure drying, ambient pressure drying, and low pressure drying according to pressure; low pressure drying is categorized into freeze-drying method and low pressure drying method. In general, freeze-drying method is performed in a high-degree vacuum state and a low-temperature environment. Despite its advantages - the lower degree of damage of food texture; the high retainability of moisture and flavor components - it is mainly used for high-price foods (e.g. coffee, beef) due to high drying costs[11,12].

As for low pressure drying method, it minimizes various chemical reactions, since it is performed at a relatively low temperature, and requires lower drying costs than freeze-drying method. In addition, it produces excellent quality products (e.g. the low oxygen concentration while drying prevents the decomposition and spoilage of the ingredients)[13]. But it has a disadvantage - the high cost of facility and the high operating cost. Also the development of it has not yet progressed, because there are only a limited number of refrigerants that can be used in high-temperature environments.

When drying shiitake mushrooms with a hot-air dryer, the operating temperature range is generally from 40 to 60°C. It is thought that when they are dried at a temperature below 45°C, their quality deteriorates (e.g. spore dispersion; the cap of a shiitake mushroom splits, causing its end to be curled). And it is thought that when they are dried at a high temperature above 55°C, there is concern about them being damaged by the heat, since they initially have high moisture contents[14].

However, a study of shiitake mushroom temperature change and its main components showed that there was no big change in protein contents when the temperature was around 30°C or higher; the fat contents hardly changed when the temperature was 40°C or higher; the reducing sugar contents also changed dramatically when the temperature was 30°C; the higher drying temperature meant the lower free amino acid contents; and the higher drying temperature meant the higher amino acids in the protein[15,16]. Judging by these, it can be seen that shiitake mushrooms can remain in optimal condition when the temperature is changed in the medium-temperature range of 30 to 40°C.

Hence the study designed and proposed a decompresses heat pump dryer (DHPD) that operates only under temperature variations, not under wind variations. The machine, optimized for drying them, can dry them at a medium-temperature of 35°C. To prove this, a physicochemical evaluation was performed, and the dryer proved to be excellent by comparative analysis with what was produced by natural drying and hot air drying.

2. Experiment method

2.1. Experimental material
Shiitake mushrooms, the testing materials, were harvested in 2017 at Hansan-myeon, S emotions, Chungcheongnam-do, Republic of Korea; to minimize their quality change during storage, they were stored in a low temperature refrigerator that worked at 5°C - 30 kg of raw shiitake mushrooms were used for the drying.

2.2. Experimental conditions
To dry them at a medium-temperature, the optimized environment for drying them, the 2-stage decompresses resistive decompresses heat pump dryer was designed, and they were dried as in figure 1. As for drying methods, sun-drying(natural drying), hot air drying, and the decompresses heat pump were performed. Sun-drying was performed for 3 days (8 hours of sunshine duration per day); hot air drying was performed with the use of Lee Hwa Industry's dryer LH-1200 (the drying temperature: 60 °C; the drying time: 24 hours); and decompresses heat pump was performed under these conditions - the amount of decompression: -2,000mmAqg; the drying temperature: 35 °C; the drying time: 18 hours.

2.3. β-glucan measurement conditions
β-glucan is well documented as lowering plasma lipids in human and animal studies[17-21]. At dietary intake levels of at least 3 g per day, oat fiber β-glucan decreases blood levels of LDL cholesterol and so may reduce the risk of cardiovascular diseases[22,23]. The β-glucan contents were measured by the method in [14] and with the use of Megazyme’s Beta-glucan kit. The total glucan value minus the value of α-glucan is the value of β-glucan.

2.4. Total polyphenol content measurement conditions
Polyphenols are abundant micronutrients in our diet, and evidence for their role in the prevention of degenerative diseases such as cancer and cardiovascular diseases is emerging[24]. Over the past 10 y, researchers and food manufacturers have become increasingly interested in polyphenols. The chief reason for this interest is the recognition of the antioxidant properties of polyphenols, their great abundance in our diet, and their probable role in the prevention of various diseases associated with oxidative stress, such as cancer and cardiovascular and neurodegenerative diseases.

100mL of distilled water was added to 5g of the sample. Then it was homogenized and agitated for 15 hours at room temperature. Next, it was centrifuged for 5 minutes at 10,000 rpm, and was filtered through Whatman No. 2 to be constant volume of 100mL. In accordance with Folin-Denis method, an absorbance value was measured at UV spectrophotometer (Infinite200pro, Tecan, Austria) 720 nm; the standard material used was gallicacid (Sigma).

2.5. Antioxidant capacity measurement conditions
As for free radical scavenging activity, the sample reducing power was measured through the method of Brand-Wiliams, etc[17]. 500µg/mL of 0.1mM DPPH in Ethanol Solution was added to 500µg/mL of the extract from the sample. Next, it was mixed well for 10 seconds, and was left as it was for 20 minutes at room temperature, and an absorbance value was measured at 525nm with the use of the microplate reader (Multiscan GO, Thermo Scientific co. Ltd., USA). Free radical scavenging activity was expressed as an absorbance ratio (%) between the sample addition group to the non-addition group, and it was calculated through the equation below:

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\text{Free radical scavenging activity(\%)} = \frac{(B-A)}{B} \times 100
\]  

(1)

Here, A is absorbance value of the sample addition group and B is absorbance value of the non-addition group.

3. Experiment result

3.1. Moisture content

Table 1 shows the moisture contents measured through the loss-on-drying method specified in Korean Food Code. The decompresses heat pump showed the highest efficiency in terms of reduction of moisture contents closely related to food storage and to the maintaining of food quality during distribution - the method reduced the moisture contents by 7.45 % when drying was performed for the same amount of time.

| Drying method | DHPD | Sun drying | Hot air drying | Raw Mushrooms |
|---------------|------|------------|----------------|---------------|
| Moisture contents | 7.45 | 22.23 | 19.74 | 84.11 |

3.2. β-glucan

According to the result of an analysis of β-glucan in each drying sample, the β-glucan contents in the sample produced through the decompresses heat pump were highest (25.94%), those in the sample produced through natural drying were second highest (22%), and those in the sample produced through hot air drying were third highest (21%).

3.3. An analysis of a functional component

According to the result of measurement of the contents of total polyphenol(figure 2), a functional component contributing to antioxidant activation, those were highest in the sample produced through the decompresses heat pump (0.76 µg/g); those in the sample produced through sun-drying and hot air drying and those in raw shiitake mushrooms were similar.
3.4. An analysis of antioxidant activation

According to the result of an analysis of antioxidant activation through measurement of SOD activation and DPPH radical scavenging of the ethanol extracts from the shiitake mushrooms dried through difference methods, all were concentration-dependent (figure 3). As for SOD activation, at a concentration of 500µg/mL, the decompresses heat pump produced the highest activation (24.0%) - raw shiitake mushrooms: 20.3%; natural drying: 22.7%; hot air drying: 23.3%. As for DPPH radical scavenging, at a concentration of 500µg/mL, raw shiitake mushrooms showed 44.1%, natural drying 35.9%, and hot air drying 40.1%, compared to vitamin C, the control group. The decompresses heat pump produced the highest DPPH radical scavenging activity - 64.4%.

4. Conclusion

When drying shiitake mushrooms with a hot-air dryer, the operating temperature range is to be from 40 to 60 °C. When the temperature is below 45 °C or is above 55 °C, problems can arise, including quality deterioration and damage by the heat. Also previous studies even mention these problems of hot-air dryer - failure to dry due to uneven heat transfer; energy efficiency.

Shiitake mushroom component change occurs only in different temperature environments and the temperature condition of 35 °C is the optimal condition for preventing that change. In consideration
of these, the study designed and proposed the 2-stage decompreses resistive heat pump vacuum dryer that is to operate only in medium-temperature environments (30 to 40 °C) - with no variations except for temperature. It could be seen that the drying method with the dryer is better in moisture contents, β-glucan, functional component, and antioxidant activation than natural drying and hot air drying performed in these temperature environments. Existing heat pump vacuum dryers operate in high-temperature environments, causing an energy efficiency burden. But it is thought that the proposed method will show good energy efficiency, since it is performed in medium-temperature environments. In the future, the expected energy efficiency aspect needs to be specified, and it is thought that studies of methods of drying various edible and medicinal foods, except shiitake mushrooms, need to be performed.

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