Study on Combined Hot-air and Microwave Vacuum Drying for Scallion

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ABSTRACT
Combined drying of hot-air and microwave vacuum was applied for scallion. The effects of different drying conditions and drying methods on its drying time and sensory quality including color, superficial aspect and shape of dried scallion was investigated. The effects of combined hot-air and microwave vacuum drying scallion under different cutting length and different microwave power was discussed. Also the performance comparison of different drying methods including hot-air drying, microwave vacuum drying, combined hot-air and microwave drying, combined hot-air and microwave vacuum drying were demonstrated. The results proved that scallion cutting length had significant effect on drying time and sensory quality; the higher microwave power resulted in little shorter drying time and obvious lower scallion quality. The total drying time of combined hot-air and microwave vacuum drying was 2.8h under the drying condition of 0.65kW microwave power, 0.085MPa vacuum level, 5mm scallion cutting length while hot-air dried at 60℃ for 2.5h. It decreased about 37.8% than hot-air drying, and increased 3.67 times than microwave vacuum drying. But the sensory state was less poor than hot-air drying, and better than microwave vacuum drying, as well as combined hot-air and microwave drying.

Key words: Scallion; Hot-air drying; Microwave vacuum drying; Combined drying; Drying effect

INTRODUCTION
Scallion is delicious and nutritious, while scallion stalk contains protein 1-2.4g, sugar 6-8.6g, fat 0.3g, Vc 14mg, iron 0.6mg per 100g, and other aromatic substances. It is a good vegetable as raw material or seasoning because of the aromatic substances and spicy taste, and has advantage of high edible and diet therapy value such as scallion stalk can cure cold, headache, fever, sweating and other symptoms. Scallion is an essential component as the seasoning in instant noodles and instant rice, and also kind of popular spices and soup products, leaves and a little stalk of scallion were main edible but not easy to save. Dried scallion can conserve scallion possessive original color, flavor, taste and nutrition of for long time, and easily recover its shape in warm water so that it is an important export dehydrated vegetable possessing wide market at home and abroad. There is a need to study advanced drying technology for scallion processing in order to obtain high quality dried scallion.

Traditional hot-air drying usually results in an undesirable hard crust formed on the surface of the material, and furthermore, a poorer quality and nutrition reservation. Microwave vacuum drying combines the advantages of both microwave heating and vacuum drying. The combination of the low temperature which characterizes vacuum drying and the rapid energy transfer of microwave heating realized a rapid drying procedure under low temperature, and henceforth, could come up with products of high quality. Therefore, the combined method of hot-air and microwave vacuum has the potential to reduce the drying time, improve the product quality, and decrease energy consumption. In actual performance, the some free moisture content of the material can be reduced using hot-air drying firstly and the remaining can be dehydrated using microwave vacuum drying procedure.

The objective of this experiment was to investigate the effects of different drying conditions and drying methods on its drying time and sensory quality including color, superficial aspect and shape of dried scallion. The effects of combined hot-air and microwave vacuum drying scallion at different cutting length and different microwave power was discussed. Also the performance comparison of different drying methods including hot-air drying, microwave vacuum drying, combined hot-air and microwave drying, combined hot-air and microwave vacuum drying were demonstrated.
MATERIALS & METHODS

Materials and Drying Equipments

Fresh scallion was purchased from local market, and the processing scallion should be fresh, no rotten and no bad. The experimental microwave vacuum drying apparatus was previously developed by the authors and was described previously. [5] The experimental microwave vacuum drying equipment (Figure 1) consisted of a vacuum drying chamber, a vacuum system, a microwave source system, a conveying system and a control system. The vacuum drying chamber was cylindrical with a diameter of 600 mm and a length of 1200 mm. The microwave source system had six magnetrons, which independently supplied microwave energy to the vacuum drying chamber through a waveguide.

![Figure1. Sketch drawing of experimental microwave vacuum drying system](image)

Experimental Procedure

First, fresh scallion was sorted, peeled root and skin, washed, and cut segments of certain length in the range of 5~25mm. Then scallion segments was dried by four drying methods including hot-air drying, microwave vacuum drying, combined hot-air and microwave drying, combined hot-air and microwave vacuum drying, respectively. The hot-air pre-drying is the same processing in these two combined drying methods which the scallion segments were dried in a hot air drying oven (Model DFG801, Huangshi Medical Instruments Factory, Hubei, China) at 60°C for between 2 and 4 h to reach the required moisture content of about 35%.

A batch of the scallion segments was dried to final moisture content less than 10% at different four drying methods and various drying conditions. The moisture content was measured according to the vacuum oven method. [6]

Drying Time

Drying time was defined as the time required reducing the moisture content of scallion from the drying start to the final moisture content of about 10% under various drying conditions using hot-air drying or microwave vacuum drying, respectively.

Drying time was defined as the time required reducing the moisture content of scallion from the initial level before being subjected to microwave vacuum drying or microwave drying to the safer level of about 10% under various drying conditions in these two combined drying methods.

The whole drying time of combined hot-air and microwave vacuum drying was the total of hot-air drying time and microwave vacuum drying time, and the whole drying time of combined hot-air and microwave drying was the total of hot-air drying time and microwave drying time.

RESULTS & DISCUSSION

Effect of Cutting Length on Dried Scallion Characteristics

Comparison in drying effects of scallion for different cutting length is given in Table 1. It was observed that the shorter cutting length led to the shorter drying times and the higher sensory quality. The scallion cutting length was 5, 10, 15, 20 and 25 mm, respectively. Under the drying conditions of microwave power of 0.65
kW and vacuum level of 0.085MPa, when the scallion cutting length was 5mm, it was obtained that the shortest microwave vacuum drying time of 18min and the highest sensory quality which has most of scallion remaining original color, a little scallion core yellow, and scallion possessive flavor and odor. When the scallion cutting length increased to 25mm, the microwave vacuum drying time rose to 35min, and furthermore, the sensory quality became lower so that scallion segments was severe scorch, part of scallion core was wetting, majority of scallion was not drying and sticking. The interior water content of scallion core was vaporized at a higher rate and part of the interior water was directly diffused to the surface, scallion segments was too longer to discharge the vaporizing water, resulting in a decrease in sensory quality.

### Table 1. Comparison in drying effects of scallion for different cutting length

<table>
<thead>
<tr>
<th>Cutting length/mm</th>
<th>Microwave vacuum drying time/min</th>
<th>Sensory status</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>35</td>
<td>Severe scorch, part of scallion core wetting, majority of scallion not drying, lower sensory quality</td>
</tr>
<tr>
<td>20</td>
<td>35</td>
<td>Part scorch, part of scallion core wetting, some scallion not drying, sticking, lower sensory quality</td>
</tr>
<tr>
<td>15</td>
<td>30</td>
<td>Slight scorch, part of scallion core less wetting, a little scallion not drying, low sensory quality</td>
</tr>
<tr>
<td>10</td>
<td>23</td>
<td>No scorch, all of scallion core drying, some scallion core yellow, good sensory quality, scallion possessive flavor and odor</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>Most of scallion remaining original color, a little scallion core yellow, high sensory quality, scallion possessive flavor and odor</td>
</tr>
</tbody>
</table>

### Effect of Microwave Power on Dried Scallion Characteristics

Table 2 shows drying effects of scallion for different microwave power. The microwave vacuum drying times were 18, 15, and 13 min at the microwave power of 0.65, 1.30, and 1.95 kW, respectively at 5mm scallion cutting length and 0.085MPa vacuum level. It was obvious that the higher levels of microwave power resulted in little shorter drying times. Because scallion drying was belong to thin layer drying, its shape and thickness take more effect on absorption and utilization of microwave energy, the microwave power increased, the drying time was not significantly shortened. Scallion sensory quality of 0.65kW microwave power was highest. Scallion core yellow of 1.30kW microwave power was serious than 0.65kW. The scallion sensory quality of 1.95kW microwave power was worse, slight scorch and some yellow scallion core was observed. While microwave power increasing, the drying speed was so rapid that ultimate water content of scallion was more difficult to control, the edges or sharp corners of scallion was easy to overheat, and some core appeared yellow, leading to the lower scallion sensory quality. [7,8]

### Table 2. Comparison in drying effects of scallion for different microwave power

<table>
<thead>
<tr>
<th>Microwave power/kW</th>
<th>Microwave vacuum drying time/min</th>
<th>Sensory status</th>
</tr>
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<tbody>
<tr>
<td>0.65</td>
<td>18</td>
<td>Most of scallion remaining original color, a little scallion core yellow, high sensory quality, scallion possessive flavor and odor</td>
</tr>
<tr>
<td>1.30</td>
<td>15</td>
<td>Most of scallion remaining original color, some scallion core yellow, high sensory quality, scallion possessive flavor and odor</td>
</tr>
<tr>
<td>1.95</td>
<td>13</td>
<td>Slight scorch, some scallion core yellow, good sensory quality, scallion possessive flavor and odor</td>
</tr>
</tbody>
</table>

### Effect of Different Drying Methods on Dried Scallion Characteristics

Figure 1 depicts the drying time comparison of 4 different drying methods including hot-air drying, microwave vacuum drying, combined hot-air and microwave drying, combined hot-air and microwave
vacuum drying, respectively. The total drying time of combined hot-air and microwave vacuum drying was 2.8h while the hot-air drying time was 2.5h and microwave drying time was 18min. The total time of combined hot-air with microwave drying was 2.9h while the hot-air drying time was still 2.5h and microwave drying time was 24min, which was close and only increased 6min to the total drying time of combined hot air and microwave vacuum drying. The hot-air drying time was 4.5h, and the microwave vacuum drying time was 0.6h, reached the shortest. The total drying time of combined hot-air and microwave vacuum drying decreased 1.7h, about 37.8% than the hot-air drying, and increased 2.2h, 3.67 times than microwave vacuum drying. [9]

![Figure 1. Comparison in scallion drying time of different drying methods](image)

It was observed from table 3 that the sensory quality of hot-air drying was the best, the dried scallion was all maintaining original color, possessive flavor and smell, and has no scallion yellow core. Because scallion drying was a kind of thin layer drying, hot-air drying did not lead to the hard surface crust so that the scallion internal evaporating water was easy to discharge, then obtaining higher sensory quality. The Sensory quality of combined hot-air and microwave vacuum drying mostly kept original color, and a little scallion core was yellow, so it was little worse than hot-air drying, but better than combined hot-air and microwave drying which has slight scorch and some scallion core yellow. The sensory quality of microwave vacuum drying was lowest than other three drying methods so that part of scallion core was wetting, some scallion was not drying and sticking.

<table>
<thead>
<tr>
<th>Drying method</th>
<th>Cutting length / mm</th>
<th>Sensory status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined hot-air and microwave vacuum drying</td>
<td>5</td>
<td>Most of scallion remaining original color, a little scallion core yellow, high sensory quality, scallion possessive flavor and smell</td>
</tr>
<tr>
<td>Combined hot-air and microwave drying</td>
<td>5</td>
<td>Most of scallion remaining original color, slight scorch, some scallion core yellow, good sensory quality, scallion possessive flavor and smell</td>
</tr>
<tr>
<td>Hot-air drying</td>
<td>5</td>
<td>All of scallion remaining original color, no scallion core yellow, higher sensory quality, scallion possessive flavor and smell</td>
</tr>
<tr>
<td>Microwave vacuum drying</td>
<td>5</td>
<td>Slight scorch, part of scallion core wetting, some scallion not drying, sticking, low sensory quality</td>
</tr>
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</table>

In summary, hot-air drying scallion has the highest sensory quality but the longest drying time, microwave vacuum drying scallion has the shortest drying time but the lowest sensory quality, combined hot-air and microwave vacuum drying scallion has the higher sensory quality than microwave vacuum drying, as well as combined hot-air and microwave drying, and shorter drying time than hot-air drying, also combined hot-air and microwave drying. Although it was not significant technological advantages for scallion sensory quality.
of combined hot-air and microwave vacuum drying than those of hot-air drying. It is necessary to carry out more technology research to improve scallion sensory quality using combined hot-air and microwave vacuum drying. Therefore, combined hot-air and microwave vacuum drying is suitable advanced drying technology for scallion drying process.

CONCLUSION

The results showed that the scallion cutting length in the combined hot-air and microwave vacuum drying had significant effect on drying time and sensory qualities. At the scallion cutting length of 5mm, it was obtained that the shortest microwave vacuum drying time of 18min and the highest sensory quality which has most of scallion remaining original color, a little scallion core yellow, and scallion possessive flavor and odor. The higher microwave power resulted in little shorter drying times and obvious lower scallion quality, so microwave vacuum drying time was shorter of 18min and scallion sensory quality was higher under the drying condition of 0.65kW microwave power, 0.085MPa vacuum level, 5mm scallion cutting length after hot-air dried at 60℃ for 2.5h. The total drying time of combined hot-air and microwave vacuum drying was 2.8h. It decreased 1.7h, about 37.8% than hot-air drying, and increased 2.2h, 3.67 times than microwave vacuum drying. But the sensory quality was little worse than hot-air drying and better than microwave vacuum drying, as well as combined hot-air and microwave drying. Combined hot-air and microwave vacuum drying is suitable advanced drying technology for scallion drying process, so that it is necessary to carry out more technology research to improve scallion sensory quality using combined hot-air and microwave vacuum drying.

ACKNOWLEDGEMENTS

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REFERENCES