Effect of Infrared Radiation (IR) Pre-Treatment on the Freeze-Drying of Sea Cucumber

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Abstract: The effects of infrared radiation (IR) pre-treatment on the freeze-drying (FD) procedure and quality of products were investigated in this study. Fresh sea cucumbers were treated by using IR radiation at 5000 W/m^2 or 10 000 W/m^2 before FD procedure. And then 10 000W/ m^2 was chosen to combine with FD to study drying rate during freeze-drying, and moisture, ash, protein, polysaccharide and saponin of fresh sea cucumber, FD sea cucumber, and FD sea cucumber assisted with IR were determined respectively. Results showed that the use of infrared short-wave rays could reduce the drying period and have no effect on the quality of the sea cucumber sample.

Keywords**: *sea cucumber, drying, infrared, freeze-drying.***

I. INTRODUCTION

Sea cucumber is a traditional delicacy prized by the Chinese consumers for their dietary and curative properties.

In China, more than 5,000 tons of dehydrated sea cucumbers are consumed every year [1]. Because the domestic throughput of dried sea cucumber is only about 3,000 tons, about 2,000 tons of dried sea cucumbers are imported every year [5]. On the other hand, the main component of sea cucumber, collagen, can make dehydration difficult, and deterioration can occur during processing. At present, most of the sea cucumbers are dehydrated by traditional methods that involve salting, repeated boiling, and exposure to solar radiation about 2–3 days [4].

Drying is a common food processing method, which can extend the shelf life of products and make products easy to transport.

Infrared radiation (IR) is an effective dehydration method, which can make energy transferring from the heating element to the product surface without heating the surrounding air. In addition, IR can impinge on and penetrate into material. Finally, it is helps to rapid evaporation of moisture from the material due to high frequencies of waves. During drying process, the absorptivity of the dried material decreases, and its reflectivity and transmissivity increase because of the decrease of water content. The absorptivity, the skin depth and the transmissivity are affected by several factors such as the density, the wavelength of IR heating and the properties of irradiated materials.

IR drying technology has many advantages such as high heat transfer coefficient, short drying time, and convenience of temperature control [2]. Owing to these advantages, IR drying technology is easy to integrate with convection or vacuum technologies to produce dry products [3].

Infrared heating has many advantages over conventional hot air drying. When IR is used to heat or to dry fruits, the radiation impinges on the exposed fruit surfaces and penetrates to create internal heating with molecular vibration of the material [7]. The depth of penetration depends on the composition and structure of the fruits and the wavelengths of IR radiation. When the food is exposed to IR radiation, the electromagnetic wave energy is absorbed directly by the dried food with low energy loss. It has been reported that the drying rate for food materials using IR heating is higher compared to conventional hot air drying and increases with increased power supply to infrared emitter. The IR heating allows more uniform heating of fruits resulting in better quality characteristics than other drying methods (Nowak & Lewicki, 2004). Combination of IR radiation with convection heating and vacuum has also been studied (Hebbar, Vishwanathan, & Ramesh, 2004; Kumar, Hebbar, Sukumar, & Ramesh, 2005;). The combination of IR and hot air heating is considered more efficient over radiation or hot air heating alone as it provides a synergistic effect. According to the previous study (Afzal, Abe, and Hikida, 1999), the use of combined far IR and hot air drying resulted in faster drying and considerably less energy consumption than using hot air drying alone. A combination of IR and FD was also studied for drying sweet potato [6].

From the literature data, it can be seen that the use of a combined method involving infrared waves helped to decrease the drying period. In our case, we wanted to learn IR waves so effectively in the form of pre-treatment before freeze-drying. So according to the Lykov method, the use of high temperatures in the initial stage of drying is more effective than in uniform drying. This is due to the fact that the influence of high temperatures in the object at the initial stage, more likely to affect the moisture and its evaporation, and not the solids of the product [8].

The disadvantages of FD is need long drying time and energy consumption also very high. To avoid disadvantages was to investigate the effects of

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IR pre-treatment on sea cucumber dehydration property and nutrient composition change during the FD drying.

II. MATERIALS AND METHODS

A. Materials

Fresh sea cucumbers (*Stichopus japonicus*), with black brown colour and good flexible texture, were collected from Bohai sea, in Weihai City, Shandong Province, China, stored at -20 ^{o}C and can be used within 1 month. The weights of the sea cucumber's body wall were 150 ±15 g. The length of the sea cucumber is 12 ± 3 cm and the thickness is 5 ± 1 cm.

The sea cucumbers dried using various methods including IR pre-treatment at 10 000 W/m^2 and without pre-treatment on FD. Sea cucumbers initial moisture content was 80 g moisture 100 g wet weight.

B. IR pre-treatment

To compare the influence of pre-treatment we were prepared at IR pre-treatment 10 000 W/m^2. And we are used near infrared lamps (NIR) with 1,1 µm wavelength.

NIR pre-treatment takes 5 (±1) min, at the temperature 100-110 ºC. The weight changes were measured every 3 hours using a digital balance during the drying.

C. Freeze Drying

The frozen sea cucumbers (100 g) and tray were put into the FD chamber. Heating shelf temperature was set at 35 ^{o}C. The pressure of the drying chamber was set at 5÷15 Pa during drying and the cold trap temperature was maintained at -80^{o}C. The samples were dehydrated until they reached the final moisture content (7% w.b.).

D. Analysis

▪ *Proximate composition analysis*

Proximate compositions of moisture, protein and ash of all the samples were measured by the methods of Association of Official Analytical Chemists as described below (AOAC (2005) Determination of Moisture, Ash, Protein and Fat. Official Method of Analysis of the Association of Analytical Chemists. 18th Edition, AOAC, Washington DC).

- moisture content was determined by oven-drying;
- Protein was determined by the method of Kjeldahl, and protein content was calculated as 6.25 times (%) N;
- Ash contents were measured by heating at 550 ^{o}C in 12 h.

▪ *Polysaccharide analysis*

The dry sample (2.0 g) was accurately weighed, placed in a 25 ml volumetric flask, and 20 ml of water was added. The sample was heated in a boiling water bath for 2 h. After cooling to room temperature, add 2 ml zinc acetate solution and 2 ml potassium ferricyanide solution, shake well and let stand for 30min, then added water to the scale. Mix, filter and discard the primary filtrate. placed 0.5 ml filtrate in a 5mL tube, 2 ml anhydrous ethanol was added, mixed for 5min, centrifuged at 3000 r/min for 5 min, the supernatant was discarded, and repeated operation for 3-4 times. Dissolve the residue in water and allow to 1.0 ml. Glucose was used as standard curve and total sugar content was determined by sulfuric phenol method. Polysaccharide content is the difference between the contents of total sugars and reducing sugars.

▪ *Determination of Saponins*

Total saponins were determined using the method reported by Monica et.al (2017) with some modifications. Sea cucumber powders and hot water were extraction in 5mL 20% aqueous ethanol assisted with ultrasound at 240W for 1h. The samples were centrifuge at 3000 rpm/min for 5 min. The extract (1 ml) was evaporated to dryness at 60ºC. The dry extracts were dissolved in 1 ml water, loaded onto D101 macroporous resin column (20x2cm) and equilibrated with water. The column was eluted with 30 ml of 70% aqueous ethanol, and the eluents were collected and evaporated at 60ºC for determination of total saponin. Briefly, samples dissolved in 0.2 ml 5% vanillin solution were reacted with 0.8 ml perchloric acid in a water bath at 60ºC for 10 min. After cooling to room temperature, acetic acid (5.0 ml) added. and the absorbance was determined at 560 nm using a microplate reader, and ginsenoside Re was used as a standard.

▪ *Rehydration ration*

The dried samples were soaked in 25^{0}C distilled water for 2 h, and then put on the filter paper of a Buchner funnel, which was held on a suction flask evacuated for 30 s to remove free water on the surface. The sample weighing was performed in triplicate. The rehydration ratio (RR) was estimate as follows:

$R_R = m_r/m_d$

Where W_d and W_r were the weights (g) of samples before and after rehydration, respectively.

III. RESULT AND DISCUSSION

The evaporation rate of sea cucumbers was closely related to the IR pre-treatment. The high radiation intensity made the temperature of product increase faster. The product centre temperature reached nearly 70 ^{0}C in 3 *min at* radiation intensity of 10 000 W/m^2, whereas it took 7 min at the radiation intensity of 5000 W/m^2. So high radiation intensity was chosen to combine with FD.

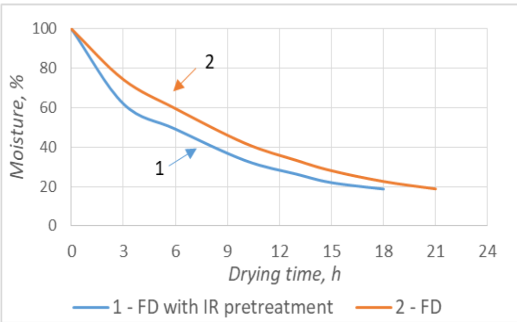

Fig. 1. Drying curves of samples of sea cucumbers with IR pre-treatment (λ=1,1 µm, q=10 000 W/m^2, v=0 m/s) and without IR on FD

The IR pre-treatment on FD tests showed higher drying rate throughout the course of drying than the FD (Fig. 1). Since infrared radiation directly penetrated into the sea cucumbers, FD with IR pre-treatment rate was higher than the FD. In this way, IR pre-treatment accelerated the drying process.

The sample weight reduction results also showed that the FD with IR pre-treatment was faster than that in FD. For example, the IR pre-treatment took 5 min to obtain 10-12% weight reduction with 10 000 W/m^2 radiation intensity as compared to 130 min for FD, respectively. This was a 1 h and 3 h – time reduction or improvement of processing efficiency for the 10-12% weight reduction, respectively.

The rate of weight reduction increased with the increase in radiation intensity. It took 5 min to achieve 10-12% weight reduction with the radiation intensities of 10 000 W/m^2, respectively. This could be because more heat was absorbed by the sea cucumbers at a higher IR intensity.

In addition, IR pre-treatment allows reducing the time of freeze-drying for 3 hours.

During the experiment, quantities content of samples were also determined. Therefore, the table 1 showed that the significantly difference between the two dry products is only in the final moisture content; the rest of the product performance is almost the same. However, the rate FD with IR pre-treatment is higher than FD process.

The rate of FD is slow and thus it takes a long time since formation of liquid water must be avoided. FD with IR pre-treatment had the faster drying rate than FD. The FD process needs about 21-22 h. FD with IR pre-treatment takes 18-19 h of processing time, which is about 10-12% less than that for FD.

Table-I: Chemical content of sea cucumber

Content of samples	Samples		
	Sea cucumber (After boiling)	FD (Dried sea cucumber)	FD with IR pre-treatment (Dried sea cucumber)
Moisture content, (%)	80.3 ± 0.8	8.3 ± 0.4	8.1 ± 0.3
Ash content, (%)	3.1 ± 0.4	12.3 ± 0.8	12.4 ± 0.8
Protein content, (%)	18.7 ± 0.5	71.02 ± 0.4	70.5 ± 0.4
Polysaccharide content, (%)	2.1 ± 0.3	8.2 ± 0.2	8.35 ± 0.2
Saponin content, (%)	0.04 ± 0.002	0.12 ± 0.005	0.11 ± 0.005

Experimental data showed that the use of infrared short-wave rays as a pre-treatment procedure reduces the drying period and does not affect the quality of the sample. As a result, it can applied in parallel in a sublimation drying in a vacuum environment, taking into account the control of heat transmission to avoid melting. The infrared pre-processing also has sterilization effect on the products, so the products could be obtained long-term storage.

The rehydration ratio was considered as one of the important quality index for the dried sea cucumbers. Because the rehydration time for the other dried sea cucumbers can take up to 3 days prior to cooking. The rehydration ratio values of dried samples estimated as it was described in earlier section. Difference between the rehydration ratio FD with IR pre-treatment and FD dried sea cucumbers were presented in Fig. 2.

The maximum of water uptake ability was for FD samples and for FD with IR pre-treatment dried samples on the average.

The degree of restoration during rehydration is dependent on different drying conditions and the final moisture content. As shown in Fig. 2, the rehydration rate was faster for the samples that had lower final moisture content.

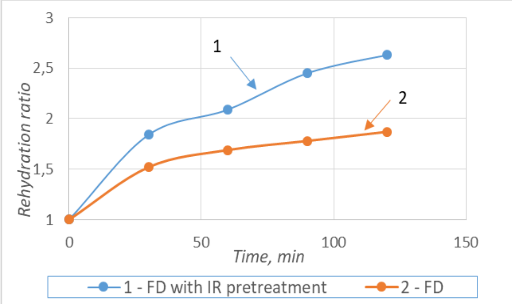

Fig.2. Relationship the rehydration ratio FD with IR pre-treatment and FD dried sea cucumbers (for the range 2 hours)

As shown in Fig. 2. FD sea cucumbers had the best, rehydration capability, and there was no significant difference between FD and FD with IR pre-treatment products under the low IR heat flux density.

IV. CONCLUSION

Combination of IR and FD pre-treatment seems to be effective for drying the fresh sea cucumbers. The test of the effect of IR waves confirms that the drying time of sea cucumbers with IR pre-treatment is shorter than that of raw materials without pre-treatment. Increase of heat flux density of IR waves reduces the drying time.

Especially when using IR pre-treatment with a heat flux density of 10 000 W/m^2, drying time is reduced by 12% or 3 hours, which is very important for manufactory production. In addition, there is no significant difference in dehydration between them, indicating that shortwave infrared rays can be used in pre-treatment of objects before drying. Moreover, the method of the basic drying process absolutely does not matter. Moreover, it allows us to save energy and extra time.

As well as the use of infrared rays before drying allows to ensure quality stability of the product. In addition, this means that it is possible to apply effective rays of infrared rays parallel in the sublimation process to achieve a better result in the future. Results of calculation of the rate of moisture vaporization seem to be in a good agreement with experimental data.

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REFERENCES

1. Bilgin S., Tanrikulu O. The changes in chemical composition of Holothuria tubulosa (Gmelin, 1788) with ambient-drying and oven-drying methods. Food Science and Nutrition, Vol.6, pp.1456-1461, 2018.
2. Nowak D., Lewicki P. Infrared drying of apple slices. Innovative Food Science and Emerging Technologies, Vol.5, pp. 353–360, 2004.

3. Mujumdar, A. S.: Handbook of industrial drying, New York: Dekker, 1995, 742 p.
4. Duan, X., Zhang, M., Li X., Mujumdar, A.S., Microwave freeze-drying of sea cucumber coated with nanoscale silver. Drying Technology, Vol.26, pp. 413-419, 2008.
5. Duan, X., Zhang, M., Mujumdar, A.S., Huang L., Wang H. A novel dielectric drying method of sea cucumber. International Journal of Food science and technology, Vol.45, pp. 2538-2545, 2010.
6. Pan Z., Shih C., McHugh T., Hirschberg E. Study of banana dehydration using sequential infrared radiation heating and freeze-drying. - Food Science and Technology, Vol.41, pp. 1944-1951, 2008.
7. Ginzburg, A. S.: Infrared radiation in food industry (in Polish). Warszawa: Wydawnictwo Naukowo-Techniczne, 1969.
8. Liao, Y.L. Chinese sea cucumbers. Bulletin of Biology, Vol.35(9), pp. 1–4, 2001.

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