Synergistic Effect of Acoustic and Vacuum Drying to Antioxidant Attributes of *Cordyceps militaris*

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**Author’s contribution**

The sole author designed, analysed, interpreted and prepared the manuscript.

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**ABSTRACT**

Acoustic drying allows the utilization of lower temperatures than conventional methodology in the drying process. Vacuum drying is one of the most energy demanding processes. Water evaporation also takes place at lower temperatures under vacuum and hence the product processing temperature can be significantly lower, offering higher product quality. *Cordyceps militaris* is a well-known entomophagus fungus with wonderful health benefits such as adaptogenic, aphrodisiac, anti-oxidant, anti-aging, neuroprotective, nootropic, immunomodulatory, anti-cancer and hepatoprotective role by its phytochemical constituents. This study focused on the synergistic effects of acoustic and vacuum drying on antioxidant properties of *Cordyceps militaris*. We noticed that acoustic drying at power 800 W in frequency 40kHz combined with vacuum drying at pressure -0.8 bar were suitable for dehydration of this valuable material. From this approach, a combination of acoustic and vacuum drying created a synergistic effect consuming less energy than single drying method because it can be performed at low temperature while maintaining the product quality and wholesomeness. Moisture content is partly removed by acoustic drying and further dehydration in a vacuum dryer to reduce moisture to a stable level.

**Keywords:** *Cordyceps militaris*; acoustic; vacuum; drying; antioxidant; synergistic.

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1. INTRODUCTION

Acoustic drying has potentially great commercial importance. It was used as a pretreatment in many dehydration applications [1]. It creates microscopic pathway inside the sample and this permits the loose movement of moisture from core to surface [2]. The moisture removal from solids produced without any change in liquid phase. The effects of acoustic dehydration are more significant at low temperature which reduces the probability of food decomposition [3]. Heat sensitive components may be dried with the acoustic drying to avoid alterations of flavour, colour and nutritional values [4]. Improved energy efficiency, better quality products, decreased environmental impact and safety of system are considered as benefits reported for this emerging technology [5].

Vacuum drying is an important process for drying highly heat-sensitive materials. The use of vacuum drying lowers the solvent boiling temperature, permitting operation at lower temperatures, directly influencing final product quality [6]. Vacuum-dried materials are characterized by better quality retention of nutrients and volatile aroma [7]. Vacuum-drying consequently requires less drying time than conventional hot-air drying and in most cases results in a higher quality dried product.

Mushrooms are popularly exploited for their excellent nutrients and therapeutic functions. Cordyceps militaris is highly valued as staple component of the traditional Chinese and Tibetan medicine [8]. Cordyceps militaris is a well-known entomophagus fungus with wonderful health benefits by its adaptogenic, aphrodisiac, anti-oxidant, anti-aging, neuroprotective, nootropic, immunomodulatory, anti-cancer and hepatoprotective role [9-13]. C. militaris is a parasitic fungus on Lepidoptera larvae which has been used as a traditional medicine in China. Polysaccharides and cordycepin exist in C. militaris that make up the fruiting body, mycelium or spores responsible for the anti-inflammatory antioxidant, anti-tumor, anti-metastatic, immunomodulatory [14], hypoglycaemic, steroidogenic and hypolipidaemic effects [15]. C. militaris inhibits cell proliferation in tumor cells in order to develop it as a new agent for the prevention and treatment of cancer [16]. Extract of C. militaris possessed anti-oxidative activity with capability to normalize superoxide dismutase and glutathione peroxide level [17]. Cordyceps has been associated with reduction in cholesterol and triglyceride and an increase in the ratio of high density lipoprotein to LDL cholesterol [18]. Extract of C. militaris included a component acting as an insulin sensitizer [19]. Cordycepin inhibited melanin synthesis related enzymes, such as tyrosinase, tyrosinase [20]. Some notable literatures mentioned to processing of C. militaris. One study determined the effect of drying methods including hot air drying and freeze drying on the quality of cordycepin production from Cordyceps militaris. The antioxidant activity and also total phenolic contents of C. militaris extract prepared from freeze drying had higher value than that of extracted from hot air drying [21]. The changes in moisture content and shrinkage ratio of Cordyceps militaris during mid-infrared-assisted convection drying were studied [22]. Not many reports mentioned to the dehydration of this valuable and sensitive source. Pupepe of the present study focused on the synergistic effect of acoustic and vacuum drying on antioxidant characteristics of Cordyceps militaris.

2. MATERIALS AND METHODS

2.1 Materials

The fruiting bodies and mycelium of Cordyceps militaris were used as the raw material. They were obtained from Can Tho city, Vietnam. After collecting, they must be quickly conveyed to laboratory for acoustic drying. Chemical substances and reagents such as Folin-Ciocalteu reagent, Na2CO3, Gallic acid, NaNO2, AlCl3・6H2O, NaoH, catechin, ethanol, methanol, potassium persulfate, phosphate buffer, potassium hexacyanoferrate, trichloroacetic acid solution, ferric chloride, ascorbic acid, ferrous sulfate, FRAP reagent, acetate buffer were all analytical grade supplied from Rainbow Trading Co. Ltd., Vietnam.

2.2 Researching Procedure

Cordyceps militaris were dried at different acoustic drying power (200, 400, 600, 800, 1000 W) and vacuum drying pressure (-0.2, -0.4, -0.6, -0.8, -1.0 bar) in the same drying temperature (40°C) to the final moisture content 6.0%. All treated samples were then stored in dry cool place before evaluating total phenolic (mg GAE/100 g), total flavonoid (mg GE/100g), DPPH (%) and FRAP (mmol Fe2+/g).
2.3 Antioxidant Capacity and Statistical Analysis

Total phenolic (mg GAE/100 g) was estimated spectrophotometrically using Folin-Ciocalteu reagent [23]. Total flavonoid (mg GE/100 g) was estimated spectrophotometrically [24]. DPPH (%) radical-scavenging activity was determined using reducing power assays [25]. The FRAP (mmol Fe²⁺/g) was determined as described by Chung et al. [26]. The experiments were run in triplicate with three different lots of samples. Statistical analysis was performed by the Statgraphics Centurion XVI.

3. RESULTS AND DISCUSSION

3.1 Effect of Acoustic Drying Power to Antioxidant Capacity of Cordyceps militaris

Ultrasonic waves can cause alternating compressions and expansions resulting in microscopic channels in the porous materials [27]. They intensify the mobility of water molecules and facilitate the evaporation process. In the present research, Cordyceps militaris were dried at different acoustic drying power (200, 400, 600, 800, 1000 W) at the same frequency 40 kHz. Present finding results showed that 800 W of acoustic drying was appropriate for semi-dehydration (see Table 1). The acoustic dehydration was applied in some notable studies. Dehydration of onion slices using sound waves was evaluated. Drying rates were increased by acoustic vibrations and the increase depended on the sound frequency [28]. The effects of ultrasonic power, radiation distance, hot air velocity and temperature on drying characteristics were studied on carrots [29]. It also be used to develop the drying process of such vegetables as apple and mushroom [30].

3.2 Effect of Acoustic Drying Combined with Vacuum Drying Pressure to Antioxidant Capacity in Cordyceps militaris

Vacuum drying technology is an important process for drying highly heat-sensitive materials. The water evaporation proceeds more rapidly at low pressures [31]. To shorten the drying time, ultrasonic treatment and vacuum drying are combined. Mechanical waves produced by the ultrasonic treatment facilitate the transfer of heat and water from inside to the surface of the food. The vacuum dehydration, by disrupting the cell walls of the food, accelerates moisture transfer, which speed up the drying rate [32].

Table 1. Effect of acoustic drying power (W) to antioxidant capacity of Cordyceps militaris

| Parameter                | Acoustic drying power (W) |
|--------------------------|---------------------------|
|                          | 200 | 400 | 600 | 800 | 1000 |
| Total phenolic (mg GAE/100 g) | 42.23±0.03<sup>a</sup> | 47.36±0.01<sup>b</sup> | 50.29±0.03<sup>bc</sup> | 54.71±0.00<sup>a</sup> | 51.47±0.02<sup>b</sup> |
| Total flavonoid (mg GE/100 g) | 17.65±0.01<sup>d</sup> | 20.61±0.02<sup>c</sup> | 21.55±0.01<sup>bc</sup> | 25.78±0.00<sup>a</sup> | 22.09±0.01<sup>b</sup> |
| DPPH (%)         | 51.64±0.02<sup>d</sup> | 54.97±0.00<sup>b</sup> | 55.42±0.02<sup>bc</sup> | 58.65±0.02<sup>a</sup> | 56.42±0.03<sup>b</sup> |
| FRAP (mmol Fe²⁺/g) | 0.41±0.00<sup>d</sup> | 0.48±0.02<sup>b</sup> | 0.50±0.00<sup>b</sup> | 0.58±0.01<sup>a</sup> | 0.52±0.00<sup>b</sup> |

Note: Data are means of three determinations (n = 3) ± SD. Means with different superscripts in each row indicate significant differences at p ≤ 0.05 based on Duncan multiple range test

Table 2. Effect of vacuum drying pressure (bar) to antioxidant capacity in Cordyceps militaris

| Parameter                | Vacuum drying pressure (bar) |
|--------------------------|-----------------------------|
|                          | -0.2 | -0.4 | -0.6 | -0.8 | -1.0 |
| Total phenolic (mg GAE/100 g) | 54.71±0.00<sup>a</sup> | 55.79±0.03<sup>b</sup> | 56.85±0.00<sup>b</sup> | 57.42±0.02<sup>a</sup> | 57.49±0.03<sup>a</sup> |
| Total flavonoid (mg GE/100 g) | 25.78±0.00<sup>b</sup> | 26.89±0.02<sup>ab</sup> | 27.63±0.00<sup>ab</sup> | 28.79±0.01<sup>a</sup> | 28.84±0.01<sup>a</sup> |
| DPPH (%)         | 58.65±0.02<sup>b</sup> | 59.13±0.04<sup>ab</sup> | 60.08±0.03<sup>ab</sup> | 60.76±0.00<sup>a</sup> | 60.80±0.02<sup>a</sup> |
| FRAP (mmol Fe²⁺/g) | 0.58±0.01<sup>b</sup> | 0.59±0.00<sup>ab</sup> | 0.61±0.01<sup>a</sup> | 0.62±0.03<sup>a</sup> | 0.62±0.00<sup>a</sup> |

Note: Data are means of three determinations (n = 3) ± SD. Means with different superscripts in each row indicate significant differences at p ≤ 0.05 based on Duncan multiple range test
In the present research, the semi-acoustic dried samples were subjected to different vacuum drying pressure (-0.2, -0.4, -0.6, -0.8, -1.0 bar). Present finding results revealed that the most antioxidant characteristics still maintained in maximum level by acoustic drying at -0.8 bar (see Table 2). The combined drying techniques can shorten drying time and improve drying efficiency and the quality of products. In another report, ultrasound-assisted vacuum drying could be used as an alternative drying method for minced meat drying due to lower drying times and higher quality parameters [32].

4. CONCLUSION

Acoustic drying based on the operation of the ultrasonic vibration in direct contact with the product. It represented an emergent, ideal and promising technology because the effects of power ultrasound were more significant at low temperature which reduced the probability of food degradation. We have successfully found the synergistic effect of acoustic and vacuum drying greatly affected to antioxidant capacity and stability of Cordyceps militaris. From this combination, the most valuable cordycepin and adenosine inside this precious natural species.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Cui L, Pan Z, Yue T, Atungulu GG, Berrios JD. Effect of ultrasonic treatment of brown rice at different temperatures on cooking properties and quality. Cereal Chem. 2010;5:403-408.
2. Bogala Madhu, Sai Srinivasa M, Srinivasa G, Jain SK. Ultrasonic technology and its applications in quality control, processing and preservation of food: A review. Current Journal of Applied Science and Technology. 2019;32:1-11.
3. Fuente-Blanco S de la, Riera-Franco E de Sarabia, Acosta-Aparicio VM, Blanco-Blanco A, Gallego-Juarez JA. Food drying process by power ultrasound. Ultrasonics. 2006;44:523–527.
4. Chemat F, Huma Z, Khan MK. Applications of ultrasound in food technology: Processing, preservation and extraction. Ultrasonics Sonochemistry. 2011;18:813–835.
5. Camarena F. Ultrasonic study of the complete dehydration process of orange peel. Postharvest Biol Technol. 2007;43:115-120.
6. Pére C, Rodier E. Microwave vacuum drying of porous media: Experimental study and qualitative considerations of internal transfers. Chemical Engineering and Processing. 2002;41:427-441.
7. Giri SK, Sutar PP, Suresh Prasad. Effect of process variables on energy efficiency in microwave-vacuum drying of button mushroom. Journal of Food Research and Technology. 2014;2:31-38.
8. Aarti Mehra, Kamal Zaidi U, Abin Mani, Vijay Thawani. The health benefits of Cordyceps militaris - A review. Kavak. 2017;48:27-32.
9. Lin R, Liu H, Wu S, Pang L, Jia M, Fan K. Production and in vitro antioxidant activity of exopolysaccharide by a mutant, Cordyceps militaris SU5-08. Int J Biol Macromol. 2012;51:153–157.
10. Shashidhar MG, Giridhar P, Udaya Sankar K, Manohar B. Bioactive principles from Cordyceps sinensis: A potent food supplement – A review. Journal of Functional Foods. 2013;5:1013-1030.
11. Chen X, Wu G, Huang Z. Structural analysis and antioxidant activities of polysaccharides from cultured Cordyceps militaris. Int J Biol Macromol. 2013;58:18–22.
12. Jing Y, Cui X, Chen Z, Huang L, Song L, Liu T. Elucidation and biological activities of a new polysaccharide from cultured Cordyceps militaris. Carbohydr Polym. 2014;102:288–296.
13. Wan Chen, Gaoqiang Liu, Huandong Yang, Huabin Zhou, Hailong Yang. Effects of processing treatments on the antioxidant properties of polysaccharide from Cordyceps militaris. International Journal of Food Engineering. 2017; 13(1), 20160076.
14. Das SK, Masuda M, Sakurai A, Sakakibara M. Medicinal uses of the mushroom Cordyceps militaris: Current state and prospects. Fitoterapia. 2010;81:961-968.
15. Wang HJ, Pan MC, Chang CK, Chang SW, Hsieh CW. Optimization of ultrasonic-assisted extraction of cordycepin from *Cordyceps militaris* using orthogonal experimental design. Molecules. 2014;19:20808-20820.

16. Wong JH, Ng TB, Sze SC, Zhang KY, Li Q, Lu X. Cordymin, an antifungal peptide from the medicinal fungus *Cordyceps militaris*. Phytomedicine. 2011;18:387-392.

17. Dong YT, Meng Q, Liu C, Hu S, Ma Y, Liu Y, Lu J, Cheng Y, Wang D, Teng L. Studies on the anti-diabetic activities of *Cordyceps militaris* extract in diet-streptozotocin-induced diabetic dprague-dawley rats. Appl. Microbiol. Biotechnol. 2010;72:1152-1156.

18. Patel KJ, Ingalhalli RS. *Cordyceps militaris*: An important medicinal mushroom. Journal of Pharmacognosy and Phytochemistry. 2013;2:315-319.

19. Silva DD, Rapior R, Hyde K, Bahkali A. Medicinal mushroom in prevention and control of diabetes mellitus. Oncol. Rep. 2012;56:1-29.

20. Jin ML, Park SY, Kim YH, Park G, Son H, Lee S. Suppression of α-MSH and IBMX-induced melanogenesis by cordycepin via inhibition of CREB and MITF, and activation of PI3K/Akt and ERK-dependent mechanisms. International J. Molecular Medicine. 2012;29:119-124.

21. Thitiphan Chimsook. Effect of freeze drying and hot air drying methods on quality of cordycepin production. MATEC Web of Conferences. 2018;192:03001.

22. Xiao-Fei Wu, Min Zhang, Zhongqin Li. Dehydration modeling of *Cordyceps militaris* in mid-infrared-assisted convection drying system: Using low-field nuclear magnetic resonance with the aid of ELM and PLSR. Drying Technology. 2019;37:2072-2086.

23. Singleton VL, Orthofer R, Lamuela-Raventos RM. Analysis of total phenols other oxidation substrates and antioxidant by means of folin-ciocalteau reagent. Methods in Enzymology. 1999;299:152-178.

24. Dewanto XZ, Wu AKK, Liu RH. Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity. Journal of Agricultural and Food Chemistry. 2002;50:3010-3014.

25. Thi ND, Hwang E. Bioactive compound contents and antioxidant activity in aronia (*Aronia melanocarpa*) leaves collected at different growth stages. Prev Nutr Food Sci. 2014;19:204-212.

26. Chung HS, Chang LC, Lee SK, Shamon LA, van Breemen RB, Mehta RG, Farnsworth NR, Pezzuto JM, Kinghorn AD. Flavonoid constituents of *Chorizanthe diffusa* with potential cancer chemopreventive activity. J Agric Food Chem. 1999;47:36-41.

27. Yetenayet B, Hosahalli R. Going beyond conventional osmotic dehydration for quality advantage and energy savings. J Food Sci Technol. 2010;1:1-15.

28. Da-Mota VM, Palau E. Acoustic drying of onion. Drying Technology. 1999;17:855-867.

29. Luo Denglin, Liu Juan, Liu Yuhong, Ren Guangyue. Drying characteristics and mathematical model of ultrasound assisted hot-air drying of carrots. Int J Agric & Biol Eng. 2015;8:124-132.

30. Riera E. Application of high-power ultrasound for dehydration of vegetables: Processes and devices. Drying Technol. 2007;25:1893-1901.

31. Bazyma LA, Kutovoy VA. Vacuum drying and hybrid technologies. Stewart Postharvest Review. 2005;4:7.

32. Asli Aksoy, Salih Karasu, Alican Akcicek, Selma Kayacan. Effects of different drying methods on drying kinetics, microstructure, color, and the rehydration ratio of minced meat. Foods. 2019;8:216.

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