The use of pulsed infrared drying in the processing of leafy plant raw materials

A N Sapozhnikov1,*, S D Sleptsov2, M A Grishin2, A V Kopylova1,3 and T A Levin1

1 Novosibirsk State Technical University, 20 K. Marks Ave., Novosibirsk, 630073, Russian Federation
2 Kutateladze Institute of Thermophysics, Siberian Branch of the RAS, 1 Lavrentyev Ave., Novosibirsk, 630090, Russian Federation
3 Siberian Research and Technological Institute of Agricultural Production Processing, Siberian Federal Scientific Centre of Agro-BioTechnologies of the RAS, P.O. box 267, Krasnoobsk, Novosibirsk region, 630501, Russian Federation

*E-mail: a.sapozhnikov@corp.nstu.ru

Abstract. The paper presents the results of research of leafy plant raw materials drying with pulsed infrared (IR) radiation by the example of spinach (Spinacia oleracea L.). The efficiency of the selected method for weight and humidity changes in the processed material has been analyzed. The specific energy consumption for removal of 1 g of moisture as well as ascorbic acid concentration in dried product have been calculated. The results of the analysis show that IR-drying of leafy plant raw materials is efficient and can be carried out in production environment.

1. Introduction

Drying of plant food raw materials is a common and widely studied heat and mass transfer process, which is used for obtaining shelf stable products. The following drying methods can be used: convective [1], microwave [2, 3], vacuum [4], freeze [5] and infrared (IR) radiation technique [6–9]. Each of these methods has disadvantages and advantages. For example, freeze drying is used for most of plant raw materials, meanwhile it requires high energy consumption. IR-drying is not widely used for these purposes, but it is more effective, because the obtained products have high degree of recoverability and nutrients preservation and their storage is possible without additional energy use. The products possess these properties due to removal of moisture from plant raw material at low ambient temperatures (40…60 °C) during the drying process. Such temperatures significantly reduce the destruction of biologically active organic substances contained in raw materials [6]. Besides, IR-drying of plant raw materials is scalable and can be carried out in technological devices of various capacities. Therefore, the research and adaptation of IR-drying methods for different food raw materials is advisable.

Spinach (Spinacia oleracea L.) is a green leafy plant raw material of interest for research. Spinach is known to have useful properties, which explain its great demand all over the world. This work studies the quality of dried spinach leaves and its drying process dynamics in the drying chamber with power consumption of $P \approx 2$ kW.
2. Experimental research
Drying was realized on the experimental setup (infrared dryer, the Russian patent No. 2265169) which is presented in figure 1. The radiation sources were quartz halogen tubular lamps KGT-220-1000 (Russia), which operate in pulsed mode and located in the side reflectors of the drying chamber. The pulsed mode refers to automatic on/off lamp switching when the set temperature on the sensor 5 is reached. Moisture released during drying is removed from the drying chamber by convective flows through grooves 7 in the upper part of the chamber.

![Figure 1. Experimental setup for IR-drying of leafy plant raw material:](image)

1 – cover, 2 – side reflectors with IR-lamps KGT-220-1000, 3 – lower mesh pallet, 4 – spill collection pallet, 5 – temperature sensor, 6 – control block, 7 – grooves for moisture removal, 8 – lid, 9 – upper mesh pallet, 10 – fan, 11 – electronic meter CAT II 300V.

The preparation of spinach included its weighing and washing. In the prepared raw material, humidity and ascorbic acid concentration were determined according to Russian national standards GOST 28561-90 and GOST 24556-89, respectively.

For spinach drying, 3 experiments were carried out in triplicate. During each experiment, different quantities of spinach were loaded into mesh pallets. In the first case, 50 g of spinach were loaded into every pallet. In the second case, 50 g of spinach were loaded into the upper pallet and 100 g of spinach into the lower pallet. In the third case, 70 g of spinach were loaded into the upper pallet and 130 g of spinach into the lower pallet. Each time the thickness of spinach layers did not exceed 5 mm. Further, the temperature of 60 °C was set on the control block 6 and the drying started. Every 20–30 min the pallets with spinach were removed from the dryer, and the processed materials were weighed. The drying process ended after 120 min from its beginning.

The total drying time and total energy consumption value were determined by the CAT II 300V electronic meter. After the spinach had been dried, its humidity and ascorbic acid concentration were calculated according to above-mentioned standards.
3. Results and discussion

Figure 2 shows the dynamics of spinach weight change during drying. From the graph, it can be seen, that when the load increases the weight of the removed moisture increases as well. After 120 min of drying 100 and 150 g of spinach, the weights of dried samples correspond to the measurement accuracy of ±2%. These facts may be associated with low effectiveness of drying, when the load of pallets is low.

Figure 2. Effect of drying time on spinach weight.

Figure 3 shows the effect of drying time on spinach humidity. The initial humidity value of spinach leaves is obtained experimentally with the accuracy of ±10%. Other values in the chart are obtained by calculation based on measuring the weight of spinach leaves during the drying process. Humidity values at the final time point are of the greatest interest, since approximately the same energy amount is spent in all cases during the drying time. It is noted that the final humidity has the lowest value at the average load of pallets.

Figure 4 illustrates the effect of pallets load on the specific energy consumption for removal of 1 g of moisture based on the integral energy consumption value. The highest energy effectiveness is seen at the highest load value. Therefore, as it shown in figure 3, the final humidity for the 200 g load value is approximately 2 times higher, than the load value of 150 g. Energy efficiency is expected to be a slow function of load value, so the expected load optimum of pallets with spinach is about 150 g.

The obtained dried spinach leaves samples kept original form but were characterizes by large brashness. At that, they neither had burnouts nor over-dried areas. Their color changes were insignificant, taste and scent met those of qualitative dried green leafy plant raw materials.

The concentration of ascorbic acid in fresh and dried spinach leaves was (772.6±77.3) mg/100 g of dry matter, which is consistent with obtained data from previous studies [3, 9]. After drying, the ascorbic acid concentration was (342.5±34.3) mg/100 g of dry matter. The decrease of ascorbic acid was about 55%, which corresponded to the value of ascorbic acid concentration after drying of 60 g of spinach by IR-radiation [9]. Therefore, when the quantity of fresh spinach increased from 60 to 100 g, the final value of ascorbic acid concentration remained almost the same. This may indicate the effectiveness of the experimental setup used in the research.
Figure 3. The effect of drying time on spinach humidity.

Figure 4. The effect of pallets load on the specific energy consumption for removal of 1 g of moisture.
Conclusion
The results of the performed research show that the use of pulsed IR-drying mode for processing spinach and other leafy plant raw materials is advisable. This technology can be widely applied both in small production and in domestic conditions.

The comparison of obtained results with previously obtained data on IR-drying of spinach [9] shows their satisfactory consistency in quality indicators and humidity of raw material and dried product. One of the advantages of the carried-out work is the increase of mass capacity of the experimental setup and relatively small energy consumption for removing 1 g of water from processed raw materials. The ascorbic acid content is acceptable for the use of dried plant raw material in food industry. It is assumed, that the production quality can be improved by replacing the IR-radiation sources by the sources with lower power capacity.

References
[1] Upadhyaya A K, Gupta B, Garg S, Singh M and Pandey M 2012 International Journal of Advanced Research in Computer Engineering & Technology 1(4) 153–7
[2] Barbosa de Lima A G, Delgado J M P Q, Silva E G, de Farais Neto S R, Santos J P S and Barbosa de Lima W M P 2016 Drying process in electromagnetic fields Drying and Energy Technologies. Advanced Structured Materials (vol 4) ed J Delgado and A Barbosa de Lima (Springer, Cham) 89–110
[3] Dadali A and Özbek B 2009 Int. Food Sci. Nutr. 60(1) 21–31
[4] Burova N, Kislitsina N, Gryazina F, Pashkova G and Kuzminykh A 2017 Revista Espacios 38(52) 35
[5] Bhatta S, Stevanovic Janezic T and Ratti C 2020 Foods 9(1) 87
[6] Volonchuk S K 2011 Siberian Herald of Agricultural Science 9–10 116–23
[7] Buyanova I V, Altukhov I V, Tsuglenok N V, Krieger O V and Kashirskih E V 2019 Foods and Raw Materials 7(1) 151–60
[8] Doymaz I, Kipcak A S and Piskin S 2015 Czech J. Food Sci. 33(1) 83–90
[9] Sarimiseli A and Yuceer M 2015 Chem. Process Eng. 36(4) 425–36