OPEN ACCESS

Ology Press

Review

Journal of Nutrition, Food Research and Technology

A review on mechanism, quality preservation and energy efficiency in Refractance Window drying: a conductive hydro-drying technique

Vahid Baeghbali, Mehrdad Niakousari

Department of Food Science and Technology, School of Agriculture, Shiraz University, Iran

Correspondence: Vahid Baeghbali, Department of Food Science and Technology, School of Agriculture, Shiraz University, Iran, Tel 989177124162, Email baeghbali@shirazu.ac.ir

Received: June 12, 2018 | **Published:** June 21, 2018

Abstract

Thermal drying consumes up to 25% of the industrial energy consumption in developed countries. Refractance Window (RW) is a relativelynew drying methodthat it is characterized by maintaining a relatively low temperature inside the food and short drying times. A RW dryer uses circulating hot water as a means to convey thermal energy to materials to be dehydrated. A RW dryer can produce high-quality products with retaining heat sensitive vitamins, color, phytochemicals content and antioxidant activity close to the freeze-dried products, while the cost of the RW equipment is less than 30 percent of the cost of a freeze-dryer and the energy consumption of RW is less than 50 percent of the energy consumption for a freeze-dryer.

Early understandings heat transfer mechanism in RW drying suggested that the moist material on a thin plastic sheet over hot water, creates a "window" for infrared radiation(IR) and as the material dries, the "window" gradually cuts off the radiation. Recently a conjugate heat and mass transfer model showed that a major portion of thermal energy is transferred via conduction; some of the researchers proposed the term "conductive hydro-drying" for the name of this technology. Another important parameter in RW drying is air convection. Forced air convection causes lower product temperature and higher moisture loss in comparison with natural convection.

Although many studies have been conducted on this technology, there are still many types of food materials for which RW drying and process optimization have not yet been investigated.

Keywords: Refractance Window drying, conductive hydro-drying, energy efficiency, product quality

Introduction

Dried vegetables, fruits and other food ingredients are widely used in prepared foods. Conservation of quality attributes such as aroma, color and nutrients has always been a challenge in dehydration of heat sensitive fruits and vegetables. Consumer demand for high quality dehydrated foods continually inspires efforts toward development of improved and innovative drying methods.[1,2]

Thermal drying consumes 10–25% of the industrial energy in the developed countries. Drying energy consumption in the United States, United Kingdom and France were 1600×10^9, 128×10^9, 168×10^9MJ/year, respectively. With rapid industrialization of emerging global economies, the energy consumed for thermal dehydration and the resulting adverse environmental impact of the greenhouse gases will unavoidably increase over time.[3]

Refractance window drying

Refractance Window (RW) is a new film drying method and it is characterized by maintaining a relatively low temperature inside the food and by requiring shorter process times.[4] To dry a similar amount of product, the cost of the RW equipment is about one-third of the cost of a freeze-dryer (FD); while energy consumption of RW is less than half of the energy consumption for a FD.[5]

RW drying system uses circulating water at 90 to 95°C as a means toconvey thermal energy to materials to be dehydrated (Figure 1). As the product does not have direct contact with the heat transfer medium during RWdrying, no cross-contamination occurs.[6] Evaporation capacity up to 10 kg m^{-2} h^{-1} shows that RW is a very efficient drying process.[7]

A RW dryer can preserve color,[9] heat sensitive vitamins and phytochemicals that some of them will be discussed in the following section.

Heat transfer mechanism

In the RW drying process, the actual product temperature is usually less than 70ºC. Unique design feature of this drying method is the use of hot water at temperatures near boiling point as the heat transfer medium. Since the hot water is circulating, thermal efficiency of the system is very high. Early proposed mechanisms for RW drying

Citation: Baeghbali V, Niakousari M. A review on mechanism, quality preservation and energy efficiency in Refractance Window drying: a conductive hydro-drying technique. *J Nutr Food Technol.* (2018);1(2): 50–54. DOI: 10.30881/jnfrt.00011

suggested that in this type of dryer, thermal energy from circulating hot water is transported to the wet product via a plastic interface which is relatively transparent to infrared radiation. Hot water's thermal energy is transmitted through the thin Mylar conveyor belt via conduction and radiation. Water molecules show high absorption for IR with wavelengths of 3.0, 4.7, 6.0, and 15.3 µm. The IR transmission trough the Mylar sheet is in this wavelength range, which results in quick drying. Moreover the IR transmission is stronger when the Mylar surface is in contact with water on one side and a moist material on the other side.[5]

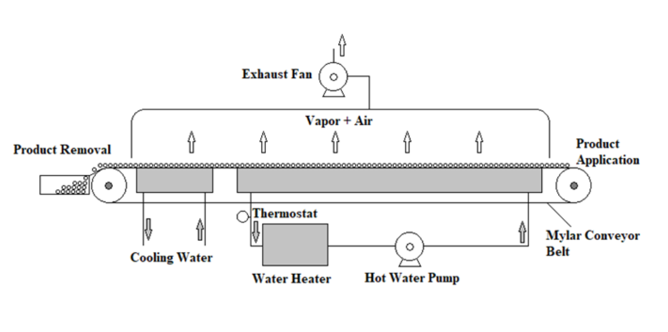

Figure 1 Schematic of a continuous RW dryer.[8]

In a recent study on RW drying of pumpkin slices, a conjugate heat and mass transfer model was created to simulate the process. Computed results indicated that there was a 5% difference in transmission of IR radiation through the plastic sheet when product is dry or wet, which is not in support of the early assumptions about the main heat transfer mechanism in this technology. The results showed that the main method of heat transfer was conduction. It was concluded that in RW drying of thin samples, the relatively low sample temperature during the later stages of the drying process was due to the development of a dried, thermally resistive layer at the base of the product which resisted against heat transfer from the plastic sheet. However, in the case of thick-sized samples, the development of air spaces between the product and the plastic sheet reduced the heat transfer rate and resulted in the low sample temperature, therefore preserving the quality of RW dried product compared to other drying techniques.[10]

In another research, time-temperature evolution of drying mango pulp surface was determined by thermography during the RW process performed with 2 mm-thick pulp and water at 95°C. After spreading, pulp temperatures quickly increased up to 70°C and remained almost steady during the constant drying rate period. From 10 to 15 min after the RW process started, the temperature began to increase in some areas, owing to their low moisture content.[7]

Effect of air convection

Effects of natural convection and forced convection of air in RW dryer was studied by Ortiz-Jerez & Ochoa-Martínez[11] in a study on drying pumpkin slices. Natural convection resulted in a higher average temperature at the different points of samples, while forced convection caused lower temperatures during the drying process. Drying curves also showed that the lowest moisture kinetics were obtained in samples dried with natural-convection, while the samples dried with forced-convection showed the highest moisture loss values.

Preservation of heat sensitive vitamins and phytochemicals

Ascorbic acid retention

Ascorbic acid is an important vitamin and an essential nutrient for humans and some animal species. It is found in many fruits and vegetables but it is very sensitive to heat and oxidation.[12] Several studies have shown that RW drying can preserve ascorbic acidcontent in the products. A study on drying strawberry purees showed that the retention of ascorbic acid was 94.0% after RW drying,which was very close to 93.6% in FD.[13] Another study also showed that ascorbic acid retention in strawberry purees dried with RW system (93%) was comparable to FD products (94%).[14] In dried asparagus using heated air, RW, and microwave assisted spouted bed, RW drying resulted in highest retention of total ascorbic acid.[15]

Anthocyanin retention

Anthocyanins are valuable and nutritional phytochemicals, which are present in various plants. They are susceptible to drying processes.[16] Research has shown that RW drying results in low anthocyanin losses. In a study 45, 41 and 23% losses in total anthocyanins content were observed in colored potato flakes after FD, drum drying and RW drying, respectively.[17] Haskap berry puree was dried using an RW dryer and more than 92% of anthocyanins were retained.[18] RW dryer produced high-quality pomegranate juice powder with antioxidant activity, anthocyanins color and anthocyanins contentclose or higher than those of the FD or spray dried samples.[8]

Carotene retention

Carotenes are colored pigments found many fruits and vegetables. β-carotene is the most common form of carotene in plants. It can be used as a food coloring and it is a precursor to vitamin A. Carotenes are also susceptible to heat and oxidation[19] and their retention in dried products is imperative to achieve a high quality products. A study on quality retention of dried carrot puree showed that RW drying is a much better method than drum drying to dry carrot puree (Table 1). The color of the RW-dried carrot purees was comparable to fresh puree,[13] and other studies on RW drying of carrots havedemonstrated similar results.[20]

Table 1 Carotene losses in carrots samples dried by drum, freeze, and Refractance Window drying methods

Dryer / Carotene Loss	Total carotene	α-carotene	β-carotene
Drum Dryer	56.0%	55.0%	57.1%
RW Dryer	8.7%	7.4%	9.9%
Freeze Dryer	4.0%	2.4%	5.4%

Vitamin B retention

Recently Nemzer et al[21] studied phytochemical and physical property retention in blueberries, tart cherries, strawberries, and cranberries as affected by FD, RW and hot air drying methods.Their results showed that RW dried cranberry and strawberry samples had higher total vitamin B retention than FD and hot air dried products.

Citation: Baeghbali V, Niakousari M. A review on mechanism, quality preservation and energy efficiency in Refractance Window drying: aconductive hydro-drying technique. *J Nutr Food Technol.* (2018);1(2): 50–54. DOI: 10.30881/jnfrt.00011

Microbial reduction

Although RW drying is comparable with freeze drying and other low temperature drying methods in terms of physiochemical quality retention, it can also reduce microbial load in its dried products. In a study on RW drying of pumpkin puree from 80% to 5% moisture content (wb) which was completed in about 5 minutes (with water at 95ºC). RW drying of inoculated pumpkin purees resulted in 4.6, 6.1, 6.0, and 5.5 log reductions of total aerobic plate counts (APC), coliforms, *Escherichia coli*, and *Listeria innocua*, respectively.The RW dryer in this study demonstrated up to 70% energy efficiency.[2]

Case studies of drying fruits and vegetables

Green asparagus

In a study on drying of green asparagus using different methods, microwave assisted spouted bed (MWSB) drying was the fastest and resulted in highest retention of total antioxidant activity (TAA) among the methods where heated air was used. TAA of RW and freeze-dried asparagus was significantly higher than heated air-drying methods. The amount of ascorbic acid in the dried products were as follows RW>freeze-drying>MWSB >spouted bed drying.[4]

Paprika

RW drying method was used to dry paprika and the quality of the product was compared with FD andhotair drying methods(forced and natural convection drying methods). The reflected color characteristics of FD and RWdried paprika was better than hot air dying methods. Also, the browning index of FD and RW dried samples were not significantly different.[22,23]

Mango

Drying process of mango was carried out using RW drying, freeze drying, drum drying, and spray drying. Results showed that the color of FD and RW dried mango powder and was close to reconstituted mango puree, but significantly lighter than drum dried, and darker than spray dried powders. In terms of bulk density, RW and drum dried mango powders had higher bulk density than freeze dried and spray driedsamples. While solubility and hygroscopicity RW and freeze-dried powders were not significant different. The microstructure of RW-dried mango powder was smooth and flaky with uniform thickness.[24–26]

Aloe-vera

Aloe-vera extract was dried using spray drying, freeze drying, and RW drying methods. Reconstituted solutions from freeze dried and RW-dried samples had higher and nearly similar consistency while solutions of spray driedsamples had the lowest viscosity. Also the activation energy for network formation of solutions reconstituted from freeze dried and RW dried samples was 24.6±0.3 and 24.7±0.4 kJ mol^{-1} was slightly higher than activation energy for network formation of spray dried solutions.[27]Another study on RW drying of aloe-vera gel also showed that RW and freeze dried products are comparable.[28]

Strawberry puree

RW-dried strawberries demonstrated color values close to that measured in freeze-dried samples. Total drying time for RW method was about 4 minutes (Figure 2) while freeze drying took 24 hours. In case of aromatic compounds, sample analysis showed that RW-dried strawberry purees had more heat-induced aldehydes and ketones and less alcohols and esters.[13]

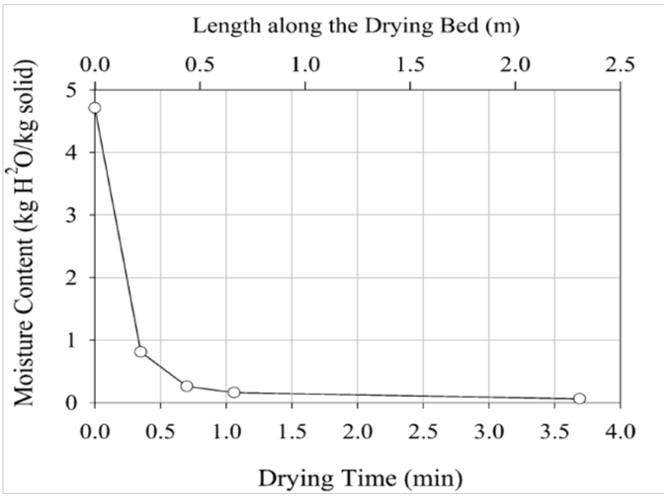

Figure 2 Moisture content against the drying time for strawberry puree dried by RW drying method.[13]

Energy efficiency

Different studies on energy consumption and energy efficiency of RW drying have concluded that in comparison with different conventional drying methods, RW drying is a very energy efficient choice (Table 2,3).

Table 2 Comparison of energy consumption of RW with other selected dryers[5]

Type of the dryer	Typical product temperature (°C)	Thermal efficiency (%)
Rotary dryer	About 175	50-25
Spray dryer	80-120	51-20
Drum dryer	120-130	78-35
RW Dryer	60-70	77-52

Table 3 Overall energy efficiency of spray, freeze and RW dryers[8]

Type of the dryer	Calculated energy needed for drying 1kg sample (kWh)	Energy consumption for drying 1kg sample (kWh)	Overall energy efficiency (%)
Freeze dryer	1.46	130.65	1.12
RW dryer	1.36	4.31	31.56
Spray dryer	1.42	11.01	12.92

Future trends

- Investigating dehydration of different food materials including microorganisms (yeast, probiotics), leaf vegetables, meat and marine products.
- Investigating the effect of RW drying on starch granules.

Citation: Baeghbali V, Niakousari M. A review on mechanism, quality preservation and energy efficiency in Refractance Window drying: aconductive hydro-drying technique. *J Nutr Food Technol.* (2018);1(2): 50–54. DOI: 10.30881/jnfrt.00011

- Modeling of drying process in RW dryer and investigating the role of different parameters and heat transfer mechanisms in the process.
- Optimization of Refractance Window drying in terms of energy consumption and process design.

Summary

Refractance Window is a relatively new film drying technique and it is characterized by high-quality products, short drying times, low cost, high energy efficiency and high evaporation capacity. RW drying can retainproduct quality in terms of heat sensitive vitamins, color, phytochemicals content and antioxidant activity as compared to freeze-dried products.

Firstly, it was assumed that the main heat transfer mechanism of RW drying system was thermal radiation via the plastic sheet through a transparent window which was created by the contact of wet material on the surface of the sheet. Recently, a conjugate heat and mass transfer model developed to simulate the RW drying process showed that a major portion of thermal energy is transferred via conduction and development of a dried, thermally resistive layer at the base or development of air spaces between the product and the plastic sheet reduces the heat flux from the hot water, therefore reducing thermal damage and preserving the quality of the product. Another important parameter in a RW drying is air convection. Forced air convection in a RW dryer causes lower product temperature during the process and higher moisture loss values in comparison with natural convection.

Although many different drying experiments have been conducted on RW drying system, some areas including optimization of RW drying in terms of energy consumption and process design and investigating the effect of RW drying on starch granules and dehydration of microorganisms (yeast, probiotics), leaf vegetables, meat and marine products should be of interest to researchers.

Conflict of interest

The authors wish to declare no conflict of interest.

References

1. Baeghbali V, Niakosari M, Kiani M. Design, manufacture and investigating functionality of a new batch Refractance Window system. In: *Proceedings of 5th International Conference on Innovations in Food and Bioprocess Technology*. 2010:7(9).
2. Nindo CI, Feng H, Shen GQ, et al. Energy utilization and microbial reduction in a new film drying system. *J Food Process Preserv*. 2003;27(2):117–136.
3. Law CL, Mujumdar AS. Energy saving in drying processes. In: *Recent Advances In Sustainable Process Design And Optimization: (With CD-ROM)*. World Scientific; 2012:577–591.
4. Nindo C, Sun T, Wang SW, et al. Evaluation of drying technologies for retention of physical quality and antioxidants in asparagus (Asparagus officinalis, L.). *LWT-Food Sci Technol*. 2003;36(5):507–516.
5. Nindo CI, Tang J. Refractance window dehydration technology: a novel contact drying method. *Dry Technol*. 2007;25(1):37–48.
6. Moses JA, Norton T, Alagusundaram K, et al. Novel Drying Techniques for the Food Industry. *Food Eng Rev*. 2014;6(3):43–55.
7. Zotarelli MF, Carciofi BAM, Laurindo JB. Effect of process variables on the drying rate of mango pulp by Refractance Window. *Food Res Int*. 2015;69:410–417.
8. Baeghbali V, Niakousari M, Farahnaky A. Refractance Window drying of pomegranate juice: quality retention and energy efficiency. *LWT-Food Sci Technol*. 2016;66:34–40.
9. Castoldi M, Zotarelli MF, Durigon A, et al. Production of tomato powder by refractance window drying. *Dry Technol*. 2015;33(12):1463–1473.
10. Ortiz-Jerez MJ, Gulati T, Datta AK, et al. Quantitative understanding of refractance window™ drying. *Food Bioprod Process*. 2015;95:237–253.
11. Ortiz-Jerez MJ, Ochoa-Martínez CI. Heat transfer mechanisms in conductive hydro-drying of pumpkin (Cucurbita maxima) Pieces. *Dry Technol*. 2015;33(8):965–972.
12. Burdurlu HS, Koca N, Karadeniz F. Degradation of vitamin C in citrus juice concentrates during storage. *J Food Eng*. 2006;74(2):211–216.
13. Abonyi BI, Feng H, Tang J, et al. Quality retention in strawberry and carrot purees dried with Refractance WindowTM system. *J Food Sci*. 2002;67(3):1051–1056.
14. Sablani SS. Drying of fruits and vegetables: retention of nutritional/functional quality. *Dry Technol*. 2006;24(2):123–135.
15. Santos PHS, Silva MA. Retention of vitamin C in drying processes of fruits and vegetables—A review. *Dry Technol*. 2008;26(12):1421–1437.
16. Tonon RV, Brabet C, Hubinger MD. Anthocyanin stability and antioxidant activity of spray-dried açai (Euterpe oleracea Mart.) juice produced with different carrier agents. *Food Res Int*. 2010;43(3):907–914.
17. Nayak B, Berrios JDJ, Powers JR, et al. Colored potatoes (Solanum tuberosum L.) Dried for antioxidant-rich value-added foods. *J Food Process Preserv*. 2011;35(5):571–580.
18. Celli GB, Khattab R, Ghanem A, et al. Refractance Window™ drying of haskap berry–preliminary results on anthocyanin retention and physicochemical properties. *Food Chem*. 2016;194:218–221.
19. Pénicaud C, Achir N, Dhuique-Mayer C, et al. Degradation of β-carotene during fruit and vegetable processing or storage: reaction mechanisms and kinetic aspects: a review. *Fruits*. 2011;66(6):417–440.
20. Hernández-Santos B, Martínez-Sánchez CE, Torruco-Uco JG, et al. Evaluation of physical and chemical properties of carrots dried by Refractance Window drying. *Dry Technol*. 2016;34(12):1414–1422.
21. Nemzer B, Vargas L, Xia X, et al. Phytochemical and physical properties of blueberries, tart cherries, strawberries, and cranberries as affected by different drying methods. *Food Chem*. 2018;262:242–250.
22. Topuz A, Dincer C, Özdemir KS, et al. Influence of different drying methods on carotenoids and capsaicinoids of paprika (Cv., Jalapeno). *Food Chem*. 2011;129(3):860–865.
23. Topuz A, Feng H, Kushad M. The effect of drying method and storage on color characteristics of paprika. *LWT-Food Sci Technol*. 2009;42(10):1667–1673.
24. Caparino OA, Sablani SS, Tang J, et al. Water sorption, glass transition, and microstructures of refractance window–and freeze-dried mango (Philippine "Carabao" Var.) powder. *Dry Technol*. 2013;31(16):1969–1978.
25. Caparino OA, Tang J, Nindo CI, et al. Effect of drying methods on the physical properties and microstructures of mango (Philippine 'Carabao'var.) powder. *J Food Eng*. 2012;111(1):135–148.

Citation: Baeghbali V, Niakousari M. A review on mechanism, quality preservation and energy efficiency in Refractance Window drying: aconductive hydro-drying technique. *J Nutr Food Technol.* (2018);1(2): 50–54. DOI: 10.30881/jnfrt.00011

26. Ochoa-Martínez CI, Quintero PT, Ayala AA, et al. Drying characteristics of mango slices using the Refractance Window™ technique. *J Food Eng*. 2012;109(1):69–75.

27. Nindo CI, Powers JR, Tang J. Thermal properties of Aloe vera powder and rheology of reconstituted gels. *Trans ASABE*. 2010;53(4):1193–1200.

28. Minjares-Fuentes R, Femenia A, Comas-Serra F, et al. Effect of different drying procedures on physicochemical properties and flow behavior of Aloe vera (Aloe barbadensis Miller) gel. *LWT-Food Sci Technol*. 2016;74:378–386.

Citation: Baeghbali V, Niakousari M. A review on mechanism, quality preservation and energy efficiency in Refractance Window drying: aconductive hydro-drying technique. *J Nutr Food Technol*. (2018);1(2): 50–54. DOI: 10.30881/jnfrt.00011