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Effect of Heat Pump Drying on Quality of Fruits and Vegetables: A Review

Md Irfan Ahmad Ansari, Chhaya, Augustine Guria, Pramod Rai

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ABSTRACT

Drying is one of the most important unit operations used in food processing sector at large scale to extend shelf-life, enhance appearance, maintain nutritional value, reduce packaging and transporting cost. The high temperature convective hot air drying process reduces the nutritional and organoleptic quality of food products. Heat pump drying is one of the options for drying of fruits and vegetables at low temperature with high nutritional and organoleptic quality apart from saving in energy consumption and operation under controlled conditions. Heat pump drying works on the principle of refrigeration cycle which controls the temperature and relative humidity of drying air in the drying process. Researchers have found that high-value heat-sensitive food products can be dehydrated through heat pump drying while preserving nutrition and phytochemicals, improving rehydration (lesser cellular structure damage) and organoleptic (odor, flavor, taste, texture and appearance) properties. This paper discusses the principle of operations, nutrient and color degradation kinetics and quality of heat pump dried fruits and vegetables.

Keywords Heat pump drying, Fruits, Vegetables, Temperature, Relative humidity, Quality.

INTRODUCTION

India is the second largest producer of fruits and vegetables in the world after china. The fresh fruits and vegetables are highly perishable due to high moisture content. They are important sources of essential dietary nutrients such as vitamins, minerals and fiber and huge amount is wasted due to poor post harvest management system. Microbial, enzymatic and chemical reaction, discoloration, textural changes are the factors which lower their quality and hence influence the consumer's acceptance. These fresh produce are dried by adopting various drying techniques to increase shelf life and promote food security. Drying is one of the most energy-intensive unit operations for fruits and vegetables to reduce the moisture content after harvest to prolong the shelf-life by reducing the water activity to a low level at which growth of microorganisms, enzymatic reactions and other deteriorative reactions are inhibited. They are dried to reduce packaging cost, lower shipping weights, enhance appearance, encapsulate original flavor and maintain nutritional value. The economic consideration, environmental concerns and product quality

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Md. Irfan Ahmad Ansari[1]*, Chhaya[2], Augustine Guria[3], Pramod Rai[4]

[1]Assistant Professor Cum Junior Scientist, [2]Assistant Professor, [3]Senior Research Fellow, [4]Junior Scientist Cum Assistant Professor
[1,3,4]Department of Agricultural Engineering, Birsa Agricultural University, Kanke, Ranchi, Jharkhand 834006, India

[2]College of Agricultural Engineering, Birsa Agricultural University, Kanke, Ranchi, Jharkhand 834006 , India

Email: irfaniitkgp2000@gmail.com
*Corresponding author

aspects are the main three goal of drying process in food industry. The drying of fruits and vegetables has been principally accomplished by high temperature convective drying and is an important cause for loss of quality such as loss of color, aroma, flavor and nutrients. Low temperature drying has great potential for improving the quality of dried products. Heat pump drying (HPD) is one of the options for drying at low temperature with saving in energy consumption and operation even under humid ambient conditions. HPD is an extension of a conventional convection air drying with an in-built refrigeration system. In HPD, the heat pump and the actual drying of the material are treated separately. One of the main advantages of HPD is the retention of quality and its successful application to drying highly valued heat sensitive fruits and vegetables. It improves product quality and reduces energy consumption (Fayose and Huan 2016) and recovers the latent and sensible heat by condensing moisture from the drying air. It is an alternative technique for drying products at lower temperature and relative humidity with lower energy consumption. It can be used in combination with vacuum condition (Artnaseaw *et al.* 2010), atmospheric freeze drying and solar drying to get better quality products in term of aroma, texture, taste and appearance. It is increasingly used in food industries due to its high thermal efficiency, high drying performance, better regulation of the drying conditions and environmental friendly (Salehi 2021). Uthpala *et al.* (2020) stated that the use of HPD is increasing in the food industry for the drying fruits, vegetables, herbs and other heat-sensitive food products in several countries of the world.

This review paper discusses the principles of heat pump dryer, nutrient and color degradation kinetics and quality attributes of heat pump dried fruits and vegetables.

Principles of operation of heat pump drying

Heat pump drying is based on the principle of the refrigeration and consists of an evaporator, a condenser, a compressor, an expansion valve and drying chamber. A heat pump is used to perform condensation and heating of the dehumidified air. The evaporator functions as dehumidifier and the condenser as heater. The schematic diagram of heat pump drying system is given Fig. 1. The first four components connected each other forms a closed cycle. The working fluid (refrigerant) and drying air, both completes its cycle by passing through various components of HPD system and generates the favorable conditions for efficient drying. The high moisture low temperature exhaust air enters the evaporator (Kivevele and Huan 2013) where the moisture present in air gets condensed and is removed from air. This dehumidified air is heated in the condenser and used as drying agent. The latent heat given up by the moist air is taken up by the refrigerant and is circulated within the refrigeration circuit. The refrigerant is evaporated in evaporator by using heat of exhaust air and then compressed in a compressor at high pressure. The heat is removed from the working fluid and returned to drying air at the condenser. The working fluid is then throttled to the lower pressure line and enters the evaporator to complete the cycle. The cycle of working fluid and drying air continues simultaneously throughout the drying process. The process is repeated until the product is dried to the desired moisture level.

Nutrient and color degradation kinetics

The understanding of nutrient and color degradation kinetics is essential to access the effect of drying temperature on nutritional and color of the dehydrated fruits and vegetables during processing and storage. The kinetic parameters during drying affect the final product quality as well as the cost of operation (Cosme-De Vera *et al.* 2021). During the drying process, various kinetic models are widely used to predict the changes in nutrient and color. It has been established by several researchers that the degradation of nutrient and color follow zero and first-order reaction kinetics. The zero order and first order reaction model are expressed as given below:

$$C = C_0 \pm kt \qquad (1)$$

$$C = C_0 \, EXP \; (\pm kt) \qquad (2)$$

Where (+) and (-) indicate formation and degradation of any quality parameters respectively. C and C_o are the value of concentration of nutrient/color at any time t and 0 respectively and k is reaction rate constant.

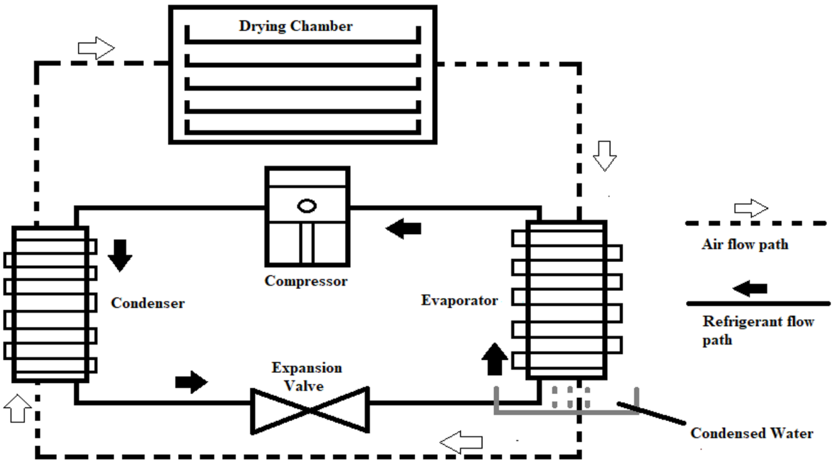

Fig. 1. Schematic diagram of heat pump dryer.

The regression analysis is carried out to get the kinetic parameters. The goodness of fitted model is determined by the highest correlation coefficient (R^2) and least root mean square error (RMSE) value.

The temperature dependence of nutrient loss and color changes are determined by the following Arrhenius equation:

$$k = A \exp\left(\frac{-Ea}{RT}\right) \qquad (3)$$

Where k_0 is frequency factor at the Arrhenius constant ($time^{-1}$), R is the universal gas constant (8.3145 J/mol K), T is the absolute temperature at which reaction occurs (K).

The activation energy is determined by the slope of the graph (ln k) versus (1/T). The simplified equation is given below :

$$\text{In } k = \text{In } A + \left(\frac{-Ea}{R}\right)\left(\frac{1}{T}\right) \qquad (4)$$

Vu *et al.* (2022) studied polyphenol degradation during HPD of soursop fruit and they identified a first–order response model that predicted polyphenol degradation during the drying of soursop fruit ($R^2 = 0.9693$). Potisate *et al.* (2015) reported that degradation of flavonoids followed first order kinetics during storage of HPD moringa oleifera leaves.

Quality of heat pump dried fruits and vegetables

The changes in quality parameters during drying process are color, visual appeal, shape of product, flavor, microbial load, retention of nutrients, porosity-bulk density, texture, rehydration properties, water activity. Several researchers reported that HPD fruits and vegetables retain product flavors, color pigments, aromatic compounds, bioactive ingredients and vitamins (Minea 2013, Chua and Chou 2014). Also, researchers have found better color and flavor retention, better rehydration properties, lesser degree of cellular structure damage in HPD products in comparison to conventional hot air dried products (Zhang *et al.* 2017). The consumer demand has increased for dried fruits and vegetables with original quality characteristics. Color is one of the most important quality attributes for dried food products because most of the time consumers choose a food product based on its visual appearance. The application of HPD contributes positively to microbial safety, better color, vitamin C retention, improved volatile compound, aroma and flavor compounds, rehydration and textural properties (Fayose and Huan 2016).

The apple dried using HPD gives porous products, leading to quick rehydration with minimum

Table 1. Comparison of heat pump drying with other drying processes (Kivevele and Huan 2013, Uthpala *et al.* 2020).

Parameters	Heat pump drying	Hot air drying	Vacuum drying	Freeze drying	Sun drying
Operating temperature range (°C)	-20 to 40	40 to very high	30 to 60	-35 to 50	30 or high
Operating % relative humidity range	10-50	Variable	low	low	Less than 60
Product quality	Very good	Average	Good	Excellent	Average
Rehydration properties	Very good	Average	Moderate	Good	Poor
Fixed cost	Moderate	Low	High	Very high	Low
Operating cost	Low	High	Very high	Very high	Low

color deterioration and shrinkage. The modified atmosphere HPD apples gave excellent color and retention of Vitamin C. Apple dried using HPD showed better rehydration properties, color preservation, lower water activity, and less cellular structure damages over hot air dried (45–65°C) samples. Chong *et al.* (2014) dried apple slices (15 mm) by HPD, vacuum-microwave, and intermittent methods and reported that the HPD gave the highest retention of total polyphenol content, antioxidant activity and the better appearance.

HPD guava, papaya and apple showed better retention of vitamic C, minimum color change and shrinkage and faster rehydration. Minea (2013) stated the higher rehydration capacity, better color retention, higher retention of vitamin C and volatile compounds for HPD products. Chong *et al.* (2013) reported that HPD followed by vacuum microwave drying gave the best results for most dehydrated fruits. The HPD onion slices resulted in better product quality. The cyclic HPD of banana and guava also gave an improved color as compared to constant drying temperature. HPD offers an attractive option to enhance product quality and reduced spoilage through better regulation of drying conditions.

Artnaseaw *et al.* (2010) carried out vacuum HPD of shiitake mushroom and it gave better color and rehydration properties. Drying of potato pieces in a cyclic HPD (started with higher temperature followed by lower temperature and the cycle continues) gave better dehydrated products without significant change in color.

Sahoo (2012) studied quality aspects during HPD of onion and stated that quality parameters such as rehydration ratio, retention of color, ascorbic acid content and pyruvic acid content of onion slices dried at 50^0C were the best. The optimum HPD temperature for fruits and vegetables lie between 30 and 45°C, where no structural damage and nutrient losses occur. Ginger dried in a HPD was found to retain over 26% of gingerol, the principal volatile flavor component responsible for its pungency, compared to only about 20% in rotary dryer. The higher volatile retention is due to the lower drying temperature. HPD ginger rhizome contains higher content of 6-gingerol than hot air tray drying and sun drying. The two stages HPD at 40°C increased the 6-gingerol content by 6% for ginger (Phoungchandang and Saentaweesuk 2011). Most of the aroma compounds of foods are more volatile than water because of a combination of high vapor pressure and low solubility of the aroma compounds in aqueous solutions (Saravacos and Krodika 2014).

The green sweet pepper dried using HPD at 30–40°C retains chlorophyll and ascorbic acid because of the lower drying temperatures. Pal and Khan (2010) reported higher retention of total chlorophyll and ascorbic acid content in heat pump dried green sweet pepper with higher rehydration ratio and better sensory score. Jovanovic (2013) observed minimum color degradation of heat pump dried fruits and better retention of nutrients and flavors.

Sevik (2014) concluded that solar assisted HPD of tomato resulted in minimum degradation of bioactive compounds i.e. 3% for lycopene, 13% for ascorbic acid, and 2% for polyphenols. Sevik (2014) reported that the bioactive ingredients retained in solar assisted HPD strawberry and the values were 150 mg ascorbic acid in dried strawberries compared to 230 mg in fresh strawberries. Artnaseaw *et al.* (2010) reported that percentage shrinkage of chilli was higher at high operating pressure but rehydration ratio decreased with increase in pressure during using vacuum HPD. The Table 1 shows comparison of heat pump drying with other drying processes. It is clear from Table 1 that quality and operating cost for HPD product is better than hot air and vacuum drying. The quality of HPD is comparable to freeze dried product but the fixed and operating cost of freeze drying is very high.

CONCLUSION

Drying is one of the most important unit operations employed for drying of fruits and vegetables. The conventional hot air drying results in loss of nutritional and organoleptic quality. The heat pump drying in one of the methods of drying which retains the nutritional component in the dried product as compare to the conventional hot air drying method. This technique offers several advantages over conventional hot-air drying for the drying of fruits and vegetables including higher energy efficiency, better product quality, and the ability to operate independently of outside ambient weather conditions. The quality and operating cost for HPD product is better than hot air and vacuum drying and it is comparable to freeze dried product but the fixed and operating cost of freeze drying is very high. This technology has immense potential for producing high quality dried fruits and vegetables because consumers are becoming more conscious about the safety and quality of food products.

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REFERENCES

Artnaseaw A, Theerakulpisut S, Benjapiyaporn C (2010) Drying characteristics of Shiitake mushroom and Jinda chili during vacuum heat pump drying. *Food and Bioproducts Processing* 88 (2-3) : 105—114. https://doi.org/10.1016/j.fbp.2009.09.006.

Bantle M, Eikevik TM, Rustad T (2009) Atmospheric freeze-drying of calanus finmarchicus and its effects on proteolytic and lipolytic activities 4th Nordic Drying Conf, June, pp 17—19.

Chong CH, Figiel A, Law CL, Wojdyło A (2014) Combined drying of apple cubes by using of heat pump, vacuum-microwave, and intermittent techniques. *Food and Bioprocess Technology* 7 : 975—989. https://doi.org/10.1007/s11947-013-1123-7.

Chong CH, Law CL, Figiel A (2013) Color, phenolic content and antioxidant capacity of some fruits dehydrated by a combination of different methods. *Food Chemistry* 141 (4) : 3889—3896. https://doi.org/10.1016/j.foodchem.2013.06.042.

Chua KJ, Chou SK (2014) Recent advances in hybrid drying technologies. *Emerging Technologies for Food Processing* , pp 447—459. https://doi.org/10.1016/B978-0-12-411479-1.00024-3.

Cosme-De Vera FH, Soriano AN, Dugos NP, Rubi RVC (2021) A comprehensive review on the drying kinetics of common tubers. *Applied Science and Engineering Progress* 14 (2) : 146—155. 10.14416/j.asep.2021.03.003.

Fayose F, Huan Z (2016) Heat pump drying of fruits and vegetables: Principles and potential for Sub Sahara Africa. *Annals of Faculty Engineering Hunedoara-International Journal of Engineering* 14 : 207—214.

Jovanovic S (2013) Quality characterization and modeling experimental kinetics in pilot scale heat pump drying of green peas. Master's thesis. Norwegian University of Science and Technology, Trondheim, Norway.

Kivevele T, Huan Z (2013) A review on opportunities for the development of heat pump drying systems in South Africa. *South Africa Journal of Science* 110 (5/6) : 1—11. 0.1590/sajs.2014/20130236.

Minea V (2013) Heat-pump-assisted drying: Recent technological advances and R and D needs. *Drying Technology* 31(10) : 1177—1189. https://doi.org/10.1080/07373937.2013.781623.

Pal US, Khan MK (2010) Performance evaluation of heat pump dryer. *Journal of Food Science and Technology* 47(2) : 230—234. 10.1007/s13197-010-0031-3.

Pal US, Khan MK, Mohanty SN (2008) "Heat pump drying of green sweet pepper," *Drying Technology* 26 (12) : 1584—1590. https://doi.org/10.1080/07373930802467144.

Phoungchandang S, Saentaweesuk S (2011) Effect of two stage, tray and heat pump assisted-dehumidified drying on drying characteristics and qualities of dried ginger. *Food and Bioproducts Processing* 89 (4) : 429—437. https://doi.org/10.1016/j.fbp.2010.07.006.

Potisate Y, Kerr WL, Phoungchandang S (2015) Changes during storage of dried *Moringa oleifera* leaves prepared by heat pump-assisted dehumidified air drying. *International Journal of Food Science and Technology* 50 : 1224—1233. 10.1111/ijfs.12744.

Sahoo N (2012) Drying kinetics and quality aspects during heat pump drying of onion (*Allium cepa* L.). *International Journal of Food Studies* 1(2) : 159—167. 10.7455/ijfs/1.2.2012.a6.

Salehi F (2021) Recent applications of heat pump dryer for drying of fruit crops: A review. *International Journal of Fruit Science* 21(1) : 546—555.

https://doi.org/10.1080/15538362.2021.1911746.

Saravacos GD, Krodika M (2014) Mass transfer properties of food. In *Engineering Properties of Food,* pp 311—358.

Sevik S (2014) Experimental investigation of a new design solar-heat pump dryer under the different climatic conditions and drying behavior of selected products. *Solar Energ* 105 : 190—205.
https://doi.org/10.1016/j.solener.2014.03.037.

Uthpala TGG, Navaratne SB, Thibbotuwawa A (2020) Review on low-temperature heat pump drying applications in food industry : Cooling with dehumidification drying method. *Journal of Food Process Engineering* 43(10). In press.
https://doi.org/10.1111/jfpe.13502.

Vu, Ngoc Duc, Tran, Nhi Thi Yen , Le, Truong Dang, Phan, Nguyet Thi Minh, Doan, An, Phu Le , Huynh, Bao, Long and Dao, Phat Tan (2022) Kinetic model of moisture loss and polyphenol degradation during heat pump drying of soursop fruit (*Annona muricata* L.) 10 (10) : 2082.
https://doi.org/10.3390/pr10102082.

Zhang M, Chen H, Mujumdar AS, Tang J, Miao S, Wang Y (2017) Recent developments in high-quality drying of vegetables, fruits, and aquatic products. *Critical Reviews in Food Science and Nutrition* 57 (6) : 1239—1255.
https://doi.org/10.1080/10408398.2014.979280.