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Feasibility of using infrared heating for blanching and dehydration of fruits and vegetables

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Abstract *The objective of this study was to evaluate the feasibility of using medium and far infrared heating for blanching and dehydration of various fruits and vegetables. The infrared blanching was referred as infrared dry-blanching (IDB) in this study since no water or steam was used. A catalytic infrared blancher/dryer was used to perform the blanching and dehydration functions. For blanching study, the fruits and vegetables, including pears, baby carrots, sweet corn and french fries, were blanched with radiation energy intensity of 5.7 kW/m^2. The pears were cut into 12.7 mm cubes and french fries had cross section of 12.7 x 12.7 mm. The sweet corn kernels were removed from the cobs before the blanching. The whole baby carrots had diameter of 15 mm. It took 2, 4, 1, and 3.5 min to inactivate the peroxidase in the pear cubes, whole baby carrots, cut corn and french fries, respectively. The IDB also showed high heating rate. It was concluded that all tested fruits and vegetables were effectively blanched in relatively short times and products had good appearances. When the pear cubes were further dehydrated to 50% weight reduction with radiation energy intensity of 2.7 kW/m^2 after the blanching, total time saving of IDB was 43.9% compared to steam blanching followed by heated air drying. The texture and appearance of IDB processed pears appeared to be superior compared to the control samples produced with steam blanching and heated air drying. Therefore, the IDB can be used for performing simultaneous blanching and dehydrations.*

Keywords. Infrared, fruits and vegetables, blanching, dehydration.

Introduction

For most processed fruits and vegetables, blanching is essential to inactivate the enzymes responsible for quality deterioration of fruits and vegetables in storage. Blanching also serves the purposes of microbial population reduction, color stabilization, and facilitation for further processing and handling. The enzyme inactivation is normally achieved by heating the fruits and vegetables to a desired temperature (70-100°C) using hot water or steam or microwave energy and holding the products for a period of time (FMC, 2003). Hot water and steam blanching require a large amount of energy and can cause significant losses of solids, nutrients, phytochemicals, and/or flavors (Aminov et al. 1976; Vanlaanen, 2003). Since blanching with hot water and steam at high temperature may also cause undesirable changes in product texture, low temperature blanching at 50-80°C has been investigated for blanching various fruits and vegetables, including carrots, bell peppers, and sweet potatoes (Dominguez et al., 1996; Fuchigami et al., 1995; Stanley et al., 1995). In general, low temperature blanching could improve the texture quality of the products, but require longer time than a high temperature blanching.

Microwave has been studied for blanching fruits and vegetables, including peaches, corn-on-the-cob, banana, peas, green beans, and carrots during last five decades. It has been shown that microwave could provide sufficient enzyme inactivation (Avisse et al., 1977; Cano et al., 1998; Devece et al., 1999; Dietrich et al., 1970; Gunes et al., 1993; Huxsoll et al., 1970). However, it has also been pointed out that microwave blanching does not save time or energy. The loss of nutrients and phytochemicals caused by uneven microwave heating is another problem prohibiting its wide uses for blanching and drying. High pressure blanching has been considered to be an alternative blanching method for inactivating enzymes. However, the firmness of treated samples was reduced significantly (Master et al., 2000). The use of this technology is still limited due to its high cost.

Due to the advantages of the infrared heating, it could be an alternative method for blanching and drying. Infrared radiation energy with specific wavelengths could penetrate into product and directly heat water or desired components to achieve the purposes of blanching and drying. Water absorbs heat energy very efficient in the range of medium and far infrared wavelengths with peak wavelengths at 3, 4.7 and 6 microns (Ginzburg, 1969). Since the medium and far infrared energy does not heat the air and medium, the energy transfer is highly efficient. When infrared heating is used for blanching, no water or steam is needed (Pan and McHugh, 2004). Therefore, the infrared blanching is called infrared dry-blanching (IDB) in this study.

Various enzymes are present in different fruits and vegetables and could catalyze or initiate undesirable changes in color, texture and flavor. The major enzymes include peroxidase, lipoxygenase, catalase, and ascorbic acid oxidase (Dauthy, 1995). Blanching to reach a peroxidase inactivation end point is common in many food industries even though some quality deterioration may be caused by other enzymes that less heat resistant to peroxidase. The inactivation of peroxidase is normally used as an indicator of blanching processing. The presence of peroxidase can be determined with two different methods, qualitative and quantitative methods. The two methods were described by Dauthy (1995) and Reuveni et al., (1992), respectively.

For certain applications, the moisture of blanched products needs to be partially removed or water activity needs to be lowered before further processing. To produce such products two sequential processing steps, blanching and dehydration (drying), are normally used. The partial removal of the product moisture could improve the processing and energy efficiencies of the overall processes. For example, if the products need to be frozen after blanching, the partial moisture removal could reduce the energy consumption due to lower water load to the freezer. It may also reduce the costs related to transport, storage and wrapping of the products. The blanching followed by dehydration process could also offer better quality, stability (color and flavor), and thawing behavior (low drip loss) of finished products.

Dehydration is the most common processing method or step, but also is the most energy consuming step in food and agricultural product processing. Dehydration of fruits and vegetables is normally carried out by using solar and mechanical methods (hot/heated air, freeze-drying, microwave drying, etc). Solar drying is simple and economical, but the products are subject to insect and rodent attack, wind damage, sudden rain, soil entry and other problems. Conventional heated air drying is more popular than freeze-drying and microwave drying because freeze-drying has high energy consumption and microwave drying can cause uneven heating. But due to the nature and relative slow drying rate of heated air drying, the texture and color of heated air dried products are less desirable than the freeze-dried products. Conventional heated air drying, which normally uses gas-fired heaters and electrically driven blowers, is the most commonly used for fruits, vegetables, nuts, grains, etc. Its energy efficiency is low and takes a long time. High drying temperature and high airflow rate may be used in some operations to improve the drying rate and productivity and reduce the processing time. However, such measures could significantly cause the deterioration in the quality of finished products and increase the energy consumption.

The applications of infrared technology in thermal processes, including blanching and dehydration, of food and agricultural products are still very limited due to lack of knowledge about the technology even though the infrared radiation has been used for other applications due to the advantages of the infrared heating (Hebbar and Rastogi, 2001; Mongpraneet et al., 2002; Paakkonen, 1998; Seyed-Yaoobi and Wirtz, 2001; Sundue, 1986). Ginzburg (1969) reported that infrared drying could save energy up to 38% for drying apple. Infrared heating does not have the problems of un-uniform heating associated with microwave drying and safety concerns and high equipment cost associated with radio frequency heating. It can also significantly shorten the processing time, reduce the space needed for equipment and enhance production and quality (Pan and McHugh, 2004). Therefore, the infrared heating and curing have been largely used for both water- and solvent-based surface coatings (paints and inks) in the automobile, electric equipment, home appliance, steel galvanizing, textile, and wood product industries.

Materials and Methods

A catalytic infrared (CIR) emitter from Catalytic Infrared Drying Technologies LLC (Independence, KS) was used in this research. The CIR emitter can generate medium and far infrared radiation energy with peak energy from 3.3 to 8 microns by catalyzing natural gas or propane gas with a platinum catalyst. In this study, natural gas was used as energy source. When it is combined with air across the platinum catalyst, natural gas reacts by oxidation-reduction to yield infrared energy and small amounts of CO_2 and water vapor. The wavelength and total emitted energy can be controlled by varying the gas supply to adjust the temperature of infrared emitter/heater. In this study, the CIR emitter surface temperature was 500°C which was corresponded to 3.7 microns of peak wavelength when the emitter was assumed as black body. The set up of the CIR blancher/dryer is shown in Fig. 1. For comparison, a steam blancher and conventional heated air dryer were used for blanching and dehydration, respectively.

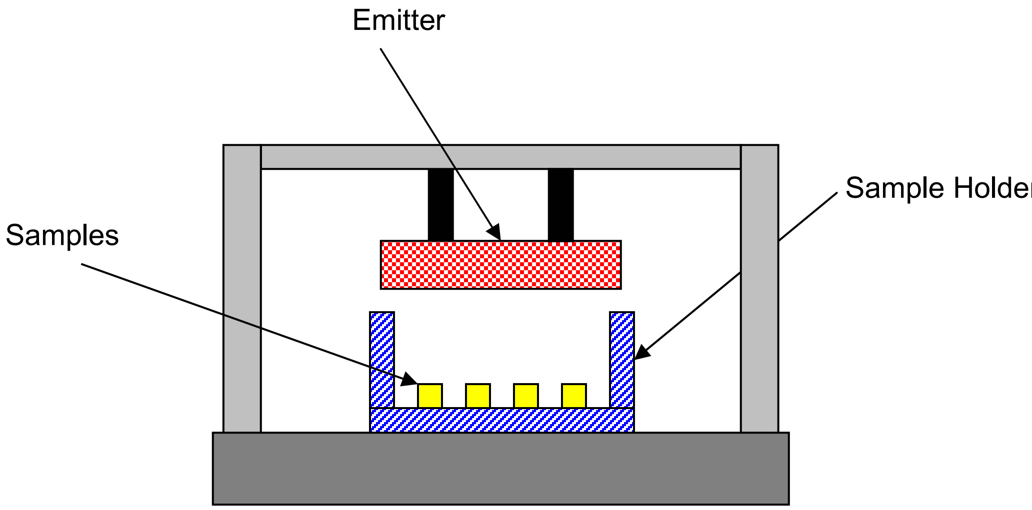


Figure 1. Catalytic infrared (CIR) blancher/dryer

To determine the heating rates of IDB and steam blanching, two different tests were conducted by using Bartlett pear slices and cubes. The 12.7 mm thick slices (like a disk) were used to exam the heating rate under one dimensional condition since one dimensional heat transfer can be assumed due to the large ratio of diameter and thickness. The cubes represented the shape of practical applications of the fruit. For the IDB blanching, samples were placed in an aluminum sample holder (baking pan) inside the CIR blancher/dryer. The sample holder surface was 115 mm from the emitter surface with infrared radiation intensity of 5.7 kW/m^2. A single slice of pear in each time was used for the one dimensional heating test. For the cube heating test, 15% loading rate (ratio of sample covered surface to total sample holder surface) was used. The center temperature of the sample was measured by using thermocouples placed at the geometric center of the samples. The heating rates of pear samples were also measured under steam blanching at 75°C.

To determine the effectiveness of IDB blanching, four types of fruits and vegetables, including pear, whole carrot, potato and sweet corn, were blanched with IDB. The samples were obtained from local food suppliers or warehouse and stored in a refrigeration facility at 0-2°C before used for the study. For the blanching study, the pears were diced to desired sizes (half-inch cubes) and dipped in 1% ascorbic and 1% citric acid solution for 3 min before the blanching or blanching followed by dehydration, which was used to prevent enzymatic browning and oxidation of processed products from occurring. The pear cubes were blanched for up to 2 min with 30 sec interval to examine the enzymatic activity of the samples. The pear cubes were also blanched with steam at 75°C for 6 min with 1 min interval to examine the effectiveness of steam blanch. The whole baby carrots, cut sweet corn and sliced potatoes were blanch with the IDB for various times to determine the necessary times to complete enzyme inactivation. The whole baby carrots had diameter of 15 mm and were turned over every minute during blanching. Sweet corn was cut from cob before blanching. The cut sweet corn required less energy for blanching since there was no need to heat the cob. The sliced potatoes (french fries) had 12.7 x 12.7 mm cross section and were also turned every minute during blanching.

For qualitative enzymatic (peroxidase) activity determination, the processed products were cut into two equal pieces right after the removal of the product from heater/dryer. The 1% guaiacol solution and 1% hydrogen peroxide solutions were sequentially applied to the cut surfaces and the color development was examined after 5 min. The colors of samples were compared with the control samples that were not blanched. No red color (dark) development indicated that enzymes were inactivated.

For studying the processing characteristics and product quality of simultaneously blanched and dehydrated products, diced and dipped pear samples were blanched and dehydrated to 50% original weight using IDB with the procedures of 500°C emitter temperature and 115 mm distance for the first 2 min (radiation energy intensity 5.7 kW/m^2) and then 470°C and 265 mm distance (radiation energy intensity 2.7 kW/m^2). The sample weight change was monitored and recorded with an electronic balance and data acquisition system. The results were also compared with the results from steam blanched pear cube samples dried with 70°C hot air at velocity of 1.2m/s. The steam blanching conditions were 75°C steam and 5 min. The texture, color, and rehydration ratios of the samples were also determined.

The texture of blanched and dehydrated pear cubes (50% weight reduction) was measured using Instron (5500R mainframe, Merlin Software) following the Texture Profile Analysis (TPA) methods described by Brown (1977). In this test, fracturability, hardness, cohesiveness, adhesiveness, springiness, gumminess, and chewiness of the samples were determined. The TPA method used two measuring cycles. The two downward cycles compressed the pear piece 60% of the original height at a rate of 15 mm/min. The two upward cycles returned the platen to its original position at a rate of 25 mm/min. The load cell was 100N and the platen was 25 mm in diameter.

The color and reflectance of blanched and dehydrated pear cubes were measured using the Minolta Spectrophotometer. The Minolta Spectrophotometer simultaneously measured the color and reflectance and then the data were downloaded into a computer. The color was measured in the L, a, b, coordinates. The samples used for color measurement included pears with 50% weight reduction in frozen, thawed in the open air for 2 hours at 23°C, and thawed in deionized water for 1 hour at 23°C (rehydrated samples).

Rehydration ratio was defined as the ratio of sample weight after rehydration and before rehydration. It was measured using five pieces of the frozen pears cubes with 50% weight reduction. Each pear piece was rehydrated in deionized water by placing it into a 50 mL beaker containing 20 grams of water for one hour at room temperature (23°C). After one hour, each piece was placed on a piece of paper towel for 1 min to remove the excess water before the sample weight was determined.

RESULTS AND DISCUSSIONS

Heating Rate

It is clearly seen that the heating rate of IDB was higher than that of steam blanching under the one dimensional condition in this test (Fig. 2). This means that the IDB resulted in higher heat penetration of infrared and higher heat transfer rate. The results also indicated that infrared heating with appropriated wavelength and energy intensity could deliver the heat needed for blanching fruits or vegetables quickly, which could reduce processing time and the negative impacts on product quality caused by using high temperature of existing blanching technology.

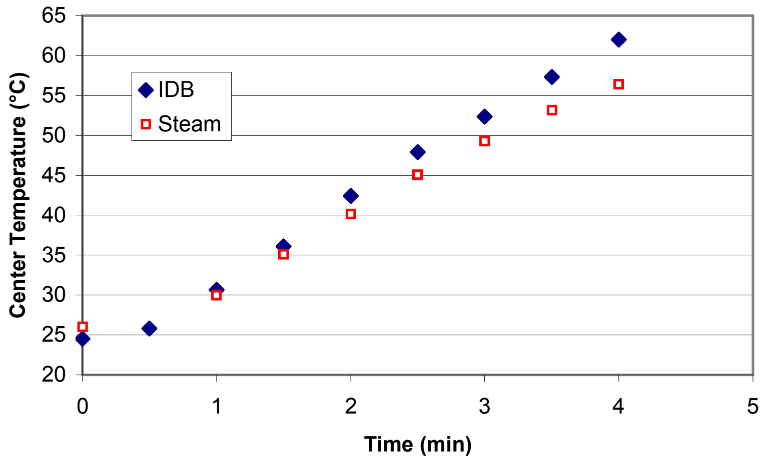


Figure 2. Temperature profiles of pear slices blanched with IDB and 75°C steam

It also needs to be pointed out that the IDB used for this test applied heating from only top side, but the steam blanching applied heating from two sides (top and bottom). If the pear samples are heated from both sides by using two emitters or if the samples are flipped during the process, the heating rate should be further increased. To improve the heating rate, the blancher can also be redesigned with a rotary drum, which holds the sample inside. As the drum rotates during heating, the samples can be heated from all surfaces uniformly. The uniform heating from all surfaces could further reduce the time needed for blanching to inactivate the enzymes.

When the 12.7 mm pear cubes were blanched with IDB and steam at 75°C, the temperature profiles at the geometric center are shown in Fig. 3. It took about 2 minutes for the center temperatures to reach 70°C for both IDB and steam blanching. Then the center temperature of steam blanched sample approached to an equilibrium temperature of 75°C. For IDB, the center temperature approached to 100°C at 4 min. For fruit blanching, it is not necessary to increase the temperature to beyond 75°C. Too high a temperature could deteriorate the texture and sensory quality. This indicated that the heat supply of IBD may need to be reduced after two minutes of the high intense heating to achieve high quality product.

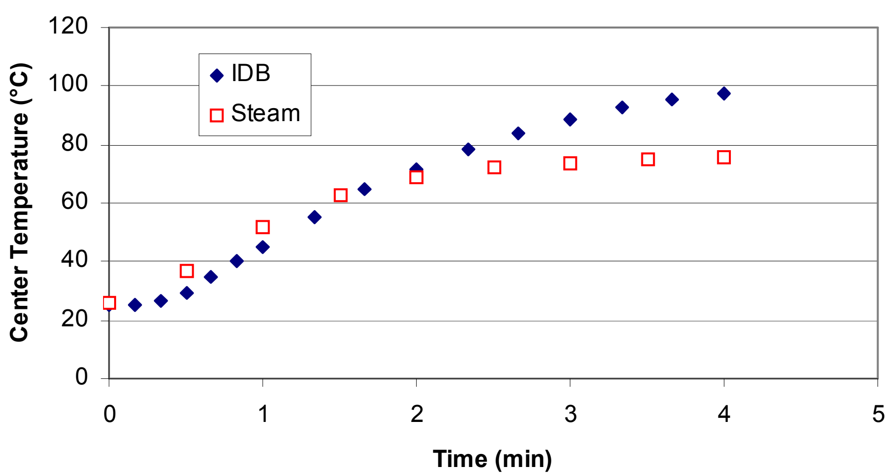


Figure 3. Temperature profiles of pear cubes blanched with IDB and 75°C steam

The heating rate results of pear cubes and slices showed that slices heated from only top surface were heated much slower than the cubes heated from all surfaces by direct radiation and reflection radiation heating. For cubes, if the loading rate is increased, there will be less space available for the reflection heating. In actual production, the loading rate should be determined based on the required processing speed.

Enzyme Inactivation

The enzymatic activities of 12.7 mm pear cube samples blanched using steam for different times are shown in Fig. 4. The results showed that it took about 5 min to completely inactivate the enzymes in the samples at 75°C. Therefore, control samples for further drying study were produced by blanching the pear cubes with steam at 75°C for 5 min.

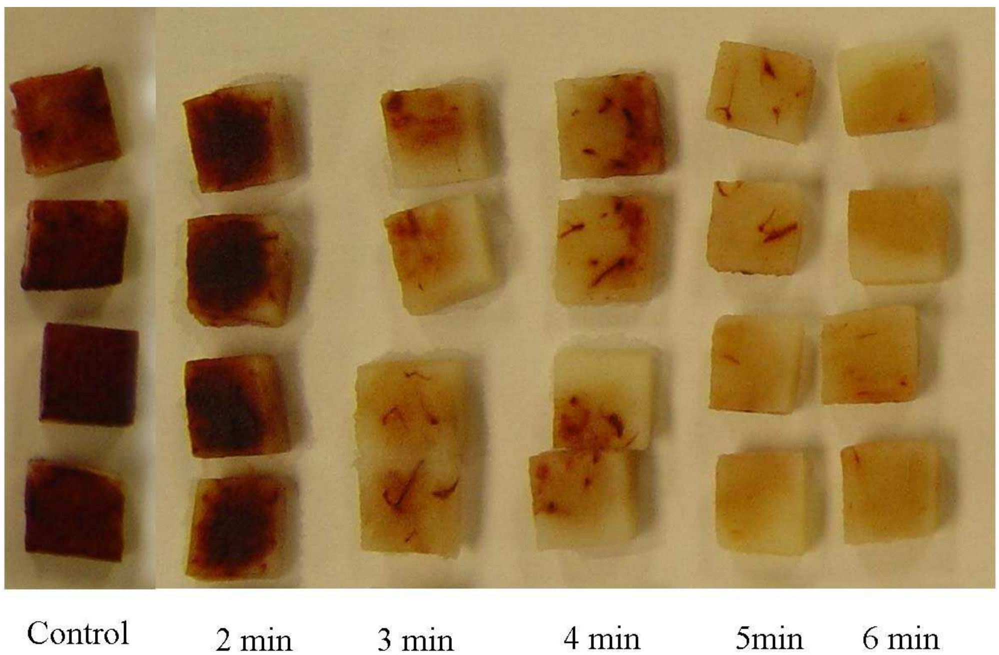


Figure 4. Enzymatic activities of pear cubes blanched with 75°C steam for various times

The enzymatic activities of the IDB blanched 12.7 mm pear samples were examined and compared with the control sample (not blanched) (Fig. 5). The results showed that 2 min IDB blanching was long enough to inactivate the enzymes. In the experiments, only several pieces of pear cubes were used each time. The samples were heated faster than that with 15% loading rate. The loading rate of sample in IDB could affect the rate of enzyme inactivation due to different heating rates as observed in the heating rate study. A slighter longer blanching time may be needed if the sample loading rate is high.

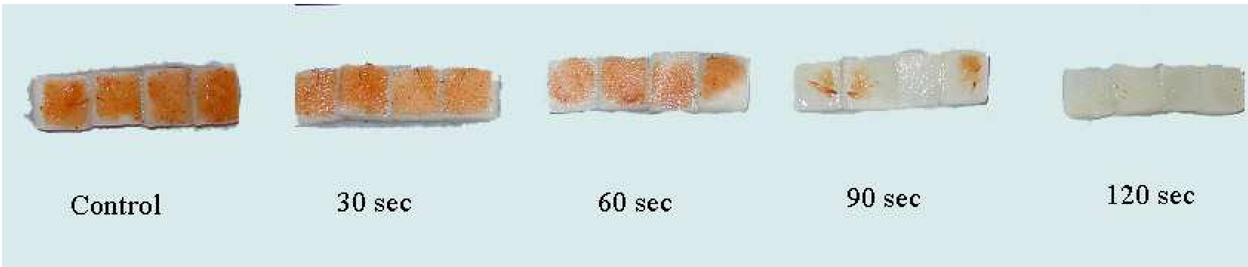
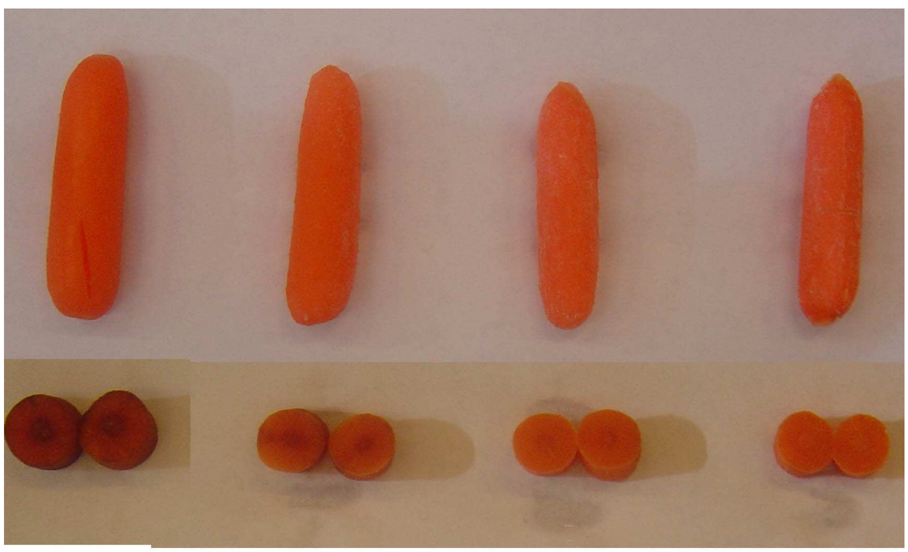


Figure 5. Enzymatic activity of pear cubes blanched with IDB for various times

To achieve simultaneous blanching and dehydration, high heating intensity of emitter may not be used for a long time which may cause discoloration of the processed products. Therefore, for achieving high quality finished products, variable heating was used in the simultaneous blanching and dehydration study.

For baby carrot blanching, the results showed that after 3 to 4 min blanching the carrots had very nice appearance with complete enzyme inactivation (Fig. 6). With the same heating conditions as used for carrots, cut sweet corn kernels were blanched for only one min and achieved complete enzyme inactivation (Fig. 7). Since the cob of sweet corn did not need to be heated during the process, less energy was needed than current existing technology.



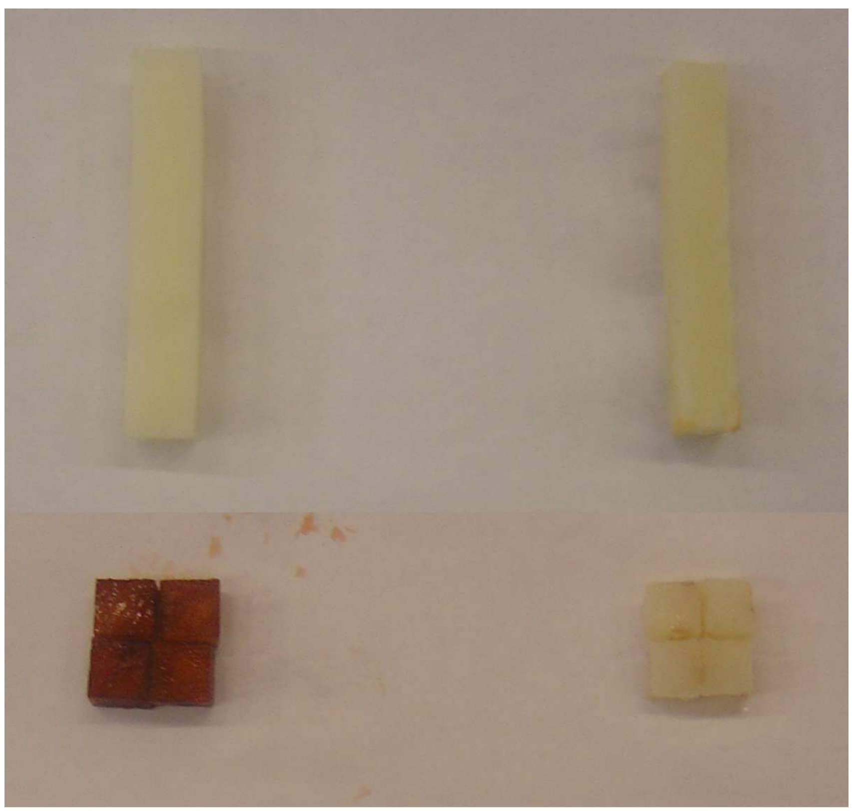
Control 2 min 3 min 4 min

Figure 6. Appearance and enzymatic activity of IDB blanched carrots

When the rectangular potato samples (french fries) were blanched, the enzymes were inactivated in 3.5 min (Fig. 8). If golden-brown color is desired, the sample can be kept in the blancher slightly longer. This result also indicated that low fat French fries can be produced with IDB technology, which will offer social, nutritional, and economic benefits.

Control 1 min

Figure 7. Appearance and enzymatic activity of IDB blanched sweet corn



Control 3.5 min

Figure 8. Appearance and enzymatic activity of IDB blanched potatoes

The approved effectiveness of the IDB technology for blanching the various fruits and vegetables indicated that the IDB technology could be used for blanching or pretreatment. The infrared heating may also be used for fast cooking.

Simultaneously Blanched and Dehydrated Products

Dehydration Rate

The IDB reduced the required dehydration time from 33.5 min of hot air drying to 21.6 min of IDB when 50% weight reduction was achieved (Fig. 9). This was a 35.5% time reduction or improvement of processing efficiency. Meanwhile, the IDB method combined two processing steps, blanching and dehydration, into one, but the hot air drying (conventional drying) needed additional blanching step which required 5 min. The total time of steam blanching and hot air drying was 38.5 min. This indicated at least 43.9% reduction of processing time by IDB compared to the existing blanching and dehydration technologies. Therefore, the improvement of processing efficiency was significant.

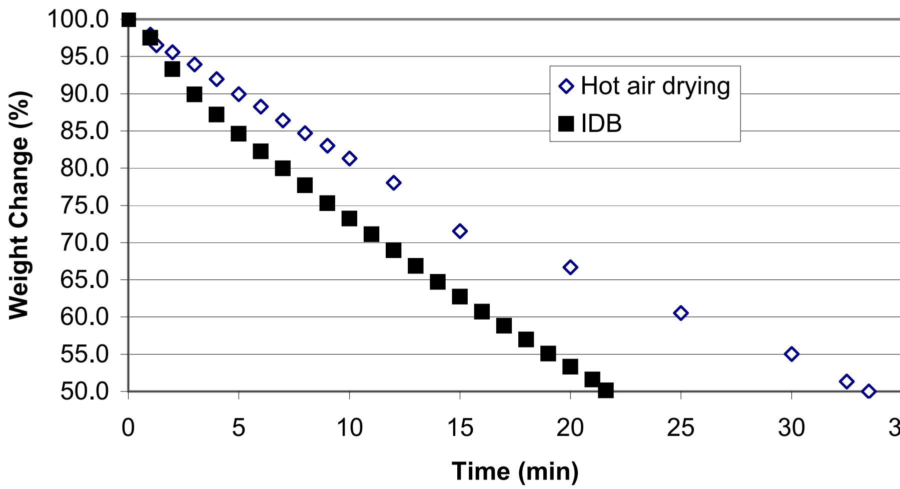


Figure 9. Weight changes of pear cubes dried with IDB and heated air

If blanching is the primary objective, it requires 2 min IDB treatment, which is corresponded to a 6.7% weight reduction. This weight reduction is primarily caused by moisture removal from the sample surface. The reduced moisture at the surface of the samples could offer all the advantages of dehydrofrozen process if a freezing process is followed after the blanching. If minimal moisture removal is desired during the blanching process, high loading rate or an enclosed sample chamber can be used for minimizing the water loss.

Texture Characteristics

From the texture measurement results, it was concluded that the sample processed with IDB was firmer than the samples processed with steam and hot air (Table 1). This was also observed with sensory evaluation during the experiment. The samples processed with IDB tended to have cleaner flavor compared to traditional methods. The texture results indicated that IDB technology could produce products with superior texture compared to current existing technology.

Table 1. Texture characteristics of pear processed with IDB and conventional method

Sample preparation	Sample #	Fracturability (N)	Hardness 1st peak (N)	Energy (mJ) area of 1st peak	Hardness 2nd Peak (N)	Energy (mJ) area of 2nd peak	Cohesiveness (ratio)	Adhesiveness (mJ)	Springiness (mm)	Gumminess (N)	Chewiness (N)
IBD	Average	18.3	18.3	20.7	12.6	4.1	0.20	0.41	1.55	3.73	5.76
	S.D.	7.7	7.6	8.9	5.0	1.6	0.02	0.18	0.09	1.57	2.42
	High	33.9	33.9	39.9	22.5	7.3	0.24	0.75	1.69	6.23	9.63
	Low	9.6	9.6	10.1	6.8	2.1	0.16	0.24	1.45	2.01	3.11
	Range	24.3	24.3	29.8	15.7	5.2	0.08	0.51	0.25	4.23	6.53
Steam blanching plus hot Air drying	Average	13.1	13.1	14.2	9.0	3.2	0.23	0.38	1.68	2.91	4.83
	S.D.	4.8	4.8	5.8	3.1	0.9	0.03	0.14	0.20	0.73	0.94
	High	24.9	24.9	29.3	17.0	5.4	0.28	0.60	2.10	4.61	6.91
	Low	8.5	8.5	8.9	6.2	2.3	0.19	0.21	1.48	2.06	3.70
	Range	16.4	16.4	20.4	10.8	3.1	0.10	0.39	0.63	2.55	3.20

Color and Rehydration

The pear samples processed with IBD and conventional method (steam blanching and hot air drying) to 50% weight reduction were frozen and thawed with two different methods. The color measurement results of frozen and thawed samples are shown in Table 2. In general, no significant difference between blanched and dehydrated samples processed with different methods was observed even though it seems that samples darkened slightly during thawing and rehydration based on the color data. In fact, after the blanched and dehydrated pear samples were rehydrated and thawed, the product appeared to become brighter due to the increased translucence as indicated by the lowered reflectance (Fig. 10). When the hydration ratios of pear samples processed with IDB and conventional methods were examined, no significant difference was found.

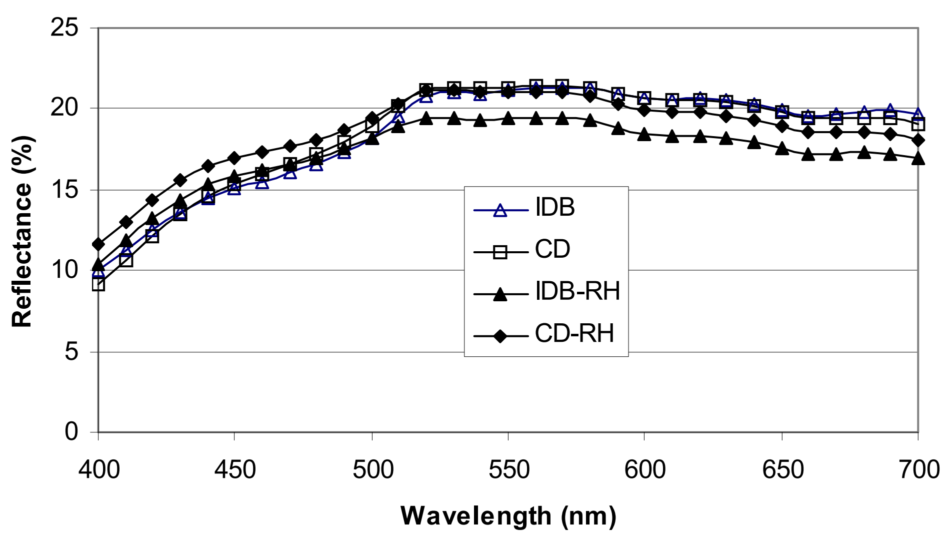


Figure 10. Reflectance before and after rehydration of pear samples processed with difference methods (CD-steam blanched and hot air dried, RH-rehydration)

Table 2. Color of pear samples processed with different methods

	Frozen			Thawed			Rehydrated		
Samples	L	A	b	L	a	B	L	A	b
IDB	56.5±2.4	-3.8±0.4	12.0±1.6	54.3±1.1	-4.7±0.4	11.1±1.6	50.6±3.9	-3.9±0.2	5.9±0.9
Blanching plus drying	54.1±2.9	-4.4±0.3	11.9±3.1	52.6±1.5	-5.0±0.4	11.2±2.2	52.3±2.4	-4.4±0.2	7.0±0.7

Conclusion

Infrared radiation heating was an effective method for blanching fruits and vegetables with high processing efficiency. Since no steam or water is used, infrared drying blanching offers many potential advantages including high energy efficiency and high quality products. It also offers environment benefits with no waste water treatment problem. The infrared heating also demonstrated the feasibility of simultaneous blanching and dehydration with significant processing time saving and high quality product compared to current processing technologies using blanching followed by dehydration. The one step infrared blanching and dehydration process needs simpler equipment than the current processing practices.

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References

Aminov, M.S., Dibirov, A.M., and Azizov, G.G. 1976. The effect of preliminary fruit treatment method on the quality of compotes. *Konservnaya-i-Ovoshchesushil'naya-Promyshlennost.* p20-21.

Avisse, C. and Varoquaux, P. 1977. Microwave blanching of peaches. *Journal of Microwave Power.* 12(1):73-77.

Brown, M.S. 1977. Texture and frozen fruits and vegetables. *Journal of Texture Studies*. 7:391-404.

Cano, M.P., Lobo, M.G. and Ancos, B-de. 1998. Peroxidase and polyphenol oxidase in long-term frozen stored papaya slices. Differences among hermaphrodite and female papaya fruits. *Journal of the Science of Food and Agriculture*. 76(1):135-141.

Dauthy, M.E. 1995. Fruit and vegetable processing. FAO Agricultrual Services Bulletin No.119.

Devece, C., Rodriguez-Lopez, J.N., Fenoll, L.G., Tudela, J. Catala, J.M., Reyes, E-de-los. and Garcia-Canovas, F. 1999. Enzyme inactivation analysis for industrial blanching applications: comparison of microwave, conventional, and combination heat treatments on mushroom polyphenoloxidase activity. *Journal of Agricultural and Food Chemistry*. 47(11): 4506-4511.

Dietrich, W.C., Huxsoll, C.C., Wagner, J.R. and Guadagni, D.C. 1970. Comparison of microwave with steam or water blanching of corn-on-the-cob. II. Peroxidase inactivation and flavour retention. *Food Technology*. 24(3):293-96.

Dominguez, R., Quintero, A., Bourne, M.C., Talamas, R., and Anzaldua-Morales, A. 1996. Texture of dehydrated bell peppers modified by low-temperature blanching and calcium addition. *IFT annual meeting: book of abstracts*, p. 88-89 ISSN 1082-1236.

FMC. 2003. Blanching and dehydration technology. Food Manufacturing Coalition available at http://foodsci.unl.edu/fmc/need-15.htm. accessed Jan 17th, 2005

Fuchigami, M., Miyazaki, K., and Hyakumoto, N. 1995. Frozen carrots texture and pectic components as affected by low-temperature-blanching and quick freezing. *Journal of Food Science*. 60(1): 132-136.

Ginzburg, A.S. 1969. Application of infrared radiation in food processing. London.

Günes, B. and Bayindirli, A. 1993. Peroxidase and Lipoxygenase Inactivation During Blanching of Green Beans, Green Peas and Carrots, *Lebensmittel-Wissenschaft und-Technologie*. 26(5):406-410.

Hebbar, H.U. and Rastogi. N.K. 2001. Mass transfer during infrared drying of cashew kernel. *Journal of Food Engineering*. 47:1-5.

Huxsoll, C.C., Dietrich, W.C. and Morgan, A.I. 1970, Comparison of microwave with steam or water blanching of corn-on-the-cob, *Food Technology*, Vol. 24, p290.

Matser, A.A., Knott, E.R., Teunissen, P.G.M. and Bartels, P.V. 2000, Effects of high isostatic pressure on mushrooms, *Journal of Food Engineering*, 45(1):11-16.

Mongpraneet, S., Abe, T. and Tsurusaki, T. 2002. Far infrared-vacuum and -convection drying of welsh onion. *Transaction of ASAE*. 45(5):1529-1535.

Nindo, C.I., Kudo, Y. and Bekki, E. 1995. Test model for studying sun drying of rough rice using far-infrared radiation. *Drying Technology*. 13:225-238.

Paakkonen, K. 1999. Infrared drying of herbs. *Agricultural and Food Science in Finland*. 8:19-27.

Pan, Z. and McHugh, T.M. 2004. Novel infrared dry-blanching (IDB), infrared blanching, and infrared drying technologies for food processing. U.S. Patent Application. 10/917,797.

Reuveni, R., Shimoni, M., Karchi, Z. and Kuc, J. 1992. Peroxidase activity as a biochemical maker for resistance of muskmelon (cucumis melo) to pseudoperonospors cubensis. *The American Phytopathological Society*. 82(7):649-753.

Seyed-Yagoobi, J. and Wirtz. J.W. 2001. An experimental study of gas-fired infrared drying of paper. *Drying Technology*. 19(6):1099-1112.

Stanley, D.W., Bourne, M.C., Stone, A.P., Wismer, W.V. 1995. Low temperature blanching effects on chemistry, firmness and structure of canned green beans and carrots *Journal of Food Science*. 60(2): 327-333.

Sundu, C. 1986. Infrared radiative drying in food engineering: a process analysis. *Biotechnology progress*. 2(3):109-119.

Vanlaanen, P. 2003. Freezing fruits and vegetables. *Texas Agricultural Extension Service*. L-2215.