STUDY ON THE OSMOTIC PRE-TREATMENT AND INFRARED RADIATION ON DRYING KINETICS AND COLOUR CHANGES DURING DRYING OF AGRICULTURAL PRODUCTS

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ABSTRACT

A combination of intermittent infrared and continuous convection heating was used to dehydrate various osmotically pretreated sample of potato (in solutions of 10%, 20% and 30% NaCl) and pineapple (in solutions of 30%, 50%, 70% Brix). In one set of runs, the infrared source was turned on and off sequentially according to a predetermined time schedule. In the other set, a thermocouple located on the surface of the drying slice exposed to the radiant heat flux measured the temperature continuously and cut off the infrared source automatically when the surface temperature reached 36 to 45°C. The effect of osmotic-IR conditions on colour changes of potato, pineapple and apple was investigated. With appropriate choice of infrared intermittency as well as osmotic pretreatment, it is possible to reduce the overall colour change while maintaining high drying rates. Results from the temperature feedback system indicated no measurable colour degradation occurred despite faster drying kinetics, reduction in drying times and minimisation in product shrinkage.

1. INTRODUCTION

One of the principal objectives of agricultural product drying is to reduce the drying time to attain desired moisture content without significant degradation of the product quality. Thermal drying can lead to discolouration and browning of agricultural products due to various enzymatic and non-enzymatic reactions. This is undesirable because colour gives the consumers a direct visual correlation to the freshness and taste of the product. At the same time, high temperatures cannot be used for faster drying because the products are heat-sensitive. This, in turn, puts a constraint on the production rate of dryers and the cost of dehydration.

One possible method of shortening the drying time is the introduction of infrared (IR) sources. Infrared sources are inexpensive and very reliable. They also have long service life, rapid time response with low maintenance costs¹. For combined infrared and convective heating, a few researchers have reported work on intermittent infrared heating but Dostie *et al*² appear to be the only ones to report shortened drying time with improved quality.

Osmotic dehydration removes water non-thermally when the product is immersed in a solution of a high osmotic pressure agent such as sugar or salt. According to Lewicki and Lenart³, food products dehydrated by osmotic process has the following advantages:

- (i) It is ready to eat and rehydration is not needed.
- (ii) The amount of osmoactive substance penetrating the food tissue can be regulated to individual requirements.
- (iii) The chemical composition of the food can be changed according to needs.
- (iv) The mass of raw material is often reduced by half.

It is noteworthy that osmotic dehydration process is not sufficient to reduce the water activity for preventing the growth of microorgansims. Therefore, from practical standpoint, it is necessary to apply other preservation methods such as freezing, pasteurisation, or drying. However, processing of osmotically dehydrated products is less costly and it preserves most of the characteristics acquired during the osmosis.

Osmotic dehydration is known to lead to quality improvement in terms of colour, flavor, taste, texture, product stability and retention of nutrients during storage^{3,4}. Several researchers have studied combined osmotic dehydration and conventional air drying of foods^{5,6,7} and convection drying with continuous infrared heating⁸. However, no work has been reported on the combination of all three techniques as yet. Despite the massive volume of literature on osmotic pretreatment, publications on the drying characteristics of osmotically dehydrated products are rather limited^{5,9}.

The objective of the present work is to determine the feasibility of minimising colour degradation and drying times for potato, apple and pineapple pieces through suitable osmotic treatment and appropriate intermittency levels of the IR heat input (with and without feedback system) in convective air drying. To quantify the global change of colour of each product during drying, the Hunter colour parameters (redness (a), yellowness (b), lightness (L) and the total colour change (E)) were studied.

2. MATERIALS AND METHODS

For each experimental test, fresh USA potatoes, apples and pineapples were purchased from the supermarket. For the present study, potatoes and pineapples were chosen as test samples for study involving osmotic dehydration while apples solely for IR-studies (with and without feedback control). The composition of the potatoes and pineapples are expected to be similar to those given by Holland *et al*¹⁰ and reported in Table 1. Note that the sugar contents of the two samples vary by an order of magnitude.

Table 1: Composition of products and material moisture content for osmosis experiments.

Material	Average initial moisture content (kg/kg dry basis)	Water (%)	Total Sugar (%)	Protein (%)	Fat (%)
Potato	5.96	81.7	1.3	1.7	0.3
Pineapple	7.92	86.5	10.1	0.4	0.2

A two-stage heat pump dryer was used for the experiment, which operates with a two-stage evaporator system with one evaporator operating at a higher pressure level with reference to the other. The desired drying air conditions were generated and computer-controlled using 3 PID controllers. Details of the two-stage heat pump dryer can be found in Hawlader *et al*¹¹ and Chua *et al*¹². Two 230V, 1000W infrared lamps 500mm in length, were installed inside the dryer a fixed distance above the trays supporting the samples. The lamps were connected to a regulating transformer, which enables the power supplied to the lamp to be varied from 0 to 240V. The voltage was kept constant at 240V for consistency, which produces an average radiative heat flux of 0.13W/m² for all the experiments conducted. The thermal inertia of the IR lamps was negligible.

2.1 Colour measurements

The colour values of each sample were measured using a Minolta CM-3500d Spectrophotometer to obtain the Tristimulus colour values (Hunter L, a and b values). Several researches^{6,12,13} have in recent works used similar equipment for their measurements of colour changes in food products. The changes in each colour parameters were calculated as follows:

$$\Delta L = L - L_0 \quad (1)$$

$$\Delta a = a - a_0 \quad (2)$$

$$\Delta b = b - b_0 \quad (3)$$

The subscript '0' refers to the initial colour parameter of each fresh sample at the beginning of the drying experiment. The total colour difference ΔE was then determined using the following equation:

$$\Delta E = [\Delta L^2 + \Delta a^2 + \Delta b^2]^{1/2} \quad (4)$$

Temperature, humidity, radiative heat flux and air velocity sensors used to measure the air inlet conditions to the drying chamber were pre-calibrated. The uncertainty for each parameter and the calibration range is shown in Table 2. The Hunter colour instrument was calibrated with white and black ceramic plates.

Table 2: Estimated uncertainties for different measurements.

Measured Property	Uncertainty	Range
Inlet and Outlet air temperatures (Type "T" thermocouple)	± 2.4%	2.5 to 90°C
Inlet and Outlet air humidity (Relative Humidity sensor)	±2.3%	22.4 to 97.3%
Air velocity (rotating anemometer calibrated by manufacturer)	±1.0%	0.5 to 30.0m/s

2.2 Reproducibility test

Three reproducibility tests were made in which the air temperature was fixed at 30°C, relative humidity kept constant at 30%, and air velocity at 2.1m/s. Table 3 shows that all colour parameters and moisture content are reproducible with an uncertainty level of ±5%.

Table 3: Reproducibility test results.

	Colour Parameters	Moisture Content
Apple	±3.12%	±3.0%
Potato	±4.74%	±4.2%

2.3 Procedure

The samples were skinned-peeled, sliced with an adjustable food-slicer to 5mm thickness and cut to from 20mm x 20mm pieces. For osmosis experiments, each set of 4 potato samples were weighed, their colour was measured before being soaked into NaCl solutions of various concentrations: 10%, 20% and 30% for 7 hours. Similarly for the pineapple samples, instead of salt solutions, the samples were soaked in 30%, 50% and 70% Brix sugar solutions for 7 hours. The samples were placed in beakers, in a weight ratio of osmotic solution/fruit of 1:50 to avoid significant alteration of the solution concentration during osmotic dehydration. The samples were taken out, blotted dry at intervals of 30 minutes before weighing. The solutions were stirred at intervals of 15 minutes.

For the air drying experiments, the samples were prepared as above, but were immersed for 3 hours in their respective osmotic solutions. Another set of 4 potatoes and 4 pineapples slabs were soaked into 2% NaHSO₃ for 5 minutes to suppress enzymatic reactions, since the focus of the work is to study the effect of drying conditions on product colour and non-enzymatic browning. The samples were weighed and the colour measured before they were placed on netted-trays in the drying chamber of the heat pump dryer directly below the infrared lamps.

During drying, replicates of each product were removed for weight and colour measurements. Each of the 4 samples were scanned at 7 different locations to obtain averages values of L, a, and b. The changes in each colour parameter were then calculated with respect to the initial values. The samples were dried until mass changes negligible.

Pure convective drying (without infrared sources) was taken as the base case in the present study. Drying tests were made for intermittency levels of α=1, α=1/2 and α=1/3 were studied with the cycle time of 30 minutes. The intermittency of IR application is defined in this study as:

$$\alpha = \frac{T_{on}}{T_{on} + T_{off}} \tag{5}$$

The air velocity was maintained at 2.0 ± 0.1 m/s with a temperature of $40 \pm 0.7^\circ\text{C}$. The relative humidity was held constant at $21.3 \pm 0.8\%$. The distance between the heat source and the material was maintained at 95 mm giving a fixed radiative flux when the IR sources were turned on.

3. RESULTS AND DISCUSSION

3.1 Colour change during osmosis

From Figure 1, it is evident that the colour of the pineapple and potato samples was affected by osmosis, and the colour changes are as significant as the colour changes during thermal drying. The overall colour change is thus due both to the non-thermal osmosis and thermal

Figure 1: Comparison of overall colour change for different osmotic treatments for potato and pineapple.

Figure 2: Comparison of moisture content versus drying time curves and drying rates curve for different osmotic treatments for potato and pineapple samples.

dehydration. In the former case, some of the natural colour is also extracted into the solution of the osmotic agent. During the latter process, colour can change also due to microcrystallisation of the solute on the surface of the samples.

The colour changes in the pineapple samples are similar for all the cases examined. All samples turned darker, as indicated by higher ΔL values. Visually, the pineapple slabs turned from pale yellow to a pleasant dark and rich yellow. ΔL is found to be the major component that contributes most to the overall colour change. The yellowness and redness values were not affected appreciably by the osmotic process or the concentration of the osmotic solution. The results are consistent with those obtained by Waliszewski *et al*¹⁴ in their experiments conducted with banana.

For potato, the concentration of the osmotic solution affects the magnitude of colour change during osmosis. While the value of L increased for the samples in 30% NaCl solution, it decreased with time in the 10% NaCl solution. This is probably because of oxidation reactions as the concentration of 10% is probably too low to eliminate it completely. This also leads to an increase in Δa values. At the same time, salt gains in greater amount by the samples in the 30% NaCl solution leads to whitening of the samples. This was more evident during the thermal drying process; a thick layer of fine salt crystals formed on the surface of these samples. Overall, the 20% NaCl solution seems to yield the least change in colour.

3.2 Effect of osmosis on drying kinetics

For all intermittency levels, the initial moisture content for samples treated with higher concentration of osmotic solutions is lower. This is logical, as the samples experience water loss and solid gain, leading to a lower dry basis value at the beginning of the drying process. Also, the end points of the curves are higher for these samples compared to the samples treated with osmotic solutions of lower concentration. This can be explained by the binding effect of the osmotic agent that has diffused into the samples during immersion in the concentrated solutions, causing water removal to be more difficult towards the end. This can be seen in the drying rates curves portrayed in Figure 2. The rate of drying of the osmosed potato is consistently lower than that of the original samples, which did not undergo osmotic dehydration. The difference between the drying rates for untreated potato and treated potato in the beginning of the drying process can be up to four-fold. However, for pineapple, the drying rates are rather similar for all cases probably because of its high natural sugar content.

3.3 Effect of intermittent IR on colour changes (pineapple and potato samples)

As expected, IR heating causes a very rapid increase in colour changes. However, the use of intermittent radiative heating during convective drying of potato does not significantly reduce the colour changes, although the maximum colour changes do occur later in drying compared to continuous infrared heating. Visually, upon drying, white fibers of the potato

appear on the surface, leading to increase in L values, which in turn increased the ΔE values. However, as heating continues, the browning effect comes into play and the L values decrease, causing the ΔE values to decrease. A note to be taken for the colour parameters of potatoes is that change in yellowness and redness is quite insignificant and the latter plays a greater role only when browning occurs at a high level, while it is the lightness that contributes most to the overall change.

On the other hand, the reduction of the overall colour change is more significant with pineapple when $\alpha = 1/3$ was employed, which displays colour changes of about the same level as those of samples undergoing pure convective drying. Although the rate of change of colour in the beginning is higher, the colour change stabilises at a level slightly above the overall colour change of the samples not subjected to continuous or intermittent radiative heating.

As for osmotically-dehydrated food, intermittent infrared heating does significantly reduce the overall colour change by up to 2 times for potato and for pineapple. This could be explained as the surface temperature rise is expected to be less for intermittent drying than for continuous drying.

3.4 Effect of intermittent IR heating (apple samples)

It is evident from Figures 3 and 4 that with an appropriate choice of α , the drying time can be reduced while minimising colour degradation. At 60°C, the best conditions for apple, was achieved at $\alpha=3/5$, where infrared lamps were switched on for 15 minutes and switched off for 10 minutes, as the reduction in drying time, approximately 50%, was attained while the colour degradation of 6.5% was observed.

Figure 3: Moisture content for apple slices during intermittent infrared convection drying at 60°C.

Figure 4: Colour degradation for apple slices during intermittent infrared-convection drying at 60°C.

Figure 5: Schematic shows the insertion of a thermocouple into a food sample and providing feedback to control the lamps.

3.5 IR-system with feedback capability

It is noteworthy that by coupling a PID controller to the IR lamp system gives rise to a feedback system that is capable of programming different temperature set-points. Such a system is capable of locating the α values to achieve optimum product quality and drying time. A type 'T' thermocouple can be inserted into a food sample being dried, thus allowing the monitoring of the temperature evolution inside the sample. Figure 5 shows the insertion of a thermocouple into a food sample.

Programming a set-point temperature for instance at 40°C enables both infrared lamps to be turned on automatically once the temperature inside the food sample falls below the

pre-selected set-point temperature of 40°C. Conversely, once the temperature inside the food sample exceeds the set-point temperature of 40°C, both infrared lamps shut off automatically. In other words, the α values are no longer pre-determined manually, but it is a variable according to the behaviour of the food samples. The air temperature was fixed at 60°C, relative humidity at 18.0%, and air velocity at 2.1 m/s.

The set-point temperatures were determined through several trial and error experiments where the behavior of the food samples at different temperatures was studied. As a result, the temperatures selected are the maximum values at which the drying rate can be enhanced without browning of the food samples. After 10 minutes, the set-point temperature was reduced when the surface moisture is all removed, maintaining the same set-point temperature would lead to colour degradation. A higher set-point temperature initially helps to achieve higher drying rates without degradation.

It can be inferred from Figure 6 that drying time can be greatly reduced, while colour degradation is kept at a minimum. The two experiments carried out used two different set-point temperatures. It can be seen that for all three food samples tested (apple, potato, and carrot), a lower drying time was achieved with a lower set-point temperature of 38°C for the first 10 minutes, and a subsequent set-point temperature of 36°C.

It might be expected that a higher set-point would yield lower drying times, but this can be explained by the fact that even though the set-point temperature of 45°C was higher, the convective heat flux, $Q_c = hA\Delta T$ (where h = heat transfer coefficient, A = surface area of food sample, and ΔT = difference between air temperature, 60°C and temperature of the food sample), was actually higher since difference in temperature was higher. Also, measurement of radiative heat flux, Q_r , by the data logger also recorded a higher

Figure 6: Moisture content for apple slices during set-point temperature infrared drying with feedback.

radiative value of 334.5 W/m^2 for the experiment carried out at a lower set-point temperature of 38°C . For the experiment carried out at a higher set-point temperature of 45°C recorded a radiative heat flux value of 325.6 W/m^2 . As compared to the experiment where infrared lamps were intermittently on and off through pre-determined values of the α , drying time was significantly reduced, and colour degradation was also lower, which clearly shows that using a set-point temperature and monitoring the food samples' behavior is more effective in reducing drying time while minimizing colour degradation.

There is no prior work on variable α intermittent drying using infrared along with convection. Due to limited time, no optimisation study could be attempted, however. Even higher values of infrared heat fluxes could possibly be used without discolouration, and this will reduce the drying time further.

Table 4 compares the results for pre-selected IR intermittent and set-point feedback systems. The results of the set-point feedback system clearly demonstrate appreciable improvements in terms of shorter drying time, reduced colour degradation and minimisation of product shrinkage.

Table 4: Table showing comparison between pre-determined α and online feedback system.

Apple samples	$\alpha = 1/4$	$\alpha = 1/2$	$\alpha = 3/5$	With feedback
Drying time	20%	25%	50%	85%
Colour ΔE	19%	25.1%	6.5%	7.8%
Shrinkage ΔL	50%	59.8%	75.4%	49%

4. CONCLUSIONS

The main findings of the present study are summarised as follows:

- (i) Intermittent infrared heating reduces drying time in convective drying of both osmosed and non-osmosed products. However, depending on the product, intermittent infrared heating may or may not reduce colour degradation, compared to continuous infrared heating.
- (ii) Osmotic dehydration affects the colour of the food product during osmosis as well as in air drying. Osmotically treated samples of potato and pineapple undergo less colour change than untreated ones during convective drying with intermittent infrared heating.
- (iii) Controlling the intermittency by a pre-determined value of on and off times of the infrared lamps decreased the drying time of apple samples, but using temperature feedback from the food samples to automatically turn the infrared lamps on and off resulted in even greater reduction in drying time and less corresponding colour degradation.

5. NOMENCLATURE

a_w	wateractivity	-
T	time	min
a	Hunter redness value	-
b	Hunter yellowness value	-
E	Hunter colour difference	-
IR	Infrared	-
L	Hunter lightness value	-
X	moisture content	kg/kg dry basis

Greek symbols

Δ	change in colour parameters	-
α	intermittence	-

Subscripts

o	initial	-
on	on	-
off	off	-

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