Characterization of Constant and Continuous Square Wave Air Temperature on Batch Drying of Agricultural Products

Kuma G. Erko, Werner C. Hofacker and Albert Esper

Abstract -A convective batch type dryer with counterflow dryer capable controlling of the setting parameters, air temperatures, air velocity and relative humidity was used. The design of experiment with the response surface methodology was applied to optimize the drying parameters. The continuous stepwise air temperature and relative humidity were then applied for further optimization. With central composite design formulation of RSM for air temperatures, an increase of temperature from 50 ºC to 90 ºC with a 10 ºC rise was applied. Furthermore, the selected region (optimum in case of RSM) of interest was discretized within a the peak to valley interval ranging from 5 ºC and 10 º C of a square wave profile of the air temperature was applied. The changing time was about minute 40 minutes depending on the critical area that was found from surface temperature depiction with quality changes. The drying samples were automatically shifted to the new set dryer with predefined drying parameters. The air temperature was found significant ($P<0.05$) over total color difference regardless of the other drying parameters, whereas air velocity and relative humidity have subsequent effect for the quality changes. The square-wave profile air temperature and relative humidity show better optimization for the total color change by controlling air temperature to maintain individual color parameters without affecting the drying rate.

Keywords: Batch type drying, Optimization Response Surface Methodology, Stepwise air temperature,

1 INTRODUCTION

In convective drying, air temperature, humidity and velocity have a significant effect on the drying kinetics and quality of food products. It is then possible to control the qualities of the products to be dried through direct control of these parameters. [1] An in accordance to Devahastin and Mujumdar has demonstrated via a mathematical model the feasibility and advantages of operating a dryer by varying the temperature of the inlet drying air in tens of reducing drying time by up to 30%. [2] has modeled all drying parameters and concluded that the temperature is the most effective factor on drying rates followed by air velocity and that relative humidity slightly affected the drying rate. In addition, it has been reported that the quality of dried products is primarily governed by the drying conditions (i.e. the temperature and duration of drying). In case of heat sensitive products such as fruits, vegetables or spices, the quality is governed by temperatures exceeding certain critical values as this may lead to the degradation of the product [3].

The optimization procedures, less quality deterioration and maximum profit always depend on the factors or decision variables. In food technology the optimization procedure using Response Surface Methodology (RSM) has been and continues to be considered, the most common approach [4]. Regardless of its simplicity and usefulness, there are a number of powerful optimization methods as well [5]. It has reported that mathematical modeling for such improvements has played a major role.

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The color change in food material during thermal processing is caused by the reactions taking place inside it, browning reactions such as Maillard condensation of hexoses and amino components and oxidation of ascorbic acid ([6,7].

The final values of color parameters can be used as quality indicators to evaluate deterioration due to thermal processing and [8]. The imaging technique could be used for studying Maillard browning [9]. The whiteness index also used as indicator enzyme-stimulated reaction [10]. Luminosity (L*) has been used as an indicator of vegetable quality deterioration [11,12]. They reported the storage and slicing method also affect the lightness of the carrot.

Through experimentation, this work has examined in the first place, the effect of drying parameters (air temperature, air velocity, and relative humidity) on quality mainly on color of the product. Response Surface Methodology (RSM) investigated the effects of those parameters, i.e. how they could degrade or possibly minimize the degradation. Secondly, The stepwise of air temperature and relative humidity strategy implemented in three stages after characterizing the effect of drying parameters applied at response surface methodology of the first strategy were examined. Furthermore, for each design stage, the drying kinetics and respective color parameters, lightness (ΔL), redness (Δa), yellowness (Δb) and total color change were studied.

2 MATERIALS AND EXPERIMENTAL PROCEDURES MATERIALS

The experiments were conducted on the potato variety, Balena that was purchased from a local farmer (Altdorf, Germany). The potatoes were prepared into cylindrical pieces of the diameter of 35 mm and of a thickness 3.5 mm.

A through flow batch type cabinet dryer, measurement, control and air conditioning unit were used.

2.1 Experimental Procedures

The experiments were defined at two main levels. The first experiments was designed by Response Surface Methodology (RSM) using Design of Expert® 10 Stat-Ease software.The second experiment was defined in square wave profile of air temperature and relative humidity profile as shown in Table 1. In the first strategy, the experiments were performed at air temperature levels between 50 □C and 90 □C, at air velocities between 0.65 m/s and 1.25 m/s and at relative humidity set between 10 % and 50%.

The drying continued until the equilibrium moisture content was achieved. This equiliblirium moisture content (approximately 0.12 kg/kgdb) was determined from the information of weight measured related to the initial stage and end stage. As the drying proceeded, the weight of the sample, surface temperatures, and other measured variables were recorded every 30 seconds and images were captured every five minutes.

TABLE 1
PROFILE OF SQUARE-WAVE AIR TEMPERATURE AND RELATIVE HUMIDITY

Run	Air Temperature, □C	Relative humidity, %	V, m/s
1	60→70→60	20	1.1
2	80→70→80	40	1.1
3	65→70→65	40→40→20	1.1
4	70→80→70	40→40→20	1.1
5	70-->60-->70	40→20→40	1.1
6	70→80→70	40→20→40	1.1
7	70→65→70	40→40→20	1.1

3 IMAGE ANALYSIS AND EVALUATION OF QUALITY

The color values were analyzed from the images captured using CCD camera DFK 21BU04.H with a mounted Computar C lens (8 mm, 2/3). The camera was calibrated reference to x-rite 24 scientifically prepared color patches that represent neutral, chromatic and primary colors. The setting values of the camera were accepted for a different color when the deviation was less than 10%. The LED D65 ring light with light diffuser Perspex® D2 DF70 2.5 mm was used to avoid the unevenness of light on the samples. The colors were expressed in CIELAB colors space system as L (lightness/darkness), a (redness/greenness) and b (yellowness/blueness). The changes in each particular color parameter were calculated with the target value to initial color parameters of each sample as follows:

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

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

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

The total color difference (ΔE) was determined using the following equations.

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^{2} + \Delta b^2} \quad (4)$$

4 SURFACE AREA SHRINKAGE

The percentage of surface area shrinkage was calculated from the image captured using the following equation:

$$S = \left(1 - \frac{A}{A_o}\right) \times 100 \quad (5)$$

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5 RESULTS AND DISCUSSION

5.1 Drying Kinetics

During drying, there is a continuous change of quality (color and shrinkage) as well as a change in nutrient contents'. Many researchers have investigated the degradation of quality during drying and the methods for controlling and determining the degradation of quality while drying with corresponding to moisture content, temperature and quality data [1,3,13,14].

Out of the drying curve for some drying strategies shown below in Figure 1 the higher drying rate of the product was observed.

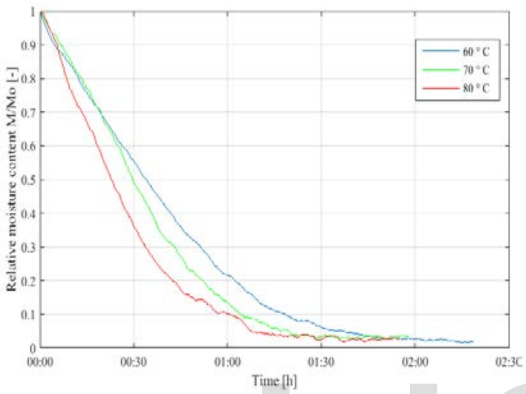

Fig. 1. Effect of air temperature on moisture removal at Va =0.95 m/s and 20% relative humidity

5.2 Drying parameter effects and Color Parameters Results

As described above convective batch type drying significantly affects the quality attributes as drying proceeded. Figure 2 represents the effect of drying parameters on the total color difference from Response Surface Methodology (RSM). As shown in Figure 2 the temperature is a prominent factor for color change (P<0.05), while velocity has a slight effect and relative humidity has no statistically significant effect (P>0.05) on the total color difference [15]. Also the works of [2,16] on the effects of drying parameters have concluded that the temperature is a very important factor on drying drying rate.

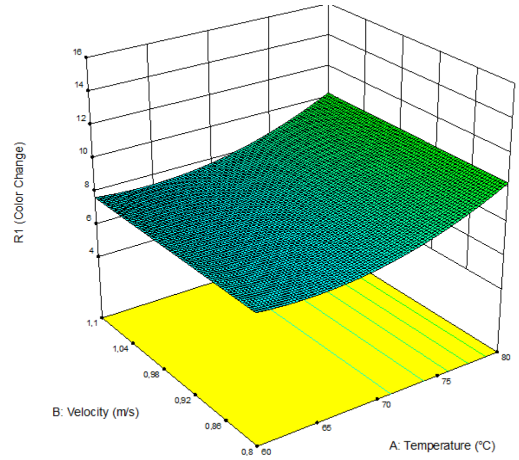

Fig. 2. Total color difference (ΔE) as a function of air temperature and air velocity, at relative

Change in Lightness (ΔL)

The lightness L* of the product had relation to moisture content and drying strategies. For drying strategies with constant low temperature in the range of 50 □C to 90 □C and regardless of the other parameters an increase in L* was observed. The constant temperature with 70 □C was able to maintain the original lightness of the potato samples. This shows that is a possibility to look for another scheme with better drying strategy and less change in lightness (ΔL). Figure 3 shows the effect of air temperature on the lightness of the potato. It can be seen that when relative moisture content reaches 0.1, the lightness tremendously changes. In addition the magenta colored line for the continuous drying optimized scheme (profile number 7 in Table 1) shows an improvement in the lightness of 30% for 80 □C and 62.5% for 70□C for which total the color difference was lower than the constant drying scheme as shown in Figure 3. [1] had reported that the observed different square-wave temperatures were used to maintain the lightness of potato samples. Temperature and relative humidity (Profiles 5 and 7) were maintained close to their original lightness level. The optimum drying region from response surface methodology running at contestant drying parameters can be verified from the results shown in Figure 2.

Change in Redness (Δa)

As shown in Figure 4, that the redness of potato was not significantly affected by drying strategies in the range set during the performed of the experiment. All constant and square-wave profiles of drying strategies maintains the redness level close to that of the original sample color. Only low temperature slightly favored the reduction in redness.

Change in Yellowness (Δb)

The yellowness color component has also a significant contribution on color change of the potato samples. As reported in the result of [13] that the rate of color component change was slower than lightness. In Table 2 and Table 3 it has shown the effect of parameters over individual color change in relation to the original color. Profile number 5 and number 7 were maintained close to the original yellowness level of the potato. Figure 3-5 show change in individual color component as a function of moisture content for a constant air temperature of 70 □C, Va = 0.95 m/s, 20% relative humidity and for the square-wave profile number 7 shown in Table 1.

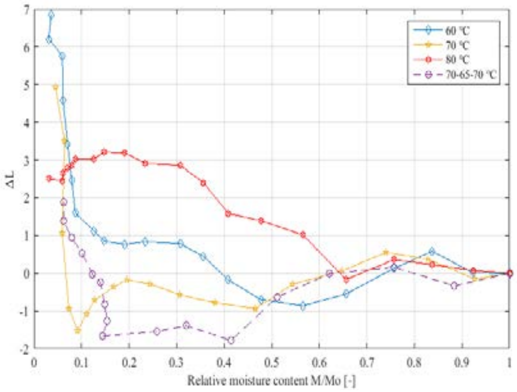

Fig. 3. Effect temperature on Lightness

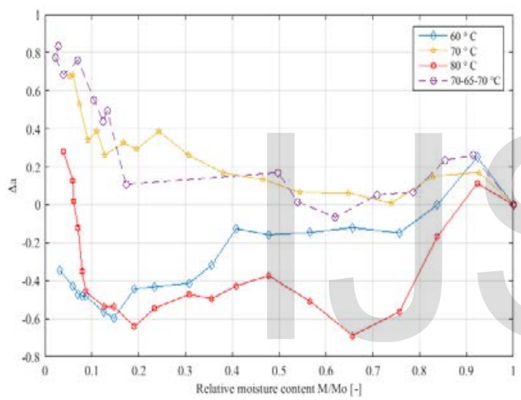

Fig. 4. Effect of temperature on redness

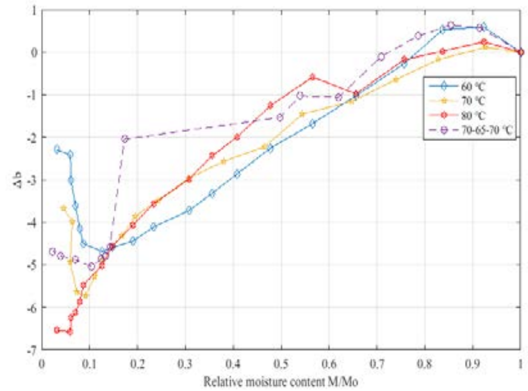

Fig. 5. Effect of temperature on yellowness

Total Color Change (ΔE)

The square wave air temperature and relative humidity returned less total color difference. For this profile, air temperature starts with 70□C and with 5 □C of Valley (Profile Number 7) has improved about 22 % from the previous optimized Response Surface Methodology design.

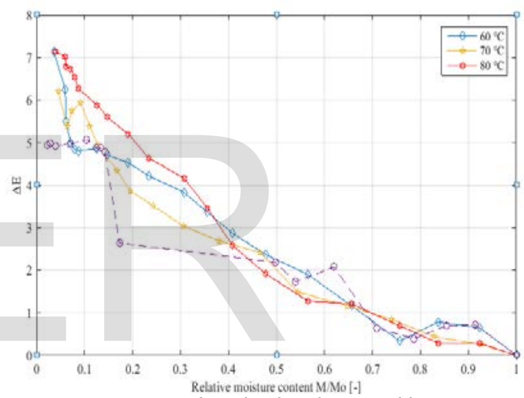

Fig. 6. Improvement of total color change with square wave temperature and relative humidity

TABLE 2
RATIO OF INDIVIDUAL COLOR TO TOTAL COLOR CHANGE

Constant Parameters			Profile 1			Profile 2			Profile 3		
ΔL/ΔE	Δa/ΔE	Δb/ΔE	ΔL/ΔE	Δa/ΔE	Δb/ΔE	ΔL/ΔE	Δa/ΔE	Δb/ΔE	ΔL/ΔE	Δa/ΔE	Δb/ΔE
-0.608	0.664	0.436	-0.599	0.299	0.743	0.761	0.172	0.625	0.048	0.511	0.858
0.851	0.345	-0.396	0.519	0.409	0.751	0.765	-0.491	-0.417	0.973	0.147	0.176
0.651	0.010	-0.759	0.962	0.265	0.073	0.696	-0.542	-0.471	0.987	0.116	-0.112
0.054	0.052	-0.997	0.981	0.172	-0.094	0.479	-0.280	-0.832	0.823	0.227	-0.521
-0.194	0.043	-0.980	0.945	0.068	-0.321	0.741	-0.092	-0.665	0.680	0.348	-0.645
-0.389	0.055	-0.920	0.903	0.067	-0.424	0.698	-0.037	-0.715	0.528	0.323	-0.786
-0.291	0.062	-0.955	0.849	0.018	-0.527	0.673	-0.006	-0.740	0.433	0.251	-0.866
-0.188	0.086	-0.978	0.784	-0.012	-0.621	0.583	0.009	-0.812	0.418	0.205	-0.885
0.652	0.161	-0.741	0.956	-0.048	-0.289	-0.300	0.028	-0.954	0.859	0.061	-0.508
0.795	0.131	-0.592	0.957	-0.051	-0.287	-0.377	0.064	-0.924	0.928	0.062	-0.367
0.797	0.103	-0.596	0.929	-0.065	-0.365	-0.435	0.073	-0.898	0.923	0.056	-0.380
0.794	0.114	-0.597	0.915	-0.065	-0.399	-0.493	0.081	-0.866	0.922	0.065	-0.383
0.781	0.127	-0.612	0.907	-0.063	-0.417	-0.463	0.106	-0.880	0.907	0.057	-0.417
0.746	0.117	-0.656	0.909	-0.068	-0.411	-0.460	0.116	-0.880	0.901	0.057	-0.430
0.757	0.129	-0.641	0.900	-0.067	-0.431	-0.452	0.130	-0.882	0.892	0.054	-0.448

TABLE 3
RATIO OF INDIVIDUAL COLOR TO TOTAL COLOR CHANGE

Profile 4			Profile 5			Profile 6			Profile 7		
ΔL/ΔE	Δa/ΔE	Δb/ΔE	ΔL/ΔE	Δa/ΔE	Δb/ΔE	ΔL/ΔE	Δa/ΔE	Δb/ΔE	ΔL/ΔE	Δa/ΔE	Δb/ΔE
-0.977	0.189	0.093	-0.465	0.467	0.802	0.599	-0.714	0.362	-0.465	0.361	0.808
-0.865	-0.217	-0.453	-0.905	0.232	0.414	0.063	-0.922	-0.381	0.230	0.338	0.913
-0.805	-0.197	-0.559	-0.976	1.266	-0.135	-0.280	-0.690	-0.668	-0.035	0.168	0.985
-0.810	-0.131	-0.571	-0.941	0.376	-0.318	-0.579	-0.366	-0.729	-0.983	0.080	-0.166
-0.831	-0.104	-0.546	-0.867	0.141	-0.494	-0.697	-0.171	-0.697	-0.861	-0.032	-0.508
-0.837	-0.056	-0.544	-0.691	0.008	-0.723	-0.713	-0.076	-0.697	-0.804	0.009	-0.594
-0.821	-0.057	-0.568	-0.449	-0.032	-0.893	-0.705	-0.021	-0.709	-0.706	0.077	-0.704
-0.811	-0.033	-0.583	-0.307	-0.027	-0.951	-0.703	-0.033	-0.710	-0.631	0.040	-0.774
-0.687	-0.012	-0.726	0.046	-0.007	-0.999	-0.608	0.031	-0.794	-0.266	0.112	-0.957
-0.684	-0.014	-0.730	0.059	0.007	-0.998	-0.603	0.035	-0.797	-0.169	0.101	-0.980
-0.676	-0.013	-0.737	0.049	0.015	-0.999	-0.601	0.050	-0.798	-0.047	0.090	-0.995
-0.665	-0.009	-0.747	0.045	0.027	-0.999	-0.601	0.045	-0.798	-0.008	0.109	-0.994
-0.661	-0.008	-0.750	0.229	0.001	-0.974	-0.614	0.036	-0.788	0.108	0.153	-0.982
-0.660	-0.012	-0.751	0.315	0.001	-0.949	-0.605	0.043	-0.795	0.191	0.139	-0.972
-0.657	-0.004	-0.754	0.402	0.000	-0.916	-0.595	0.049	-0.802	0.282	0.156	-0.947

6 Shrinkage

In Figure 7, the surface shrinkage of potato significantly influenced by the all parameters considered. The higher the air temperature and lower relative humidity resulted in shrinkage reduction. However, if we increase the relative humidity resulted in shrinkage increases [4] has reported for Apple increasing both temperature and velocity shrinkage resulted in a reduction of shrinkage. At low air velocity product surface resistance prevails, that resulted in products shrinks uniformly, due to internal minimum stress [17]. Furthermore drying at a higher temperature resulted in case hardening (stiff) that limit the shrinkage as surface become low surface moisture.

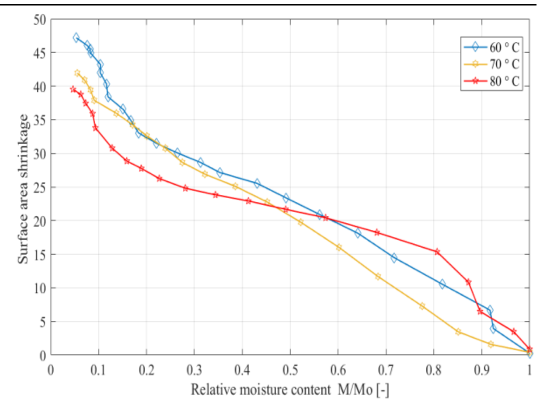

Fig. 7. Effect of Temperature on the shrinkage at Va =0.95 m/s and 20% relative humidity

7 CONCLUSIONS

The effect of drying parameters on agricultural products wa investigated applying at two different strategies. Research design with Response Surface Methodology (RSM) was applied to constant drying parameters and an optimum drying condition was determined for batch type drying depending on the less total color change relative to the original color of the product. Furthermore, drying parameters have an effect on individual color parameters (L, a,b).

The second strategy was applied to control individual color parameters. According to the information from the first strategy, it has been shown that the square wave air temperature and relative humidity have more capacity for individual color retention. Lightness and yellowness significantly contribute to the total color change of potato. The air temperature has a prominent effect on drying rate subsequent with air velocity and relative humidity.

Therefore, from the result investigated so far it is possible to improve the convective batch type drying by controlling and studying the effect of drying parameters and responses of agriculture products for each particular parameter.

For future work, research has to be conducted on the other products whether these strategies can be applied or not. Moreover, the air temperature effect has to be carefully investigated as its most considered the important and controlling parameter.

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