Application of the Concept of Glass Transition Temperature for Better Color Retention and Less Shrinkage of Dried Potato Slices

Addisalem HailuTaye[ab], Werner C. Hofacker[a]

[a]*Institute of Applied Thermo-and Fluid dynamics, University of Applied Sciences, Konstanz*

Alfred Wachtel Strasse 8, 78462 Konstanz, Germany

Tel.:+49-7531-206-593, E-mail: hofacker@htwg-konstanz.de

[b]*Collage of Agriculture and Veterinary Medicine, Jimma University Jimma, Ethiopia*
E-mail: addisalemh@gmail.com

Abstract- *In this study, the influence of the temperature with five temperature profile levels on color change and shrinkage was determined. One level of temperature profiles was kept constant. The remaining four levels of the temperature profile were stepped down from high temperature to low temperatures before the samples have attained moisture content at which glass transition temperature is reached. The response variables of color changes and shrinkage were continuously measured. The basic third order polynomial equation was used to fit the quality parameters. Change in lightness as a function of time was best fit to fourth order polynomial function. Shrinkage and change in redness and yellowness versus time were best fit to a third order polynomial function. The fitness of the obtained models was good since the lack of fit for each of the models was not significant. The models were significant for all parameters described ($p < 0.001$). Moreover, the coefficient of determination R^2 for most models was greater than or equal to 90%. Hence, the models obtained for the responses were adequate. Drying the samples for short time by applying high temperature in a rubbery state and to proceed the process at a temperature less than or equal to glass transition temperature in the glassy state resulted in less change in redness, yellowness, and shrinkage and improved in a change in lightness of potato slices.*

Keywords: color change; drying; glass transition temperature; temperature; shrinkage

1. Introduction

Drying is one of the techniques used to preserve food products by removing water up to a certain level at which microbial spoilage and chemical reactions are greatly minimized[1]. It is clear that the dried product has longer shelf life, smaller volume, lower transportation and storage cost compared to the fresh product[2]. Fruits, vegetables, roots and tubers are sensitive to drying process parameters (special drying temperature and time) which can cause quality deterioration of the drying samples through oxidation, color change, shrinkage, loss of texture, and nutritional functional properties[3].
The color is an important quality attribute of the dried product, which occurs in the interaction among the light, observed object, and observer [4]. In addition to color, shrinkage is also another very important parameter connected to the dried product quality. Consumers critically evaluate color and shrinkage. These parameters are often the basis for a customer's selection or rejection of the product. The color change during a drying process is due to chemical and biochemical reactions[5]. As reported by [5] the rates of both reactions depend strongly on the processing parameters. Raivo et al. [6] studied the effect of glass transition on rates of non-enzymatic browning in food systems and reported the presence of very slow browning below glass transition temperature. Rahman [7] also reports the stability of food products in the glassy state. At this state, compounds involved in the deterioration reactions takes time to diffuse over molecular distances and approach each other to react. Although glass transition temperature of food products has been pointed out to be responsible for the deterioration mechanisms during processing, and an indicator of food stability, the quantifiable expressions between quality parameters and glass transition have not been found yet [8]. Therefore, the objective of this study is to minimize color degradation of the dried products and to reduce the shrinkage of the sample, by stepping down temperature profiles before the sample develops a moisture content at which its corresponding glass transition temperature takes place.

2. Materials and methods

The experiment was conducted on Belana, a potato variety or cultivar, purchased from a local farmer at the Lake Constance in South Germany. The potatoes were stored in the fridge at a temperature of 4°C. Prior to conducting each experiment, the potatoes were washed, carefully selected free of any damages like bruises, and then thinly cut into slices of 3.5 mm thickness using an electric food slicer (Graff, Germany).

The drying device comprises of three main parts: the humidifier, the air heater, and the drying chamber. Ambient air is sucked into the humidifier by a radial fan. The humidifier consists of spray nozzles, a packed bed, a water bath (50 l), a heater (31 kW) and a refrigerating unit (8 kW). Three Pt-100 sensors were inserted into the humidifier (one for controlling water bath temperature and the remaining two for monitoring the dew point temperature). The air passes the packed bed in counter flow to the water. The water needed for humidifying the air is taken from the tap. The air heater includes four heating units (40kW). After passing the heater, the air is led into the drying chamber in the through flow. Air temperature is measured using Pt-100 sensors placed at the respective inlets. Air velocity is measured using a hot wire anemometer. A precision pyrometer (Heitronics KT15II) is installed on the top of the drying chamber for non-invasive determination of surface temperature. The system is controlled using a programmable logic control (Siemens S7=300). Programming of the PLC and data acquisition is carried out using the human-machine interface (HMI) software WinCC. Data is saved in the CSV format and processed in Microsoft Office Excel. Samples were dried until they reached an equilibrium moisture content of approximately 0.042 and 0.037 for drying at a temperature of 80 °C and 70 °C, respectively. At the end of the drying experiments, samples were put into an electric oven for 48 hours at a constant temperature of 70 °C for the dry matter's determination.

Moisture ratio (MR) is termed as

$$MR = \frac{M_t - M_e}{M_o - M_e} \text{--} (1)$$

where M_t, M_o and M_e are the instantaneous, initial, and the end moisture content in (gw/g ts), respectively.

The values of Me are relatively small when compared with the values of M_t and Mo for long periods of drying time. Therefore, equation 1 can be simplified to: MR= M_t/Mo.

2.1. Determination of Color Changes and Shrinkage

Image analysis was carried out using a special program written for samples' color and shrinkage determination by [9]. The sample was analyzed for L, a, b and number of pixels. The change in total color difference was calculated using eq (2). Change in a sample size due to shrinkage(s) was calculated using eq (3) as a ratio of the current surface area (A) to the original surface area of a sample (A_o).

$$\text{TCD} = \sqrt{(\text{L} - \text{Lo})^2 + (\text{a} - \text{a}_0)^2 + (\text{b} - \text{bo})^2} - -(2)$$

Where a_o, b_o and L_o represent the initial values for the redness, yellowness and lightness of the samples, respectively; and a, b and L represented the instantaneous individual readings of the mentioned parameters.

$$S = \frac{A}{A_o} \text{-------------------} (3)$$

2.2. Experimental Design and Statistical Analysis

The experiment was carried out using five selected temperature profiles (Table 1) for the through-flow drying arrangement. Models for quality parameters: total color change, change in lightness, change in redness, change in yellowness and change in shrinkage as a function of drying time were developed using the basic third order polynomial equation (Equation 4).

$$\text{Y} = ß_o + ß_1 x + ß_2 x^2 + ß_3 x^3 + \varepsilon - - - - - - - (4)$$

Where ε stands for the random fluctuation (error). In this case, the response variable Y is predicted from predictor (or explanatory) variables X, X^2 and X^3 and b_0, b_1, b_2 and b_3 are the regression coefficients.

2.3. Temperature Profiles Selection

The temperatures profiles shown in Table.1 were selected based on the effect of glass transition temperature on the drying behavior of the potato slices. The graph of glass transition temperature and changing points of temperature profiles depicted in Fig 1. The difference between air temperature and glass transition temperature (T-Tg) values of selected profiles at moisture ratio (MR) less than or equal to 0.28 are presented in Table 2. In the rubbery state, the value of T-Tg of temperature profile II is negative whereas the other temperature value has a positive value of T-Tg. In glass state, the T-Tg values of the temperature profiles I, II and III are less than or equal to 0. The T-Tg values of temperature profiles IV and V are -40 and-30 respectively.

Table.1. Drying temperature profiles at dew point temperature of 10 °C and air velocity of 1m/s

Profiles	Drying conditions
I	At a constant air temperature of 120 °C
II	Stepping the air temperature down (at moisture ratio of 0.28) from an initial value of 120 °C to a final drying temperature of 70 °C
III	Stepping the air temperature down (at moisture ratio of 0.28) from an initial value of 120 °C to a final drying temperature of 80 °C
IV	Stepping the air temperature down (at moisture ratio of 0.16) from an initial value of 120 °C to a final drying temperature of 70 °C
V	Stepping the air temperature down (at moisture ratio of 0.16) from an initial value of 120 °C to a final drying temperature of 80 °C

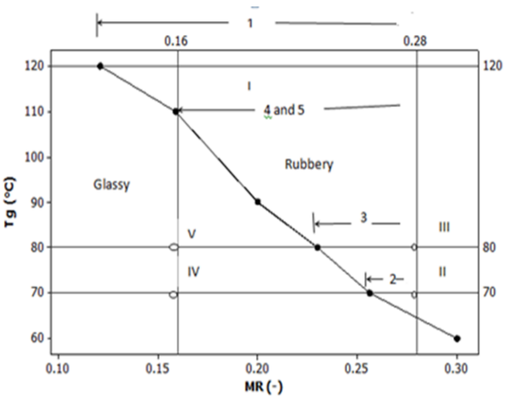

Fig. 1. Glass transition temperature and changing point of temperature profiles (graph modified from[10]

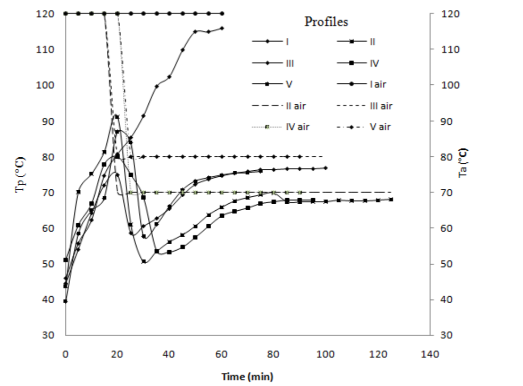

Fig.2. Product and air temperature as a function of time for profiles I, II, III, IV and V

Table 2. T-Tg of selected profiles at MR≤0.28

Profiles	(T-Tg) in °C in the rubbery state	(T-Tg) in °C in the glass state
Profile I	≤46	≤0
Profile II	≤-4	≤0
Profile III	≤6	≤0
Profile IV	≤46	≤-40
Profile V	≤46	≤-30

Where T is air temperature and Tg is glass transition temperature

3. Results and Discussion

3.1. Product Surface Temperature and Air Temperature

Fig.2 depicts product and air temperature as a function of the drying time for temperature profiles I, II, III, IV and V. For the constant temperature profile I, as the drying time increases, the increment in product temperature was observed. Gradually the product's temperature approached the air temperature. As the heat gain of the samples from the hot air increased, the product surface temperature also increased until a temperature of the samples reached equilibrium with the drying temperature [11]. An increase in heat gain of the samples led to an increase in warming of the product. Until the change in temperature is allowed to the samples, the pattern of product surface temperature becomes similar for all temperatures profiles. After the change in temperatures allowed to the samples for all time varying temperature profiles takes place, the reduction in value of product temperatures was observed. The reduction in surface temperature value of the samples is due to heat loss from the sample. A subsequent increase in product temperature with time was also observed.

3.2. Moisture Ratio

Potato slices with initial moisture contents in the range of 79.41- 83.07(w.b) were dried until reaching their equilibrium moisture contents. The sample moisture content was expressed as dimensionless moisture ratio in order to avoid ambiguity results due to differences in samples initial moisture content. Fig.3 depicts the moisture ratio as a function of drying time for different profiles. The samples dried by exposing at a temperature profile I resulted in a faster reduction in moisture content as compared to the samples dried by exposing to others temperature profiles. Moisture diffusivity of the samples is higher when processed at higher drying temperature [11]. For the remaining profiles, faster reduction in moisture content was initially observed. Then the increments in moisture content of the samples were observed at the time temperature changes of air were allowed to the samples. These results are due to change in temperature gradient direction as observed in Fig 2. Then the reduction in moisture content of the samples with an increase in drying time was proceeding for all time varying temperature profiles. Finally, almost no changes in the reduction of the moisture content of the samples were observed for all temperature profiles.

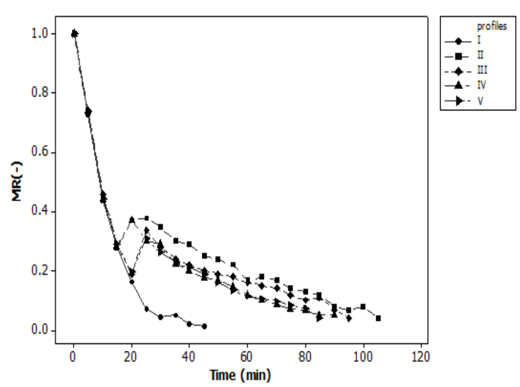

Fig.3. Moisture ratio as a function of drying time for different temperature profiles I, II, III, IV and V

3.3. Total Color Difference

The third order polynomial regression equations describing the effect of temperature profiles on a change in the total color difference of potato slices are shown in Table 2. The R^2 value shows that regression model explains in a range from 93% to 99 % of the variance in change in total color difference. The linear and the third-order regression term of total color difference exhibited positive and the second order regression term negative effect on color retention of the potato samples for all temperature profiles, except for temperature profile II. Fig.4. depicts changes in total color difference versus time for temperature profiles I, II, III, IV and V. The change in total color difference increases with time. At the end of drying stage, the highest value of the total color difference (TCD=7.9) was observed for temperature profile I as compared to all other temperature profiles. The lowest value of the total color difference (4.7) was obtained for the temperature profile II, since at lower moisture ratio <0.28, the samples were dried at a temperature of less than or equal to glass transition temperature. All time-varying temperature profiles resulted in better color retention as compared to temperature profile I. The increase in temperature of a product above its Tg increases molecular mobility, and also affects diffusion of the matrix and results in an increase in rates of deteriorative changes: enzymatic reaction, non-enzymatic browning and oxidation [12].

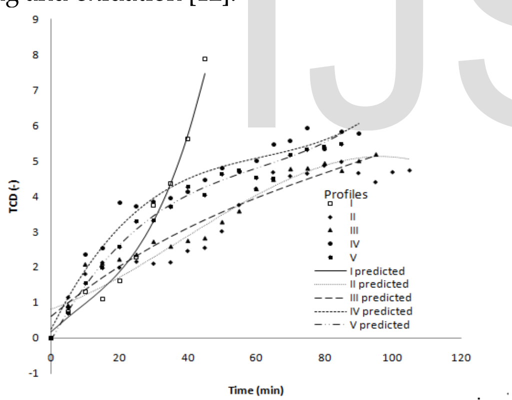

Fig. 4. Changes in total color difference versus time for temperature profiles I, II, III, IV and V

3.4. Change in Redness (∆a)

As shown in Fig.5, all temperature profiles resulted in redness above the original level. This means that the redness values of all dried potato chips were greater than the redness values of fresh potato. Leeratanarak et al, [11] also report the hot air dried potato chips show higher redness values as compared to the fresh potato. Krokida et al,[13] studied the kinetics on color changes during drying of apples, bananas, carrots and potatoes. Krokida's study concluded that the redness values increase during drying for apples, bananas and potatoes. The highest redness level increment (∆a=4.1) was observed at constant temperature profile I. The lowest change in redness (∆a=1) was obtained for the sample dried at a temperature profile II. This means profile II was the best option for maintaining the redness of the original samples. This is an indicator of potato slices, at lower moisture ratio <0.28, dried at a temperature less than or equal to glass transition temperature resulted in good retention in redness of the samples.

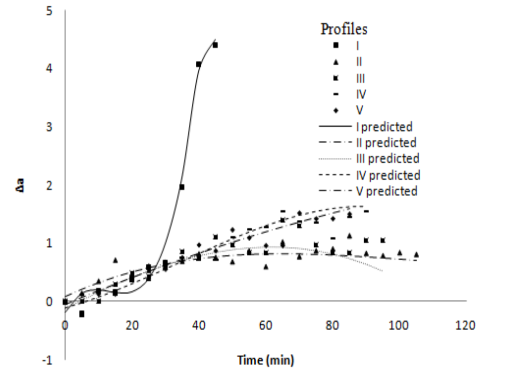

Fig.5. Changes in redness versus time for temperature profiles I, II, III, IV and V

3.5. Change in Lightness (∆L)

Changes in lightness versus time for temperature profiles I, II, III, IV and V are shown in Fig.6. The samples dried at temperature profiles II, III and IV resulted in lightness above the original level. For the samples dried at temperature profiles I, the increase in lightness was observed for the first 10 min of drying and at drying time interval of 15-30 min. However, at drying time interval of 10-15 min and from 30 min until the end of drying process a decrease in change in ∆L value was observed. Profile V almost maintained the original lightness of the fresh product. Profile II would appear to be a better option with an increase in lightness. The trend of the result for the constant temperature profile I agree with the finding of [14],[15]. The trend of the result of ∆L for all temperature profiles, except for temperature profile I, agrees with the trend result of [16]. At the end of the drying process, change in lightness values recorded -4, 4.1, 3.6, 3.3 and 0.24 of potato slices dried at temperature profiles I, II, III, IV and V, respectively.

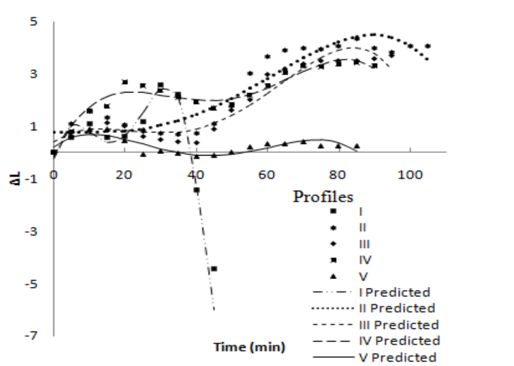

Fig.6. Changes in lightness versus time for temperature profiles I, II, III, IV and V

3.6. Change in Yellowness (∆b)

Fig.7. depicts changes in yellowness versus time for temperature profiles I, II, III, IV and V. Change in yellowness decreases with time of drying cubically for all temperature profiles (Table.2.). All temperature profiles resulted in a reduction of the yellowness of the samples as compared to the original. However, temperature profile II resulted in good retention in yellowness as compared to the remaining temperature profiles. The trend of the results agrees with the result of [17]. At the end of the drying process, the change in yellowness values were -4.42, -2.27, -3.49, -4.46, and -5.25 for temperature profiles I, II, III, IV and V, respectively.

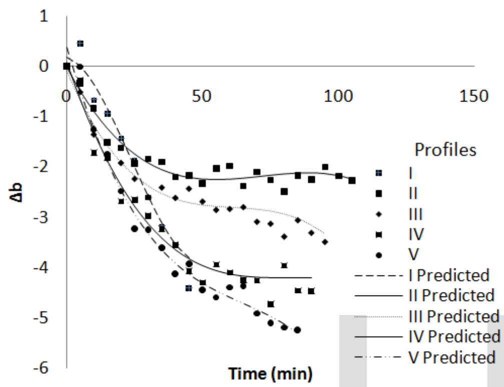

Fig.7. Changes in yellowness versus time for temperature profiles I, II, III, IV and V

Table 2. Equations for the responses investigated and their statistics at P<0.005

Profiles	Response	Model	R^2
I	TCD(-)	$TCD=0.1625+0.9051t-0.001786t^2+0.000075t^3$	0.98
	ΔL	$-0.145734+0.497873t-0.067202t^2+0.00307964t^3-4.32446e^{-005}t^4$	0.95
	Δa	$-0.1902+0.1021t-0.008482t^2+0.000213t^3$	0.97
	Δb	$0.1718-0.01639t-0.004394t^2+0.000062t^3$	0.98
	A/Ao	$A/Ao=1.006-0.01958t+0.000571t^2-0.000008t^3$	0.99
II	TCD(-)	$TCD=0.8183+0.03335t+0.000697t^2-0.000006t^3$	0.93
	ΔL	$\Delta L=0.793497+0.00154225t+0.000508766t^2-3.1398e^{-005}\ t3-2.31726e^{-007}t^4$	0.93
	Δa	$\Delta a=0.07533+0.02708t-0.000309t^2+0.00001t^3$	0.80
	Δb	$\Delta b=-0.0266-0.1023t+0.001508t^2-0.000007t^3$	0.94
	A/Ao	$A/Ao=0.9754-0.009634t+0.000125t^2-0.000001t^3$	0.96
III	TCD(-)	$TCD(-)=0.6070+0.08073t-000536t^2+0.000002t^3$	0.95
	ΔL	$\Delta L=0.415376+0.0929784t-0.00568084t^2+0.000119864t^3-7.06586e^{-007}t^4$	0.92
	Δa	$\Delta a=-0.1251+0.03076t-0.000157t^2-0.000001t^3$	0.86
	Δb	$\Delta b=-0.0957-0.1269t+0.002022t^2+0.00011t^3$	0.97
	A/Ao	$0.9799-0.01042t+0.000152t^2-0.0001t^3$	0.97
IV	TCD(-)	$0.2439+0.1933t-0.002782t^2+0.000015t^3$	0.96
	ΔL	$\Delta L=-0.225561+0.302375t-0.0122382t^2+0.0009t^3-9.69807e^{-006}t^4$	0.94
	Δa	$\Delta a=-0.1185+0.01588t+0.000310t^2-0.000003t^3$	0.94
	Δb	$\Delta b=0.0731-0.1582t+0.0019t^2-0.000008t^3$	0.97
	A/Ao	$A/Ao=0.9841-0.009595t+0.000125t^2-0.000001t^3$	0.98
V	TCD(-)	$TCD(-)=-0.0617+0.1767t-0.0023276t^2+0.000013t^3$	0.99
	ΔL	$\Delta L=0.612674+0.325413t-0.0152951t^2+0.000252046t^3-1.3214e^{-006}t^4$	0.82
	Δa	$\Delta a=-0.0553+0.02451t+0.000059t^2-0.00003t^3$	0.93
	Δb	$\Delta b=0.3774-0.1873t+0.002524t^2-0.000013t^3$	0.98
	A/Ao	$A/Ao=0.9950-0.01182t+0.000197t^2+0.000001t^3$	0.98

3.7. Shrinkage

Fig.8. depicts the change in normalized shrinkage versus time for potato slices dried at temperature profiles I, II, III, IV and V. The slope of a diagram is reduced with increasing drying time for temperature profiles II, III, IV, and V. At the end of drying stage, samples dried at all time varying temperatures resulted in significantly less shrinkage as compared to constant temperature profile I. The constant temperature profile keeps 58% of its original surface area. This means that there is 42% of shrinkage in surface area. Profile II keeps about 67% of its original surface area. The remaining 33% of its surface area was shrinking. This means that the samples dried at temperature profile II resulted in 27% less shrinkage of dried potato slices as compared to temperature profile I. As Bonazzi and

Dumoulin,[18] mention in his book the result of [19], during drying of pasta, Willis et al. (1999) observed a higher shrinkage when samples were dehydrated at 100 °C and 50% relative humidity than in samples dehydrated at 40 °C at the same air relative humidity. In the first case, the temperature of the pasta was higher than the glass transition temperature, and the product remained in the rubbery state and shrank uniformly during the whole drying process. In the second case, the surface of the material became glassy, decreasing shrinkage and increasing residual stresses in the dried material. Leeratanarak et al. [11] reported 48% and 50% of surface shrinkage of potato slices dried at constant temperatures of 80°C and 60°C, respectively.

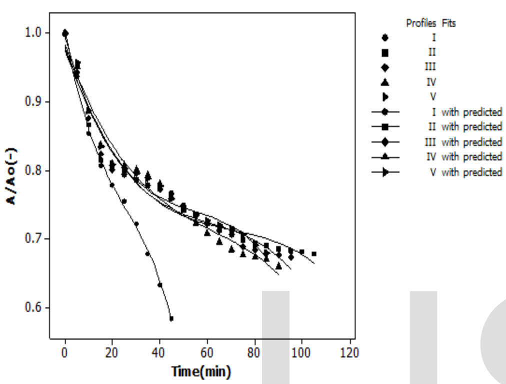

Fig.8. change normalized shrinkage versus time of potato slices dried at temperature profiles I, II, III, IV and V.

4. Conclusions

The sample dried at constant temperature resulted in a reduction in quality of color and high shrinkage of the samples. The samples were dried at a high temperature initially and proceeded at temperatures less than or equal to glass temperature in the range of moisture ratio less than 0.28 which resulted in better color retention and less shrinkage. In general, drying the samples, by applying a high temperature of an air initially and then reducing the drying temperature at less than the glass transition temperature of the sample has a positive effect on the quality attributes of the drying products. Further research would be needed to apply the concept of glass transition temperature on others drying foods.

5. Acknowledgment

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