The Bioscan 10(2): 521-525, 2015
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES
www.thebioscan.in

EFFECT OF PRE- DRYING AND FRYING KINETICS OF SWEET POTATO (*IPOMOEA BATATAS L.*) CHIPS

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KEYWORDS
Drying kinetics
Frying
Hardness
Sweet potato

Received on :
21.10.2014

Accepted on :
13.05.2015

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ABSTRACT

Experiments were conducted at different drying temperature (40, 60 and 80⁰C) and frying time (60, 120, 180, 240 and 300 Second). MINITAB statistical software was used to study the statistical analysis of independent and dependent variables in terms of ANOVA. Page's model is showing best model with high coefficient of regression (r^2) 0.9980, 0.9994 and 0.9980 than Exponential models, (r^2) 0.9948, 0.9988 and 0.9950 for 20 mm thick slice at a temperature 40, 60 and 80°C respectively. Oil content of 20 and 30 mm thick sweet potato chips were reported, 68.1 and 68.7% for fresh sample and after drying up to 5% moisture (db), oil content reduced up to 11.4 and 13.2 % respectively. Optimum quality of Sweet potato chips (Moisture content 1.25 % db, 39.1 % oil content and hardness 5.02 N) were obtained at fried temperature of 170°C for 180 seconds and the sensory ratings were observed as R_a = 5.8, R_h = 6.4, R_m = 6.1, R_o = 6.8. For colour of fried chips, moisture content and drying time have significant effect ($p<0.05$) and Pre-drying temperature was non-significant ($p>0.05$) for hardness of chips. The chips dried to lower moisture content had more hardness. Based on sensory rating chips dried at 200% db at a temperature of 60°C and fried at 170°C for 180 s resulted best quality of chips.

INTRODUCTION

Sweet Potato (*Ipomoea batatas L*) is a tuberous root plant, originally from the Central and Southern America and classified according to the format, size and internal colour (Peixoto and Mirnanda, 1984). Root crops like Sweet potato were treated as more potential food in drought tolerant area to promote food security than any other food crops (Gunjan Jha, 2011). Drying is depend upon the factors like moisture content, temperature and relative humidity (Gopalan *et al.*, 1999) and frequently used as industrial preservation method to minimized the water activity to retard the biochemical, chemical and microbiological deterioration of vegetables (Doymaz and Pala, 2003). Natural colour and textural properties of the food materials have an important aspect for consumer attraction which can be preserved with the adequate drying (Dhanapal *et al.,* 2013). Drying characteristics of sweet potato chips were studied with the help of mathematical modelling. Bouchan and Payal (2004) revealed that oil absorption increased with reducing the thickness of food sample (Mehta and Swinburn, 2001) and Gamble *et al.,* (1987), have found that absorption of oil influenced during frying with the variation in slice thickness and moisture content of potato and potato chips packed into polythene bag after frying enhance the quality standards and shelf life (Bal, 1990). The best frying temperature and time for frying vary with the variety, specific gravity of the tubers (Nema *et al.*, 2004) and drying demands special attention for preservation of vitamins and minerals present within fruits and vegetables (Gopalan *et al.*, 1999). Goburdhun and Jhurree (1992) have observed non-significant reduction of fatty acids in treated oils compared to pure soybean oil. Alberto *et al.*, (1998), have studied that frying at lower temperature extended the processing time. Potato chips absorbed nearly 38 % and 65 % of the total oil content during frying and cooling stage respectively (Dura *et al.*, 2006). Rojas *et al.*, (2006), have observed the deep-fat frying had no significant effect on carotenoid contents at any frying conditions. Pedreschi *et al.*, (2007), have studied the soaking of potato slices in sodium chloride solution before frying dramatically reduces acryl amide formation in potato chips. Marique *et al.*, (2003), have studied the colour variation of individual chips during frying for apex, centre and the basal parts. Tendency of people to consume processed and packaged food products are gradually increasing which encourage the food industries to launch new and innovative varieties of food products having lesser oil content and lower cost because high fat content food materials are decreasing the consumer preferences.

In view of the above, this research has been focused on moisture removal pattern with drying and oil absorption during frying of dried chips and as well as studied the fittest combination of frying temperature and moisture of dried chips for minimum oil absorption.

MATERIALS AND METHODS

Materials

The Sweet potato *(Ipomoea batatas L. Lam)* of uniform shape and size without any defect on visual inspection was procured from a local farmer near Central Institute of technology, Kokrajhar, India. Stainless steel core extractor diameters of 3 cm were used for slicing of sweet potato. A laboratory scale Precision rice cooker (Make: RE Pabst CO, U.S.A; Model: PCS 3E) with temperature control (range: 0ºC to 250ºC) and perforated frying container was used as deep fat fryer (Alberto *et al.*, 1998). A solvent extractor (Make: Buchi; Switzerland, Model: E-914) with petroleum ether (BP: 40º - 60ºC) was used to measure the oil content of chips (Meireles, 2009). A digital thermometer was used to record the temperature during frying of sweet potato chips. Moisture content of fresh sweet potato chips has been measured with oven drying method (AOAC, 1999).

Experimental designs

The full factorial experimental design was adopted. The experimental plan is summarized in the following Table1.

Methods

Fresh white sweet potato was first peeled using peeler than sliced using a hand operated slicer with thinness of 5 mm. Sweet potato chips were blanched with 0.1 % KMS to retain the colour by preventing the browning (Sra *et al.*, 2011). After blanching, frying was done in two phases. In first phases fresh samples were dried at 40ºC, 60ºC and 80ºC to the predetermined moisture content then fried at 170ºC for different frying times. Fried chips were kept on blotting paper and cooled at room temperature for 5-7 minutes. Then chips were packed in polyethylene bags (thickness 95 micron, density 0.92) and stored at room temperature.

Hardness and crispness

Hardness of fried Sweet potato chips was measured using a texture analyser (Make: Stable Micro System, UK; Model: TA – Hdi) (Harry Chandler, 1999) with placing the sample on "crisp fracture support rig (HDP/CFS) using 25kg load cell on heavy duty platform (HDP/90) and using 5mm spherical stainless probe (P/5S). Measurement was carried out at Pre-Test Speed of 1.0 mm/s, Test Speed of 1.0 mm/s, Post-Test Speed of 10.0 mm/s, Distance of 3mm and Trigger Force of

Table 1: Experimental design with dependent and independent variables

Independent Variables	Values	Dependent Variables
Slice Thickness	5 mm	
Oil type	Refined Oil (Soybean)	
Frying temperature	180ºC	
Drying temperatures	3 (40ºC, 60ºC and 80ºC)	Oil content of fried chips (%). Moisture content of fried chips (% db).FFA Content of oil.Hardness.Colour.
Time of frying	5 (60, 120, 180, 240, 300 sec)	

FFA= Free fatty acid, sec=Second, db=Dry basis

Table 2: Drying behaviour of sweet potato chips at different drying temperatures (40⁰,60⁰ and 80⁰ C)

At 40⁰ C		At 60⁰ C		At 80⁰ C	
Time(Min)	MC(%db)	Time(Min)	MC(%db)	Time(Min)	MC(%db)
0	294.25	0	294.25	0	294.25
5	272.8	5	251.34	5	244.22
10	252.08	10	214.89	10	213.53
15	233.65	15	187.98	15	180.38
20	218.5	20	179.67	20	151.85
25	205.59	25	161.52	25	131.73
30	193.53	30	142.53	30	119.05
40	172.8	40	121.09	40	84.64
50	153.36	50	101.4	50	68.41
60	138.78	60	83.69	60	51.52
70	121.73	70	69.61	70	30.63
80	111.56	80	49.36	80	17.47
90	103.18	90	31.33	90	8.95
105	91.51	105	19.82	105	2.56
120	80.86	120	9.46		
135	70.54	135	6.11		
150	61.44	150	2.20		
165	52.66				
195	37.58				
225	25.27				
255	16.47				
285	8.54				
315	5.5				
345	2.66				

M.C= Moisture Content, db= Dry basis and Min=Minute

Table 3: Parameters and regression coefficients for drying models

T(°C)	D(mm)	Exponential model				Page's model			
		A	K	r^2	SEE	k	n	r^2	SEE
40	20	0.95	0.0112	0.9948	0.022	0.0217	0.87	0.9980	0.0139
	30	0.95	0.0111	0.9948	0.0255	0.0211	0.86	0.9980	0.0136
60	20	1.02	0.0277	0.9988	0.0113	0.0206	1.07	0.9994	0.0078
	30	1.05	0.0216	0.9920	0.0335	0.0075	1.16	0.9986	0.0131
80	20	1.03	0.0355	0.9950	0.0246	0.0218	1.13	0.9980	0.015
	30	1.03	0.0362	0.9940	0.0268	0.0212	1.15	0.9978	0.0163

T = Temperature, D = Diameter, A = Exponential model constant, K = Drying constant for Exponential model, r^2 = Coefficient of regression, SEE = Standard error of estimation, k = Drying constant for Page's model, n = pages model constant.

Table 4: Analysis of Variance (ANOVA) for moisture content (% db) of fried Sweet potato chips

Source of variation	DF	SS	MSS	F_{cal}	p-value
D	1	133.64	130.2	4.24	0.043
T	2	31.96	15.98	0.51	0.604
MC	2	1478.51	739.26	23.46	0.000
FT	4	3561.78	890.44	28.26	0.000
Error	80	2520.77	31.51		
Total	89	7726.66			

DF = Degree of freedom, SS = Sum of squares, MSS = Mean sum of squares, D = Diameter, T = Temperature, MC = Moisture content, FT = Frying time.

Table 5: Analysis of Variance (ANOVA) for colour of fried chips

Source of variation	DF	SS	MSS	F_{cal}	p-value
D	1	0.1778	0.1778	1.09	0.299
T	2	1.8000	0.9000	5.54	0.056
MC	2	7.8000	3.9000	24.00	0.000
FT	4	31.6222	7.9056	48.65	0.000
Error	80	13.0000	0.1625		
Total	89	54.4000			

DF = Degree of freedom, SS = Sum of squares, MSS = Mean sum of squares, D = Diameter, T = Temperature, MC = Moisture content, FT = Frying time.

Auto - 5g. Here samples were selecting with most uniformity, *i.e.* in terms of size and shape, and removed from packets after 12 hours of frying. The initial fracture of the sample was indicated by the first peak force. The maximum peak force during the first compression cycle was taken as the hardness. Each experiment was repeated three times and the data reported were the average of the same.

Determination of Free Fatty Acids (FFA)

The percentage of free fatty acids was calculated using the following expression (Ranganna, 2005).

$$FFA = \frac{28.2x\ TV\ xN}{W} \quad \text{......[1]}$$

Where,

TV = Volume of NaOH used in ml,

N = Normality of NaOH

W = Weight of sample in gm

Data Analysis

Study the effect of drying on frying behaviour of Sweet potato chips with statistical correlation of data in terms of analysis of variance (ANOVA) between independent and dependent variables was conducted using MINITAB statistical software. ANOVA predicted the level of significance with which a particular operating variable influence the given process. The software measured p- value, where the value (1-p) represented the probability at which the effect of that operating variable was significant. The lower the value of p, the more significantly that operating variables influences the particular process. In this study p- value < 0.05 (indicating 95 % confidence level) was taken as basis for deciding whether the effect of a particular variable is significant or not.

RESULTS AND DISCUSSION

Drying behaviour

The drying behavior of Sweet potato chips were determined for 30 mm slices at temperatures of 40°, 60° and 80°C to analyze the effect of drying conditions on drying rate. Average drying rate was computed with help of following approximation as suggested (Nema and Prasad, 2004).

$$\left(\frac{dM}{dt}\right)_{avg} = \frac{Mt - Mt + \Delta t}{\Delta t} \quad \text{......[2]}$$

The average drying rate represents the rate of moisture removal from time t to t+Dt, attributed to the middle of the time interval. The average rate of drying is expected to continuously decrease with time except for constant rate drying periods. The drying behaviour of chips at different temperatures is shown in Table 1. The table depicts that drying takes place under falling rate and no constant rate period is clearly identifiable. Drying of sweet potato chips up to 2.66, 2.51 and 2.56 (%, db) at temperature of 40, 60 and 80°C required 345,

Table 6: Analysis of Variance (ANOVA) for hardness

Source of variation	DF	SS	MSS	F_{cal}	p-value
T	2	11501433	5750722	5.09	0.448
MC	2	13233910	6616965	5.86	0.005
FT	4	65209692	16302423	14.44	0.000
Error	36	40646642	1129073		
Total	44	130591688			

DF = Degree of freedom, SS = Sum of squares, MSS = Mean sum of squares, D = Diameter, T = Temperature, MC = Moisture content, FT = Frying time.

Table 7: Selected operating conditions in order of decreasing overall sensory rating

Operating conditions				Mean Sensory ratings			
Chips diameter (mm)	T_{pd} (⁰C)	MC_{bf} (%, db)	T_f (sec)	Ra	Rh	Rm	Ro
30	40	200	135	5.1	6.3	6.1	7.1
30	60	200	180	5.8	6.4	6.1	6.8
30	40	200	180	5.6	6.4	6.1	6.6
30	60	300	270	5.3	6	6.1	6.6
30	40	300	270	6.0	6.1	5.6	6.3
30	60	200	180	5.2	6.8	5.9	6.3
30	40	200	180	5.2	6.2	5.2	6.3

T_{pd} = Pre-drying temperature, MC_{bf} = Moisture content before frying, T_f = Frying time, Ra, Rh, Rm and Ro = sensory ratings.

150 and 105 minutes respectively (Table 1), indicates that drying time was decreased with increasing of drying temperature and also noticed that moisture removal rate is maximum but colour and crispiness were degraded in the case of drying at 80ºC.

Modelling of drying behaviour

The studies carried out on drying, diffusion is generally accepted to be the main mechanism during the transport of moisture to be evaporated from the surface. As the constant rate period was absent in drying of Sweet potato slices (Table 1), the following two commonly used models, which describe the drying behaviour in falling rate period, were tested.

$MR = Ae^{-kt}$ (Exponential model).. [3]

$MR = e^{-kt^n}$ (Page's model)...[4]

Where,

$$MR = \frac{M - M_e}{Mi - M_e}$$

It can be noted from the drying data that the final moisture content is very small compared to the initial moisture content of 294.25 % db. Equilibrium moisture content is assumed to be negligible and MR is calculated as M/M_i. These models were fitted to the experimental data using 'Curve Expert 1.3' software to determine the models constants. 'A' is the exponential model constant very close to 1 (0.95 to 1.02) and that the value of 'n' in page's model is also close to 1 (0.86 to 1.16) means effect of the both two models are close to each other.

The suitability of the two models was examined on the basis of standard error of estimation (SEE) and coefficient of regression (r^2). The model constants along with r^2 and SEE are presented in the Table 2.

For 20 cm thick slices of chips, coefficient of regression (r^2) reported 0.9980, 0.9994 and 0.9980 (Page's Model) and 0.9948, 0.9988 and 0.9950 (Exponential Model) respectively indicates that for all the drying experiments, r^2 value for Page's model are slightly higher and standard error of estimation (SEE) values are less than exponential model concluded that, page's model is fittest to adequate drying (Table 2).

Moisture losses during frying

ANOVA for final moisture content of chips (Table 3) indicates that the effect of diameter (p = 0.043), initial moisture content (p = 0.000) and frying time (p = 0.000) on final moisture content of chips is significant but non-significant for drying temperature (p = 0.604). As the effect of pre-drying temperature on the final moisture content of fried chips is non-significant, the data corresponding to pre-drying temperature is averaged out. Oil absorption characteristics of the sweet potato chips increased with decreasing moisture during frying and obtained most appropriate frying at temperature of 170ºC for 180 second.

Oil absorption during frying

The typical representation of the oil content on dry basis is inadequate, when moisture was constant during frying. Therefore, the oil content is converted to moisture free basis (% mfb) along with dry basis oil content. In all the cases, oil content increases with time of frying. Therefore, oil absorption is maximum for fresh (un-dried) slices and minimum for the slices dried to less than 5 % db moisture content. Also as ANOVA indicated the affect of pre-drying temperature on oil absorption is insignificant. From the data it appears that pre-dry the samples is preferred to minimize the oil absorption during frying. The Sweet potato slices dried to less than 5 % db have oil content of 11.4 and 13.2 % mfb and without drying as fresh absorb higher oil content of 68.1 and 68.7 % mfb for 20 and 30 mm diameter during frying respectively.

Characteristics of Sweet potato Chips after Frying

Colour

Colour of the sample is specified with colour code ranged between 1 (lightest) and 5 (darkest). It was determined by visually comparing with a computer generated colour chart. ANOVA of colour of fried chips (Table 4) shows that the effect of diameter ($p = 0.299$) and temperature ($p = 0.056$) is non-significant where as moisture content ($p = 0.000$) and time of frying ($p = 0.000$) has a significant effect on colour of chips revealed that moisture content and time of frying influenced the colour of fried chips.

Hardness

Hardness of fried Sweet potato chips was measured using a Texture analyzer with three replicates. The ANOVA of hardness (Table 5) depicts that the effect of moisture content and frying time on hardness is significant ($p < 0.05$), whereas the pre-drying temperature has non-significant effect ($p > 0.05$).

Optimization for fittest model

Production of Sweet potato chips on industrial scale need to be optimized the best fit combination of significant factors. The overall acceptability was considered as main responses for optimization. Due to consideration of all the significant factors as drying temperature, drying time and final moisture content, optimized condition of drying was observed for 60^0 C, 150 second and 2.51 (% db) respectively and data table of operating conditions and various sensory ratings were rearranged in order of decreasing on the basis of overall acceptability.

The operating conditions resulting in R_a above 80 percentile (*i.e.*, R_o in top 20%) are identified. Similarly, the sensory ratings based on the other characteristics above 80 percentile are also identified. These are shown in bold in the Table 6.

Research findings also reveals that the operating conditions (Chips diameter, Moisture content before frying and Pre-drying temperature), of drying at moisture content of 200 (% db), temperature of 60ºC and frying at 170ºC for 180s, results the best quality Sweet potato chips which contain moisture of 1.25 % db and oil of 39.1 (% db) with a moderate crispy nature having hardness of 5.02 N (Table 6). At these conditions the sensory ratings are $R_a = 5.8$, $R_h = 6.4$, $R_m = 6.1$, $R_o = 6.8$.

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