Modelling temperature and slice thickness effect on b-carotene, carbohydrate and moisture contents of orange-fleshed sweet potato flour

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Abstract: In this study, the effect of oven temperature (OT) and slice thickness (ST) of orange-fleshed sweet potato (OFSP) on β-carotene, carbohydrate, and moisture contents of OFSP flour was studied. A 2^2 full factorial experimental design with two replications was used. The washed, peeled and sliced OFSP roots were dried to constant weights in an oven. The dried slices were milled into flour using a grinder and then sieved using a 200 µm sieve to achieve particle size uniformity. The colour parameters, carbohydrate, and moisture contents of the resultant flour were determined. Statistical analyses were carried out using Design Expert 12 software at (p < 0.05) significance level. Results showed that OT had significantly negative effect while ST had significantly positive effect on the pigments, carbohydrate, and moisture contents of OFSP flour. Both OT and ST, however, had significantly positive interaction effect on the dependent variables. At the design points and their proximities, linear equations were found to be adequate. However, at the centres of the design space, the linear equations were found inadequate for predictions, which indicated the need for further studies on quadratic or cubic model development. The results mean that 10 mm thick slices oven-dried at 85°C would give properly dried (9.4% M.C.) high-protein (6.7%) flour; while 10 mm thick slices dried at 45°C would give high carbohydrate (76%) flour with good colour retention.

Keywords: carbohydrate, carotene, colour, orange-fleshed, pigments, potato flour

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1 Introduction

The sweet potato (*Ipomoea batatas L*) is a root crop grown in hot and humid regions (Fessehaye and Rungarun, 2017). It is a staple food for humans; it is used as animal feed and serves as a raw material for food-based industries (Fessehaye and Rungarun, 2017). Sweet potato contains carbohydrate, protein, vitamin A, Vitamin C, Vitamin B_6, Calcium, Iron, Potassium, Phosphorus, Zinc and Magnesium (Haruna et al., 2018). Sweet potato in Nigeria is commonly consumed as roasted or boiled tubers (Haruna et al., 2018). In Africa, Nigeria is the highest producer of Sweet Potato with an estimated ten-year average production of 3.45 million tonnes (Olatunde et al., 2016) with estimated post-harvest loss of above 35% arising from high perishability factor (Haruna et al., 2018). Common varieties of sweet potato grown in Nigeria include those with white, yellow or purple root tubers resulting from their different pigments and phenolic contents (Olatunde et al., 2016; Ngoma et al., 2019). Orange-fleshed sweet potato (OFSP) is a variety with orange-coloured root tubers (Figure 1). OFSP is currently in high demand because of its unique high composition of Vitamin A and beta-

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carotene (Haruna et al., 2018; Kolawole et al., 2018). Colour is an important quality index for fresh fruits and vegetables (Pathare et al., 2013). Colour can show the severity of heat treatment of biological materials and thus can indicate quality deterioration (Pathare et al., 2013).

OFSP tubers are dried and converted into flour which is more stable and less bulky and reduces post-harvest losses. Drying is a common technique used to extend the shelf-life of several food products. Drying techniques include oven drying, freeze drying, cabinet drying, solar drying, and sun-drying (Fessehaye and Rungarun, 2017; Haruna et al., 2018). However, the hot air oven drying technique is a recommended technique for rapid and massive drying of plant and animal materials (Haruna et al., 2018). Generally, the ultimate qualities of processed biological products are influenced in many ways by drying (Fessehaye and Rungarun, 2017). In order, therefore, to produce high-quality flours from dried root crops, appropriate slice thickness and drying temperature must be known and adopted for each specific crop.

OFSP is popular because of its carbohydrate and β-carotene contents. Therefore, the objectives of this study were to investigate the magnitudes and directions of the effects of oven temperature and OFSP slice thickness on the β-carotene, carbohydrate, and moisture contents of the resultant flours and to determine if linear models could be used for predictions over a wide experimental design space**.**

2 Materials and methods

2.1 Materials

Fresh matured tubers of OFSP were procured from a farm in Umuahia, Abia State, Nigeria. Other materials used for the study were: hot-air oven DHG-9053A, RT5°C – 200°C, ± 1°C), weighing balance (HX502T, 500 g, 0.01 g), stainless steel kitchen knife, measuring rule, vernier caliper (RDDC 706, ± 0.02 mm), a Corona manual grinder (UN970HL168M6CNAFAMZ), and a 200 µm sieve (Retsch-Allee).

2.2 Experimental design

Design of experiments (DOE) is a powerful technique for exploring new processes, gaining increased knowledge of the existing processes, and optimizing these processes for achieving improvement in product quality and process (Jiju, 2008). In production processes, it is often of primary interest to explore the relationships between the key input process variables and the output performance characteristics. For many optimization problems in industries the root cause of the problems is sometimes the interaction between the factors rather than the individual effect of each factor on the output performance responses. For quantitative process variables, two levels are generally required especially when a linear relationship is assumed (Jiju, 2008). The analytical tools of DOE often include analysis of variance (ANOVA), main effect plots, interaction effect plots, response surface plots and regression models (Jiju, 2008). It is widely accepted that the most commonly used experimental design in manufacturing companies are full and fractional designs of 2-levels and 3-levels (Jiju, 2008). Two-level factorial designs are of special importance because they require relatively few runs per factor studied. And when the factors are quantitative, although unable to fully explore a wide region in the factor space, they often determine a promising direction for further experimentation (Box et al., 2005). In experiments involving 2^k order design it is always important to examine the magnitude and direction of the factor effects to determine which variables are likely to be important (Montgomery, 2013).

A 2^2 full factorial experimental design with two replications was used for this study. The independent factors and their levels were oven temperature (45°C and 85°C) and potato slice thickness (10 and 30 mm). The design matrix is shown in Table 1. Sample number 1(10 mm thick potato slice was the first randomly selected sample that was oven-dried at 45°C. Sample number 7(10 mm thick potato slice was the second randomly selected sample that was oven-dried at 85°C). And sample number 2 (30 mm thick potato slice was the third randomly selected sample that was oven-dried at 85°C; and so on).

Table 1 Experimental design matrix

SN	RR	Factor 1 OT: Oven temperature (°C)	Factor 2 ST: Slice thickness (mm)
1	1	45	10
2	3	45	30
3	4	85	10
4	7	85	30
5	8	45	10
6	5	45	30
7	2	85	10
8	6	85	30

Note: SN = Sample number; RR = Randomized runs

2.3 Flour preparation

The OFSP tubers were washed with distilled water, peeled and cut into 10 and 30 mm thick rectangular shapes with a sharp stainless kitchen knife. Each standard batch of the same thickness was divided into two batches and randomly assigned for oven drying operation. The slices were loaded into trays and dried in the hot air oven until constant weights were attained. The dried slices were then milled into flour. A 200 μm aperture mesh screen was used to obtain flours with a uniform particle size. The flour powder was then packaged in nine ziplock plastic bag samples ready for analyses. The sample preparation stages are shown in Figure 1.

2.4 Content analyses

The CIELAB colour parameters (L^*, a^*, b^*) of the OFSP flour samples were measured using a Chroma Meter (CR-400, Konica Minolta Sensing Inc., Osaka, Japan). The samples were placed in the sample holder and the colour measurements were done in duplicates. The colour analyses were done at the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. In the CIELAB colour system, parameter a^* measures red colouration, parameter b^* measures orange or yellow colouration, and parameter L^* measures the lightness of the colour (Pathare et al., 2013). As a result of the highly significant correlation ($p < 0.001$) between β-carotene content and b^* colour parameter (Ginting, 2013), the colour parameter b^* was used as a measure of the β-carotene content of the flour. The carbohydrate content, moisture content, and protein content were determined using standard methods of the American Association of Cereal Chemists (AACC, 2000).

Figure 1 Step by step processing of orange-fleshed sweet potato to flour

2.5 Data analyses

Analysis of variance (ANOVA), analytical plots and regression modelling were done using Design Expert 12 software at ($p = 0.05$) significance level. An online One-way ANOVA with post-hoc Tukey HSD Test Calculator was used for separation of means.

2.6 Models confirmation (verification) experiment

Four runs of models confirmation experiment were performed with values of the independent variables selected at the mid points of the design space (OT = 65°C; ST = 20 mm) so as to test for curvature or non-linearity of the models (Table 2). If the result of the confirmatory experiment falls within the interval of predicted value ± 3 (S.E.) or if the predicted value falls within the ninety-nine percent confidence interval of confirmatory mean value ± 3 (S.E.), the linear model is adequate or good (where S.E. (standard error) is obtained by $sd/\sqrt{n}$: sd is sample standard deviation and n is number of samples) (Jiju, 2008; Design Expert 12).

Table 2 Experimental design matrix for models confirmation test

SN	OT (℃)	ST (mm)	*b**	Carb (%)	MC (% w.b.)
1	65	20			
2	65	20			
3	65	20			
4	65	20			

3 Results and discussion

3.1 Effect of oven temperature and slice thickness

Table 3 shows the effect of oven temperature and slice thickness of OFSP on pigment, carbohydrate, and moisture contents of OFSP flour. The effects are discussed as follows:

Table 3 Effect of oven temperature and slice thickness on pigment, carbohydrate and moisture contents of OFSP flour

SN	Colour parameter *b**	Carbohydrate (%)	Moisture content (% w.b.)	Protein (%)
1	33.82 ±0.36[a]	76.16 ±0.01[a]	11.40 ±0.04[a]	3.83±0.03[a]
2	32.01 ±2.57[b]	70.53 ±0.24[b]	11.20 ±0.28[a]	6.72±0.04[b]
3	1.72 ±0.16[c]	62.87 ±0.00[c]	9.38 ±0.04[b]	6.72±0.03[b]
4	20.61 ±0.71[d]	74.88 ±0.00[d]	11.78 ±0.04[a]	4.81±0.01[c]

Note: SN = Sample number; 1 = 10 mm (ST) at 45°C (OT); 2 = 30 mm at 45°C; 3 = 10 mm at 85°C; 4 = 30 mm at 85°C; values are means ±standard deviations of two replicates. Within the same column, values with different letters (a-d) differ significantly ($p < 0.05$)

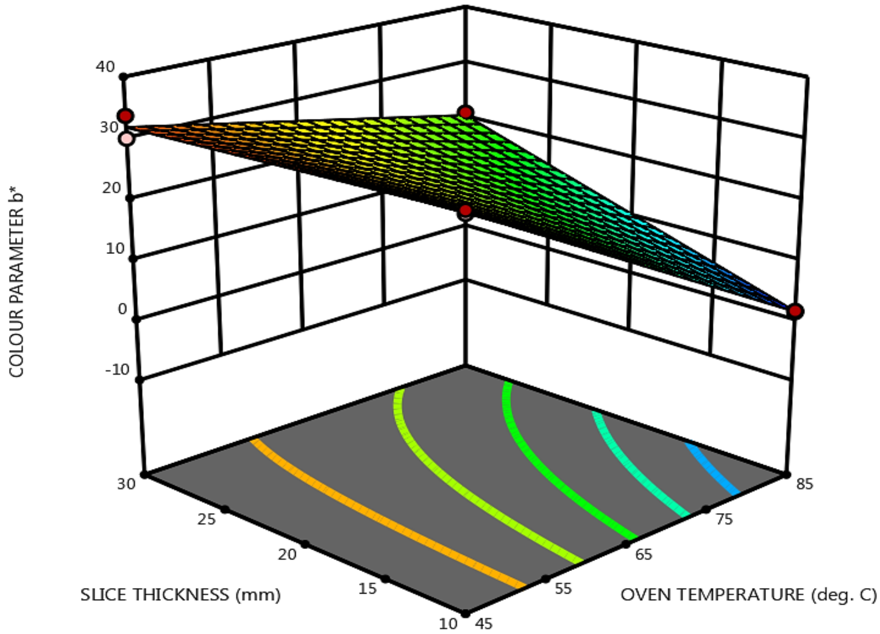

Figure 2 Response surface plot of slice thickness and oven temperature against flour colour parameter b^*

3.1.1 Effect of OT and ST on colour parameter b^*

A positive value of colour parameter b^* indicates orange and yellowness (Pathare et al., 2013; Kolawole et al., 2018). Statistical analysis showed that increasing the oven temperature (OT) significantly reduced the colour parameter b^* of the flour (when the slice thickness (ST) is low, i.e. 10 mm); while increasing the ST significantly increased b^* (when the OT is high, i.e. 85°C). Both variables, therefore, significantly interact to affect the orange and yellowness colour parameter b^*. In other words, at low OT (45°C), ST has significant negative (reducing) effect on β-carotene (b^*) content of the flour produced. This means that 10 mm thick slices of OFSP oven-dried at 45°C will produce flour of higher β-carotene content than 30 mm thick slices oven-dried at 45°C. At high OT (85°C), ST has significant positive (increasing) effect on β-carotene. This means that 30 mm thick slices of OFSP oven-dried at 85°C will produce flour of higher β-carotene content than 10 mm thick slices oven-dried at 85°C. Conversely, at low ST (10 mm), OT has significant negative effect on β-carotene (b^*), and at high ST (30 mm), OT has significant positive effect on β-carotene. That is to say, that in order to produce OFSP flour with high β-carotene content, low slice thickness and low oven temperature drives the process. Thus, flour with the highest value of b^* (34.58) was obtained from 10 mm thick samples dried at 45ºC; while the lowest value of 1.72 was obtained from 10 mm thick samples dried at 85ºC (Figure 2). The finding that drying or heating reduces the colour pigment parameters of OFSP has been documented (Fessehaye and Rungarun, 2017; Kolawole et al., 2018). The major cause of larger loss of β-carotene is high heating intensity occasioned by high temperature and low slice thickness which causes isomerization of carotenoids (Ruttarattanamongkol et al., 2016; Grabowski et al., 2008; Nicanuru et al., 2015).

3.1.2 Effect of OT and ST on carbohydrate content

Statistical analysis of results showed that, at low OT (45ºC), ST has significant negative effect on carbohydrate content of the flour produced. This means that 10 mm thick slices of OFSP oven-dried at 45ºC will produce flour of higher carbohydrate content than 30 mm thick slices oven-dried at 45ºC. At high OT (85ºC), ST has significant positive effect on carbohydrate. This means that 30 mm thick slices of OFSP oven-dried at 85ºC will produce flour of higher carbohydrate content than 10 mm thick slices oven-dried at 85ºC. The possible reason why ST has a positive effect on carbohydrate content at high OT is the fact that thicker samples when dried to a constant weight would contain more carbohydrate than thinner samples.

Conversely, at low ST (10 mm), OT has significant negative effect on carbohydrate content, but at high ST (30 mm), OT has significant positive effect on carbohydrate. This trend was reported by Haruna et al. (2018) and Ruttarattanamongkol et al. (2016). The reason could be as a result of the high removal of moisture which tends to increase the concentration of nutrients (Ruttarattanamongkol et al., 2016).

The range of average values of carbohydrate recorded in this study was 62.87% ± 0.00% – 76.16% ± 0.01% (for 200 µm flour particle size). Haruna et al. (2018) who dried 0.5 mm thick samples of OFSP in hot air oven at 40ºC – 60ºC reported a higher range (85% – 87%) (for flour particle size of 75 µm). The reason for the difference could be as a result of the higher removal of moisture from the 0.5 mm thick samples occasioning higher concentration of carbohydrate (Nicanuru et al., 2015), or due to starch gelatinization (Fashina et al., 2017). Due to significant (p < 0.05) interaction effect of OT and ST, flour with the highest carbohydrates content (76%) was achieved at OT of 85ºC and ST of 30 mm; while the lowest (62.87%) was at 85ºC and 10 mm (Figure 3).

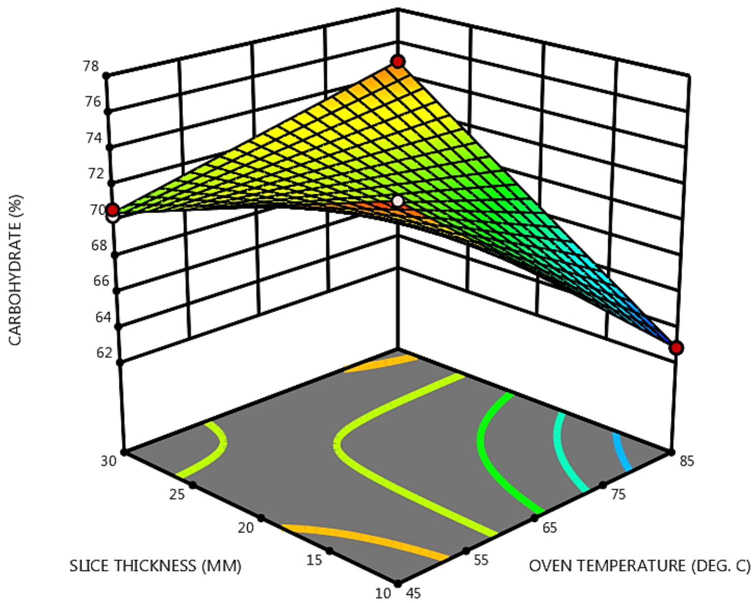

Figure 3 Response surface plot of slice thickness and oven temperature against flour carbohydrate content

3.1.3 Effect of OT and ST on moisture content

The analysis of variance (ANOVA) of experimental results showed that at low OT (45°C), ST of 10-30 mm has no significant effect on moisture content of the flour produced. This means that 10-30 mm thick slices of OFSP oven-dried to constant weight at 45 °C will produce flour of statistically equal moisture content. At high OT (85°C), ST has significant (p < 0.05) positive effect on the flour moisture content. This means that 30 mm thick slices of OFSP oven-dried to constant weight at 85°C will produce flour of higher moisture content than 10 mm thick slices oven-dried at 85°C. This is probably as a result of lower surface area availability per unit mass of samples with higher thickness (Behera et al., 2017), or greater drying difficulty due to the increased distance travelled by moisture to the surface (Limpaiboon, 2011). On the other hand, at low ST (10 mm), OT has significant negative effect on flour moisture content, but at high ST (30 mm), OT has no significant effect on moisture content. This was because thinner samples had a faster drying rate than the thicker slices (Wu et al., 2018). This increase in moisture loss by thinner samples was due to the reduced distance the moisture travelled and increased surface area exposed for a given volume of the samples (Allen et al., 2016). Due to ST and OT interaction, the highest flour moisture content (11.8%) was recorded at 85°C (OT) and 30 mm (ST) and the lowest (9.4%) was recorded at 85°C and 10 mm indicating higher interaction impact of ST (Figure 4). Haruna et al. (2018) and Olatunde et al. (2016) indicated that a moisture content of 12.5% was considered critical within a locality with ambient temperature of about 29°C and 10% was recommended for long term storage of flour.

3.1.4 Effect of OT and ST on protein content

ANOVA of experimental results showed that at low OT (45°C), ST of 10-30 mm has significant positive effect on protein content of the flour produced. This means that 30 mm thick slices of OFSP oven-dried to constant weight at 45°C will produce flour of higher protein content than 10 mm thick slices oven-dried at 45°C. At high OT (85°C), ST has significant negative effect on protein. This means that 10 mm thick slices of OFSP oven-dried to constant weight at 85°C will produce flour of higher protein content than 30 mm thick slices oven-dried at 85°C. Also, at low ST (10 mm), OT has significant positive effect on protein content; but at high ST (30 mm), OT has significant negative effect on protein content. The flour with the highest protein content (6.72%) was achieved by drying 10 mm thick slices at 85°C in the oven or drying 30 mm slices at 45°C; while the lowest (3.83%) was achieved at 45°C (OT) and 10 mm (ST) (Figure 5). That was probably, because drying at high slice thickness or high temperature causes minimal protein denaturation (Korese et al., 2022), or because of concentration of nutrients as a result of moisture reduction (Nicanuru et al., 2015).

3.2 Modeling the effects of OT and ST

The effect of OT and ST on colour parameter b*, carbohydrate and moisture contents of OFSP flour are modelled as shown below. The effect of the variables on the protein content was not modelled in this study, because OFSP was considered essentially a carbohydrate resource.

3.2.1 Modelling colour parameter *b**

The model equation in terms of actual factors of the effect of OT and ST on the pigment colour parameter b* is given by Equation 1.

$$Colour\ parameter\ b^* = 82.47 - 1.06 \times OT - 1.25 \times ST + 0.03 \times OT \times ST \quad (1)$$

(Adequate precision = 33.73, Adjusted R^2 = 0.99, Predicted R^2 = 0.98, and PRESS = 28.97)

The Predicted R^2 of 0.98 is in reasonable agreement with the Adjusted R^2 of 0.99; i.e. the difference is less than 0.2. Adequate Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 33.73 indicates an adequate signal. This model can, therefore be used to navigate the experimental design points and their proximities. The equation in terms of actual factors (Equation 1) can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. The model equation in terms of coded factors of the effect of OT and ST on the pigment colour parameter b^* is given by Equation 2. The coded equation is useful for identifying the direction and magnitude or relative impact of the factors by comparing the factor coefficients. Thus, oven temperature has 2.5 times more effect on b^* than slice thickness. And OT has a negative effect while ST has a positive effect on b*.

$$\text{Colour parameter } b^* = 22.04 - 10.87 \times OT + 4.27 \times ST + 5.18 \times OT \times ST \quad (2)$$

3.2.2 Modeling of carbohydrate content

The model equation in terms of actual factors of the effect of OT and ST on the carbohydrate content is given by Equation 3.

$$\text{Carbohydrate} = 103.87 - 0.55 \times OT - 1.27 \times ST + 0.02 \times OT \times ST \quad (3)$$

(Adequate precision = 156.2, Adjusted R^2 = 0.99, Predicted R^2 = 0.99)

Based on the coded model equation, oven temperature has more relative impact (2.24) than ST (1.60) on carbohydrate, with OT having a negative effect and ST a positive effect.

3.2.3 Modelling of moisture content

The model equation in terms of actual factors of the effect of OT and ST on the moisture content is given by Equation 4.

$$\text{Moisture content} = 13.87 - 0.07 * \text{Oven temperature} - 0.11 * \text{Slice thickness} \quad (4)$$

(Adequate precision = 23.38, Adjusted R^2 = 0.98, Predicted R^2 = 0.95)

Based on the coded model equation, oven temperature has less relative impact (0.26) than ST (0.66) on moisture content, with OT having a negative effect and ST a positive effect.

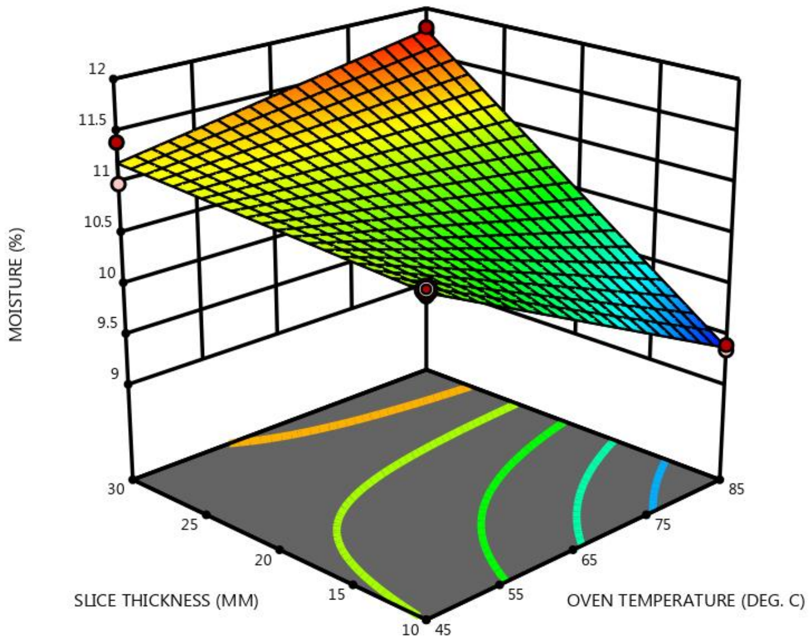

Figure 4 Response surface plot of slice thickness and oven temperature against flour moisture content

3.3 Results of models confirmation (verification) experiments

The results of the models confirmation experiments are shown in Table 5 with the standard errors calculation. The standard errors (S.E.) were 0.23, 0.24, and 0.18 for colour, carbohydrate, and moisture content models. The experimental mean value of 28.33 for b^* is outside the predicted value range of 27.57 ± 3 (0.23) = (27.57 ± 0.69). In other words, the average observation from the confirmation experiment is outside the confirmation node's prediction interval and therefore, the linear model is confirmed not good ((Jiju, 2008; Design Expert 12). Also, since 71.46 is more than 68.72 ± 3 (0.24) =

(68.72 ± 0.72) for carbohydrate, the linear model is not good as well. Again, since 8.33 is more than 7.12 ± 3 (0.18) = (7.12 ± 0.54), the linear model for the moisture content is also not confirmed; suggesting that either quadratic or cubic models might be better for b-carotene, carbohydrate, and moisture content predictions throughout the factors' design space.

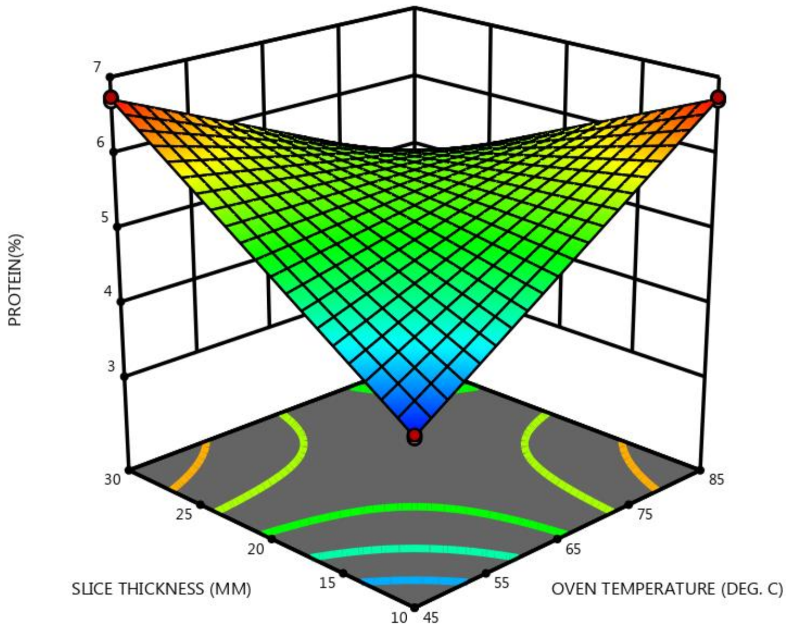

Figure 5 Response surface plot of slice thickness and oven temperature against flour protein content

Table 4 Experimental design matrix and results for model confirmation test

SN	OT (°C)	ST (mm)	b*	Carbohydrate (%)	MC (% w.b.)
1	65	20	28.50	70.90	7.95
2	65	20	28.70	71.60	8.40
3	65	20	27.80	71.88	8.70
4	65	20	27.80	70.95	8.75
Average			28.20	71.33	8.45
Standard error			0.23	0.24	0.18

4 Conclusions and recommendation

This study has shown that OT and ST significantly influence the β-carotene, carbohydrate, and moisture contents of the resultant OFSP flour.

Oven temperature had significantly negative effect while slice thickness had significantly positive effect on β-carotene, carbohydrate, and moisture contents of OFSP flour. Both oven temperature and slice thickness, however, had significantly positive interaction effect on the dependent variables.

Linear regression models developed in this study were adequate for the experimental design points and their proximities, but, inadequate for predictions at the centre of the design space because of the presence of curvature. This indicates the need for further studies on quadratic and cubic models.

Properly dried (9.4% M.C.) high-protein (6.7%) flour can be produced by oven-drying 10 mm thick slices at 85°C; while high carbohydrate flour with good colour retention can be produced by oven-drying 10 mm thick slices at 45°C.

Having established the direction of the effect of OT and ST on β-carotene, carbohydrate, and moisture contents of OFSP flour, the optimization and development of non-linear models are recommended.

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