ISSN 1819-1894

Asian Journal of Agricultural Research

http://knowledgiascientific.com

Knowledgia SCIENTIFIC
A Place to Publish Outstanding Research

OPEN ACCESS
Asian Journal of Agricultural Research
ISSN 1819-1894
DOI: 10.3923/ajar.2017.57.65

Research Article

Optimization of Color and Thermal Properties of Sweet Cassava (*Manihot esculenta* Crantz Var. UVLNR 0005) Flour Using Response Surface Methodology

[1]Adewale Olusegun Omolola, [1]Patrick Francis Kapila, [2]Tonna Ashim Anyasi, [2]Afam Israel Obiefuna Jideani and [3]Godwin Ainamensa Mchau

[1]Department of Agricultural and Rural Engineering, School of Agriculture, University of Venda, Private Bag X5050, 0950 Thohoyandou, Limpopo Province, South Africa
[2]Department of Food Science and Technology, School of Agriculture, University of Venda, Private Bag X5050, 0950 Thohoyandou, Limpopo Province, South Africa
[3]Department of Horticultural Sciences, School of Agriculture, University of Venda, Private Bag X5050, 0950 Thohoyandou, Limpopo Province, South Africa

Abstract

Background and Objective: Cassava is an essential foodstuff in the tropical regions of the world. It is high in calories and also a very good source of revenue for many countries. Present study focused on optimizing quality of cassava (UVLNR 0005) flour in terms of color and thermal qualities. **Materials and Methods:** A central composite rotatable drying experiments comprising of two factors: drying temperature (60-70°C) and drying time (15-20 h) was designed using Stat-Ease design expert software. The software was also used to carry out one-way analysis of variance ($p<0.05$), regression analysis, optimization of color and thermal properties and obtain contour plots for interactions between the drying conditions, color and thermal properties. **Results:** Results indicated that the drying conditions used in this study had no significant effect on color and thermal properties of cassava (UVLNR 0005) flour. The range of L* (lightness/darkness), a* (redness/greenness), b* (yellowness/blueness), hue, chroma and WI (whiteness index) were 87.67-93.57, -0.27-1.1, 8.4-11.83, 84.87-91.5, 8.4-11.87 and 82.88-89.42, respectively. The onset, peak, conclusion temperatures and enthalpy of gelatinization ranged between 93.68-114.21, 100.35-118.49, 108.73-123.51 and 3.74-11.54°C, respectively. Mathematical models obtained for the prediction of color and thermal properties at different drying temperatures and time were characterized with insignificant ($p>0.05$) lack of fit test and high regression values. Drying conditions of 65.34°C drying temperature, 16.48 h drying time were found optimum for product quality at a desirability of 0.78. **Conclusion:** It was concluded that use of the optimum drying conditions obtained in this study for drying cassava chips can help preserve the color and thermal qualities of cassava flour.

Key words: Cassava, response surface methodology, thermal properties, flour, optimization, models, contour plots, drying

Citation: Adewale Olusegun Omolola, Patrick Francis Kapila, Tonna Ashim Anyasi, Afam Israel Obiefuna Jideani and Godwin Ainamensa Mchau, 2017. Optimization of color and thermal properties of sweet cassava (*Manihot esculenta* crantz var. UVLNR 0005) flour using response surface methodology. Asian J. Agric. Res., 11: 57-65.

Corresponding Author: Adewale Olusegun Omolola, Department of Agricultural and Rural Engineering, School of Agriculture, University of Venda, Private Bag X5050, 0950 Thohoyandou, Limpopo Province, South Africa Tel: +27739543311

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Cassava is an essential foodstuff in the tropical regions of the world. It is high in calories and also a very good source of revenue for many countries. World largest producers of cassava include Nigeria, Brazil and Thailand in downward order with Nigeria producing approximately 53 million tons annually[1,2]. It is a highly recognized source of carbohydrate, riboflavin, thiamin and nicotinic acid[3], with starch as the major component (80% d.w.) of cassava root[4]. Amylopectin with about 5-6% branches has been implicated as the key molecular component of cassava starch[5] consisting of approximately 80% of the molecular composition and amylose containing approximately 20%[6]. The consumption of cassava roots and leaves involves cooking before its intake mostly to remove the hydrocyanic acid present in the plant. Processing of the roots includes its conversion to different forms of paste, flour and starch as well as it has been consumed raw or freshly boiled[7]. Cassava flour has therefore found application as soup thickeners, gravies, sauces, cakes, or as composite flour in the production of bread, biscuits and other snacks[8] as well as use in thick porridges or dumplings.

Lewicki and Jakubczyk[9] reported that thermal properties of agricultural foodstuffs are intrinsic and depicts the capability of agricultural foodstuffs to conduct and transmit heat energy. The capability of food products to conduct and transmit heat energy is an essential factor in modeling and designing food processing equipment. It is also required in analyzing heat flow pattern during food processing which in turns determines the extent of heat processing on food quality. Furthermore, thermal properties are dependent on temperature and food constituents[10]. According to Nesvadba[11], a linear relationship exists between moisture contents thermal properties of food; an indication that moisture contents can significantly influence thermal properties of agricultural products. This is due to the significant ability of water to conduct and transmit heat energy as compared to other food constituents[12-14].

The outlook of many agricultural products is determined by their colour[15]. Different agricultural product has different color range preferred by consumers and buyers. Consumers and buyers preference with regards to color of food products is dependent on several factors. These include inconsistency among consumers, their maturity and racial origin and physical nature of the environment at a time of judgment[16]. This study investigated color and thermal properties of cassava (var. UVLNR 0005) flour using response surface and determined the optimum drying conditions that can help in preserve and enhance the quality of cassava during post harvest processing as it is lacking in the literature.

MATERIALS AND METHODS

Source and preparations of cassava flour: Cassava roots of the variety (UVLNR 0005) used were obtained from the University of Venda (Univen) experimental farm in Limpopo province of South Africa. The experimental analysis was carried out in the Department of Food Science and Technology at Univen, Thohoyandou, South Africa between February and April, 2017. Roots were properly washed to remove soil particles after harvesting. Cleaned roots were peeled and sliced to a thickness of 2 mm before drying in a forced air laboratory oven (Labotec Instrument-model 278, South Africa). The drying experiments which consist of drying temperature and time were designed using State-Ease software (Table 1 and 2). Oven dried chips were milled into flour using a miller (Retsch ZM 200 miller, Haan, Germany) at 16,000 rpm for 2 min. Flour was preserved in sealable polyethylene bags and stored at -20°C until further analysis was conducted.

Color determination: The surface color characteristics L* (lightness/darkness), a* (redness/greenness) and b* (yellowness/blueness) of UVLNR 0005 cassava flour were obtained with the aid of a colorimeter (ColourFlex, HunterLab, USA)[17]. Hue angle, whiteness index (WI) and chroma of flour were determined using Eq. (1-3)[18,19,20] respectively:

Table 1: Experimental runs and color properties for cassava (UVLNR 0005) flour under different oven-drying conditions

Temperature(°C)	Time (h)	L*	a*	b*	Chroma	Hue	WI
60	20.00	87.67±0.04	1.10±0.00	11.83±0.04	11.87±0.04	84.67±0.09	82.88±0.05
70	20.00	88.90±0.08	0.80±1.11E-16	10.33±0.04	10.33±0.04	85.70±0.00	84.82±0.10
65	21.04	89.97±0.04	0.40±0.04	9.27±0.04	9.30±0.04	87.43±0.04	86.34±0.02
70	15.00	88.30±0.00	0.70±1.11E-16	10.13±0.04	10.50±0.00	86.37±0.04	84.51±0.01
72.07	17.50	90.00±0.21	0.20±2.77E-17	9.30±0.00	9.30±0.00	88.67±0.09	86.34±0.15
60	15.00	88.30±0.28	1.03±0.04	11.33±0.04	11.37±0.04	84.83±0.28	83.68±0.22
57.93	17.50	90.97±0.04	0.30±0.00	10.13±0.04	10.17±0.04	88.30±0.14	86.42±0.05
65	13.96	89.80±0.00	0.10±1.38E-17	10.40±0.00	10.40±0.00	89.67±0.04	85.43±0.03
65	17.50	93.57±0.04	-0.27±0.04	8.40±0.00	8.40±0.00	91.50±0.24	89.42±0.07
65	17.50	88.80±0.00	0.20±2.77E-17	9.90±0.00	9.90±0.00	88.93±0.09	85.05±0.02

L*: Lightness/darkness, a*: Redness/greenness, b*: Yellowness/blueness and WI: Whiteness index. Values recorded as Mean±Standard Deviation

Table 2: Experimental runs and thermal properties for cassava (UVLNR 0005) flour under different oven-drying conditions

Temperature (°C)	Time (h)	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (j g^{-1})
60	20.00	111.20±4.08	118.31±2.89	123.51±2.69	9.04±1.01
70	20.00	114.21±4.87	118.49±3.39	123.06±0.41	11.54±5.54
65	21.04	94.05±3.55	103.83±2.74	112.01±1.93	7.53±2.29
70	15.00	98.01±7.77	105.91±7.09	112.25±6.84	7.70±5.51
72.07	17.50	106.20±3.58	111.79±2.89	115.21±2.76	5.74±2.28
60	15.00	110.46±2.10	113.78±1.68	116.95±1.48	6.27±2.04
57.93	17.50	93.79±2.12	102.92±3.02	111.57±3.22	3.74±1.89
65	13.96	93.68±4.97	100.35±5.77	109.62±3.65	4.03±2.09
65	17.50	94.87±5.13	102.57±4.24	108.73±2.22	3.81±1.18
65	17.50	103.30±1.39	110.39±1.57	114.99±1.95	6.19±0.17

T_o (°C): Onset temperature, T_p (°C): Peak temperature, T_c (°C): Conclusion temperature, ΔH (j g^{-1}): Enthalpy of gelatinization. Values recorded as Mean±Standard Deviation

Table 3: ANOVA of the effect of model parameters on color characteristics of cassava (UVLNR 0005) flour

	L*		a*		b*		Chroma		Hue		WI	
Factors	F-value	p-value	F-value	p-value	F-value	p-value	F-value	p-value	F-value	p-value	F-value	p-value
A-temperature	5.99E-04	0.9816^	0.20	0.679^	1.12	0.3494^	0.96	0.3836^	0.42	0.5516^	0.13	0.7402^
B-time	0.78	0.4259^	3.03	0.1567^	1.77E-04	0.99^	0.012	0.9196^	1.94	0.2364^	0.38	0.5716^
A^2	0.26	0.6363^	2.08	0.2227^	1.18	0.339^	1.15	0.3434^	2.59	0.1825^	0.51	0.5155^
B^2	0.68	0.4562^	2.08	0.2227^	1.46	0.2941^	1.43	0.2976^	2.48	0.1905^	0.94	0.3881^
AB	0.09	0.7789^	0.18	0.6905^	0.33	0.597^	0.59	0.485^	0.056	0.8242^	0.16	0.7065^

^Not significant at (p>0.05), A: Linear effect of oven temperature, B: Linear effect of drying time, AB: Interaction of oven temperature and drying time, A^2: Quadratic effect of oven temperature, B^2: Quadratic effect of drying time, L*: Lightness/darkness, a*: Redness/greenness, b*: Yellowness/blueness and WI: Whiteness index

$$\text{Hue angle} = \tan^{-1}\left(b/a\right) \quad (1)$$

$$\text{WI} = \sqrt{(100 - L)^2 + a^2 + b^2} \quad (2)$$

$$\text{Chroma} = \sqrt{\left(a^{*2} + b^{*2}\right)} \quad (3)$$

Determination of thermal properties: A differential scanning calorimeter (DSC 4000, Perkin-Elmer, Shelton, CT, USA), was used to determine the thermal properties of the flour according to the method of Anyasi *et al.*[21] with slight modification. Approximately 10 mg of cassava flour was weighed into an aluminum pan and mixed with 10 μL of distilled water. Crimper press (Perkin-Elmer, Shelton, CT, USA) was used to hermitically seal the aluminum pan. The sample was stored overnight at 4°C overnight in order to equilibrate it. Flour was heated at 10°C min^{-1} over a heating regime of 20-140°C. Onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and enthalpy of gelatinization ΔH were determined from the curves with the aid of Pyris software (Perkin Elmer Shelton, CT, USA).

Statistical analysis: All data were processed using a commercial statistical package, Design-Expert statistical package Version 8.0.1.0 (Stat-Ease Inc; Minneapolis USA, version) was used to design the drying experiments and analyze data collected during the experiment. These analyses include one-way analysis of variance (p<0.05), regression analysis and optimization of color and thermal properties[17]. The Design-Expert statistical software was also used to obtain contour plots for interactions between the drying conditions, color and thermal properties.

RESULTS AND DISCUSSION

Results obtained showed variation in the color range of the cassava flour. The L* values were 87.67-93.57, a* values of -0.27-1.1, b* values of 8.4-11.83, hue values of 84.87-91.5, chroma values of 8.4-11.87 and 82.88-89.42 for WI, respectively (Table 1). Analysis of variance on the effect of drying temperature and time on color characteristics of (UVLNR 0005) cassava flour showed that linear effects of oven temperature (A): Drying time (B): Interaction effects of oven temperature and drying time (AB): Quadratic effects of oven temperature (A^2): Drying time (B^2): All had no significant effects on the color parameters L*, a*, b*, hue, chroma and WI of the flour (Table 3). Mathematical models expressing the relationship between L*, a*, b*, hue, chroma, WI and drying conditions of the samples are shown in Table 4. Contour plots showing the variation of L*, a*, b* hue, chroma and WI angle with change in drying conditions for the flour samples are shown in Fig. 1-3. The redness and yellowness of the flour samples increased with increase in drying time and temperature respectively (Fig. 1a, b), while lightness and WI of the flour samples

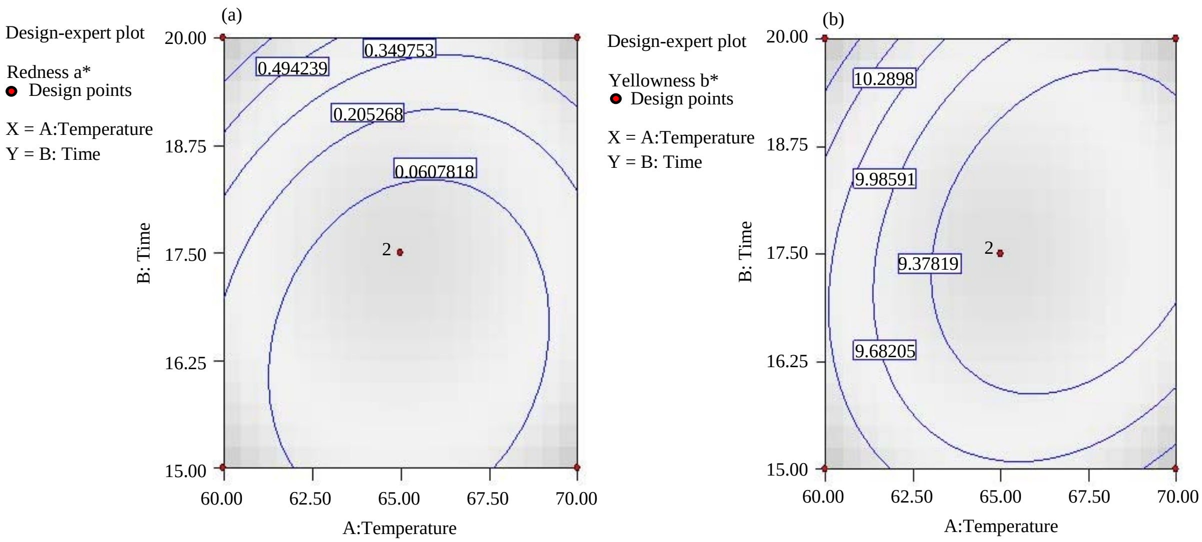

Fig. 1(a-b): Contour response surface plot for the effects of oven temperature (°C) and drying time (h) on (a): Redness (a*) and (b): Yellowness (b*) of cassava (UVLNR 0005) flour

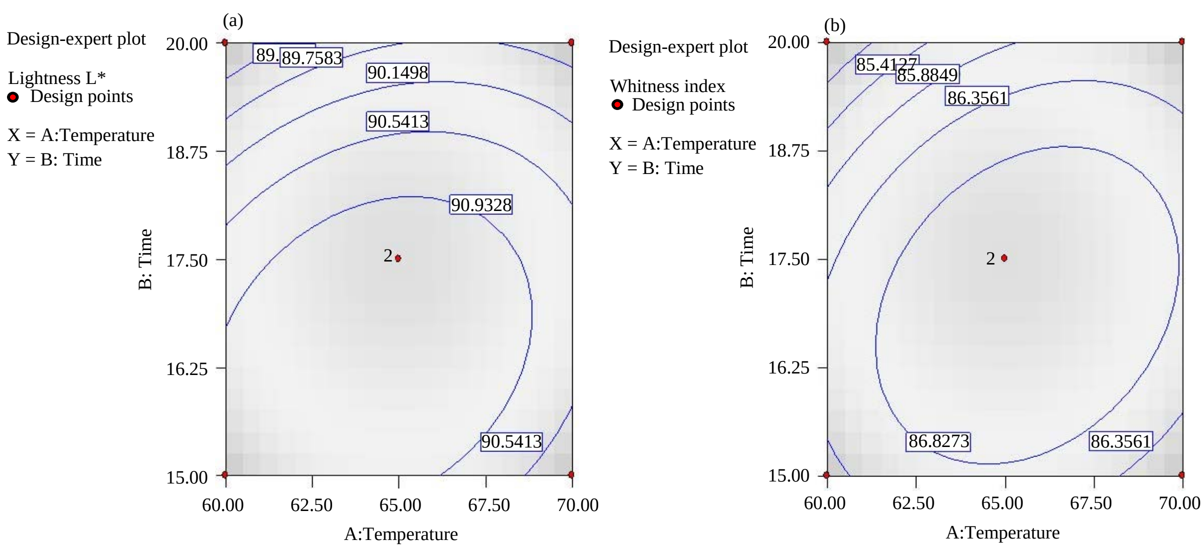

Fig. 2(a-b): Contour response surface plot for the effects of oven temperature (°C) and drying time (h) on (a): Lightness (L*) and (b): Whiteness index (WI) of cassava (UVLNR 0005) flour

Table 4: Regression models relating color characteristics and model parameters for cassava (UVLNR 0005) flour

Response variables	Models	Lack of fit p-value	R^2
L*	$91.19-0.018A-0.64B-0.49A^2-0.79B^2+0.31AB$	0.9133^	0.53
a*	$0.035-0.055A+0.22B+0.24A^2+0.24B^2-0.075AB$	0.5806^	0.61
b*	$9.15-0.38A-4.758E-003B+0.51A^2+0.57B^2-0.29AB$	0.6357^	0.50
Chroma	$9.15-0.35A+0.038B+0.50A^2+0.56B^2-0.38AB$	0.641^	0.50
Hue	$90.22+0.44A-0.93B-1.43A^2-1.40B^2-0.22AB$	0.5856^	0.60
WI	$87.24+0.26A-0.45B-0.69A^2-0.94B^2+0.42AB$	0.8508^	0.73

^Not significant at ($p>0.05$), A: Linear effect of oven temperature, B: Linear effect of drying time, AB: Interaction of oven temperature and drying time, A^2: Quadratic effect of oven temperature, B^2: Quadratic effect of drying time, L*: Lightness/darkness, a*: Redness/greenness, b*: Yellowness/blueness and WI: Whiteness index

increased with decrease in drying temperature and time (Fig. 2a, b). Conversely, chroma increased with increase in drying time and temperature (Fig. 3a) while hue decreased with increase in drying time (Fig. 3b).

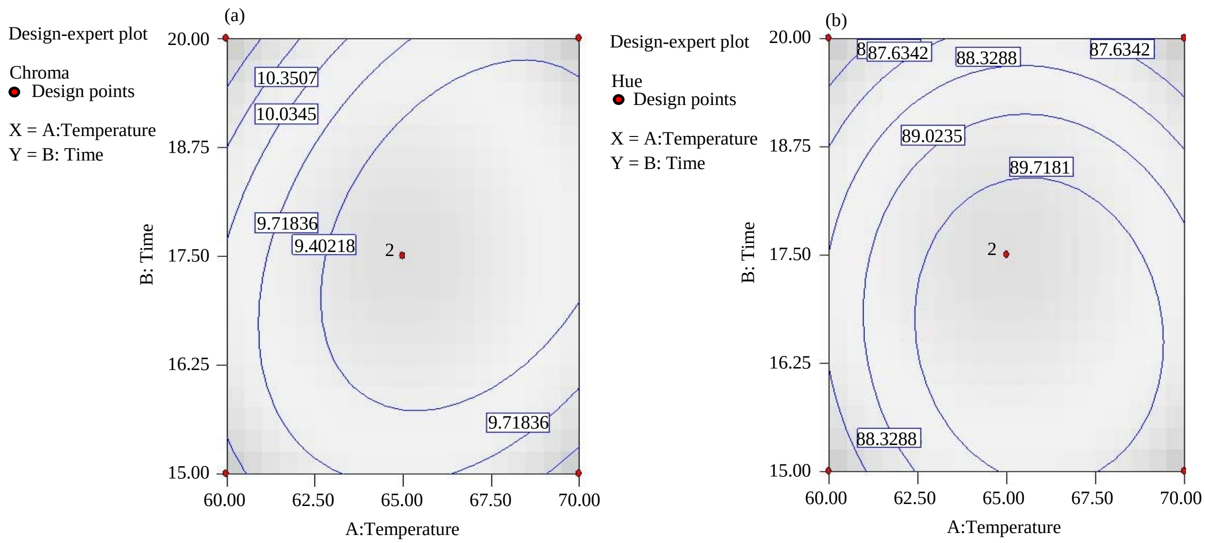

Fig. 3(a-b): Contour response surface plot for the effects of oven temperature (°C) and drying time (h) on (a): Chroma and (b): Hue of cassava (UVLNR 0005) flour

Table 5: ANOVA of the effect of model parameters on thermal properties of cassava (UVLNR 0005) flour

	T_o (°C)		T_p (°C)		T_c (°C)		ΔH (j g⁻¹)	
Factors	F-value	p-value	F-value	p-value	F-value	p-value	F-value	p-value
A-temperature	0.077	0.7956^	0.044	0.8438^	1.72E-08	0.9999^	0.85	0.41^
B- time	0.36	0.5819^	0.63	0.4702^	1.09	0.3556^	2.65	0.1786^
A^2	0.48	0.527^	0.47	0.5296^	0.68	0.4555^	0.36	0.5791^
B^2	3.24E-03	0.9573^	0.028	0.8761^	0.3	0.6149^	0.94	0.3863^
AB	0.56	0.496^	0.24	0.6478^	0.12	0.745^	0.042	0.8482^

^Not significant at (p>0.05), A: Linear effect of oven temperature, B: Linear effect of drying time, AB: Interaction of oven temperature and drying time, A^2: Quadratic effect of oven temperature, B^2: Quadratic effect of drying time, T_o: Onset temperature, T_p: Peak temperature, T_c: Conclusion temperature, ΔH: Enthalpy of gelatinization

Table 6: Regression models relating thermal properties and model parameters for cassava (UVLNR 0005) flour

Response variables	Models	Lack of fit p-value	R^2
T_o (°C)	$99.09+1.01A+2.18B+3.34A^2+0.28B^2+3.86AB$	0.3623^	0.53
T_p (°C)	$106.49+0.61A+2.30B+2.62A^2+0.63B^2+2.01AB$	0.4234^	0.66
T_c (°C)	$111.86-2.828E-004A+2.25B+2.35A^2+1.55B^2+1.06AB$	0.4519^	0.73
ΔH (j g⁻¹)	$5.00+0.08A+1.49B+0.73A^2+1.18B^2+0.26AB$	0.4055^	0.53

^Not significant at (p>0.05), A: Linear effect of oven temperature, B: Linear effect of drying time, AB: Interaction of oven temperature and drying time, A^2: Quadratic effect of oven temperature, B^2: Quadratic effect of drying time, T_o (°C): Onset temperature, T_p (°C): Peak temperature, T_c (°C): Conclusion temperature, ΔH (j g⁻¹): Enthalpy of gelatinization

Thermal properties of (UVLNR 0005) cassava flour under different drying conditions are shown in Table 2. Results revealed an onset temperature of 93.68-114.21°C, peak temperature of 100.35-118.49°C, conclusion temperature of 108.73-123.51°C and enthalpy of gelatinization of 3.74-11.54°C, respectively. The highest values of T_o, T_p, T_c and ΔH recorded were obtained at 70°C drying temperature 20 h drying time, 70°C drying temperature 20 h drying time, 60°C drying temperature 20 h drying time and 70°C drying temperature 20 h drying time respectively. ANOVA shows that the drying conditions had no significant effects on T_o, T_p, T_c and ΔH of the flour samples (Table 5).

Regression models relating the thermal properties to actual levels of drying conditions reveals that lack of fit test and regression values of the models were not significant and high respectively (Table 6). The variability of drying temperature and drying time on the thermal properties of the flour samples as reflected in Fig. 4(a-b), 5(a-b) showed that T_p, T_o, T_c and ΔH increased with increase in drying temperature and time respectively. Values of T_o, T_p, T_c and ΔH obtained in this study were higher than that obtained in other studies on gelatinization of cassava flour and starch (Table 7).

The result of optimization of the drying conditions of (UVLNR 0005) cassava was 65.34°C drying temperature,

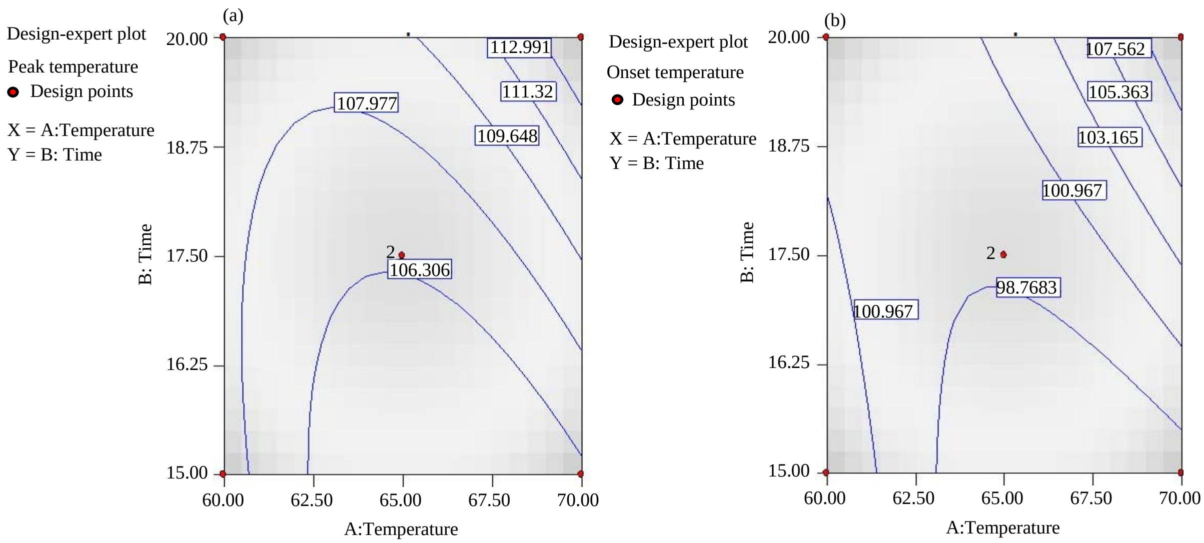

Fig. 4(a-b): Contour response surface plot for the effects of oven temperature (°C) and drying time (h) on (a): Peak temperature and (b): Onset temperature of cassava (UVLNR 0005) flour

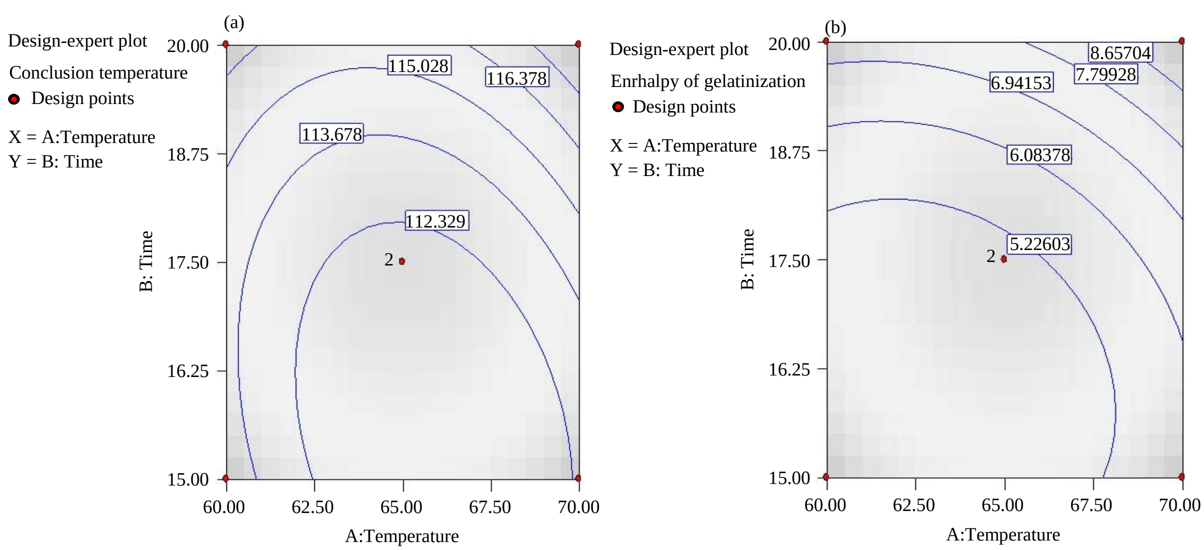

Fig. 5(a-b): Contour response surface plot for the effects of oven temperature (°C) and drying time (h) on (a): Conclusion temperature and (b): Enthalpy of gelatinization of cassava (UVLNR 0005) flour

Table 7: Comparison of gelatinization temperatures of the present study with previous studies

Method	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (j g^{-1})	Reference
DSC	50.7-57.7	54.7-61.3	59.8-67.2	7.19-9.20	Asaoka *et al.*[22]
DSC	53.3-55.8	58.2-59.5	64.2-66.2	7.11-8.70	Asaoka *et al.*[23]
DSC	65.4-69.4	69.2-73.2	74.9-78.5	2.7-3.4	Moorthy *et al.*[24]
DSC	62.4	69.3	84.1	4.8	Perez *et al.*[25]
DSC	93.68-114.21	100.35-118.49	108.73-123.51	3.74-11.54	Present study

16.48 h drying time with a desirability of 0.78. The optimum values of L*, a*, b*, WI, chroma, Hue, T_o, T_p, T_c and ΔH at the optimized drying conditions were 91.30, -0.08, 9.23, 87.27, 9.22, 90.39°, 98.22°C, 105.65°C, 111.18°C and 4.64 j g^{-1}, respectively.

Color of cassava (UVLNR 0005) flour: It is an established fact that consumer's preference of the physical quality of various agricultural products including color is influenced by drying operations[26,27]. Upon drying at varying drying conditions, the color characteristics L*, a*, b*, hue, chroma and whiteness index (WI) of cassava flour samples varied with drying temperature and time. These variations can be attributed to the degradation of color inducing compound due to heat and oxidation during drying[28,29,17,18].

The general and acceptable color change of the flour samples used in this study was determined in terms of whiteness index and lightness of the samples. This is due to the fact that the characteristic and acceptable color for cassava flour is white. WI and lightness color properties therefore shows the extent of whiteness of agricultural products and indicates the level of discoloration during processing[30,31]. These two color parameters usually correspond to consumer preference for food products such as starch or flour with regards to purchase and consumption. The a* and b* values obtained for all the flour samples used in the study implies that samples were less red and yellow in color, hence justifying the relatively high whiteness and lightness values of the flour samples reported in the result of the study. Akintunde and Tunde-Akintunde[30] and Kyere[32] also reported low values of a* (-0.06-7.50) and b* (4.92-8.99) and high values of L*(52-80.02) for cassava starch and yam flour, respectively which correlate with the trend observed in this study. However, the slight variation in the values of L*, a* and b* reported by Akintunde and Tunde-Akintunde[30] and Kyere[32] against this study can be attributed to varietal difference and drying methods used.

Mathematical models expressing the relationship between L*, a*, b*, hue, chroma, WI and drying conditions (Table 4) shows that lack of fit test p-value and regression values (R^2) of the models were low and not significant. Non-significant lack of fit test and high regression values (R^2) are indication of good fitness of the models when applied[33]. The implication of the contour plots showing the variation of L*, a*, b* hue, chroma and WI angle with change in drying conditions for the flour is that processing cassava at the temperature range used in this study could help preserve the color of cassava flour, hence increasing its consumer acceptability, utilization and application in food systems.

Thermal properties of cassava (UVLNR 0005) flour: The high lack of fit test and regression values of the models (Table 6) obtained in this study suggests that the models can be used to describe the operational relationship between drying temperature, drying time and thermal properties. Similarly, the high values of T_o, T_p, T_c and ΔH obtained in this study can be attributed to structural differences, genetic constitution, environmental conditions, varietal differences and experimental protocols such as rate of heating, moisture level and sample preparation[34]. According to literature, gelatinization parameters of food materials can be influenced by the water content of the food product as well as the heating rate of the DSC, as low water content has been reported to bring about peak multiplicity, peak broadening and increased gelatinization temperature[34,35,5]. Water content also impacts plasticizing action which results in an increase in ΔH values[36]. Higher gelatinization temperatures as observed in the present study compared to other studies (Table 7) can also be attributed to the presence of long-chain double helical crystallites of amylose responsible for elongation of starch granules in the flour[37-39]. The values of heat of enthalpy observed in this study compares favorably with values reported by Asaoka *et al.*[22], Asaoka *et al.*[23], Da Cruz Francisco *et al.*[38] and Rolland-Sabate *et al.*[40] for different cassava varieties.

Optimization of drying conditions, color and thermal properties of (UVLNR 0005) cassava flour: The result of optimization of the drying conditions of (UVLNR 0005) cassava obtained in this study implies that drying cassava (UVLNR 0005) at the optimum drying conditions will preserve the color of cassava flour by minimizing discoloration such as yellowness, redness thereby maximizing lightness and WI. It will also boost energy management by minimizing T_o, T_p, T_c and ΔH. These results are useful indices needed for developing value-added cassava product for feed and human as well as for the global food ingredient industry.

CONCLUSION

This study investigated the optimization of color and thermal properties of cassava (UVLNR 0005) flour using response surface methodology. The drying conditions of 65.34°C drying temperature, 16.48 h drying time were found optimum for cassava flour quality in terms of color and thermal properties at a desirability of 0.78. The study has shown that response surface approach was effective in investigating the color and thermal properties of (UVLNR 0005) cassava flour.

SIGNIFICANCE STATEMENT

This study discovers the drying temperature and time range that can be beneficial for color and thermal qualities of cassava flour. This study will help the researcher to uncover the optimum drying temperature and time for cassava processing and also develop models that can predict color and thermal properties of cassava that many researchers were not able to explore and therefore lacking in literature. Thus, a new theory on the optimization of color and thermal properties may be arrived at for the benefit of the cassava processing industry.

ACKNOWLEDGMENT

The authors acknowledge the University of Venda, South Africa for financial support under the Research grant number PR07.

REFERENCES

1. Garcia-Segovia, P., A.M. Urbano-Ramos, S. Fiszman and J. Martinez-Monzo, 2016. Effects of processing conditions on the quality of vacuum fried cassava chips (*Manihot esculenta* Crantz). LWT-Food Sci. Technol., 69: 515-521.
2. FAO., 2016. Food outlook: Biennial report on global food markets. Food and Agriculture Organization of the United Nations, Rome, Italy.
3. Westby, A., 2002. Cassava Utilization, Storage and Small-Scale Processing. In: Cassava: Biology, Production and Utilization, Hillocks, R.J., J.M. Thresh and A. Bellotti (Eds.). CABI, Wallingford, UK., ISBN-13: 9780851998831, pp: 281-300.
4. Olomo, V. and O. Ajibola, 2003. Processing factors affecting the yield and physicochemical properties of starch from cassava chips and flour. Starch, 55: 476-481.
5. Zhu, F., 2015. Composition, structure, physicochemical properties and modifications of cassava starch. Carbohydr. Polym., 122: 456-480.
6. Brimer, L., 2015. Cassava Production and Processing and Impact on Biological Compounds. In: Processing and Impact on Active Components in Food, Preedy, V. (Ed.). Chapter 10, Academic Press/Elsevier Inc., Oxford, UK., ISBN: 978-0-12-404699-3, pp: 81-87.
7. Suresh, R., M. Saravanakumar and P. Suganyadevi, 2011. Anthocyanins from Indian cassava (*Manihot esculenta* Crantz) and its antioxidant properties. Int. J. Pharm. Sci. Res., 2: 1819-1828.
8. Kim, T.K., 2016. Edible Medicinal and Non-Medicinal Plants, Volume 10: Modified Stems, Roots, Bulbs. Springer, Dordrecht, Netherland, ISBN-13: 9789401772761, pp: 308-353.
9. Lewicki, P.P. and E. Jakubczyk, 2004. Effect of hot air temperature on mechanical properties of dried apples. J. Food Eng., 64: 307-314.
10. Kudra, T., 2004. Energy aspects in drying. Drying Technol. Int. J., 22: 917-932.
11. Nesvadba, P., 2005. Thermal Properties of Unfrozen Foods. In: Engineering Properties of Foods, Rao, M.A., S.S.H. Rizvi and A.K. Datta (Eds.). 3rd Edn., Chapter 4, CRC Press/Taylor & Francis Group, USA., ISBN-13: 9780824753283, pp: 157-167.
12. Kouchakzadeh, A. and T. Tavakoli, 2009. The effect of moisture and temperature on thermophysical properties of Iranian pistachios. World Applied Sci. J., 7: 1552-1558.
13. Rahman, M.S., X.D. Chen and C.O. Perera, 1997. An improved thermal conductivity prediction model for fruits and vegetables as a function of temperature, water content and porosity. J. Food Eng., 31: 163-170.
14. Sweat, V.E., 1995. Thermal Properties of Foods. In: Engineering Properties of Foods, Rao, M.R. and S.S.H. Rizvi (Eds.). Marcel Decker Inc., New York, USA., pp: 99-138.
15. MacDougall, D.B., 2002. Colour Measurement of Food: Principles and Practice. In: Colour in Food: Improving Quality, MacDougall, D.B. (Ed.). Chapter 3, Woodhead Publishing, Cambridge, UK., ISBN-13: 9781855735903, pp: 33-63.
16. Francis, F.J., 1999. Colorants. Eagan Press, St. Paul, MN., USA., ISBN-13: 9781891127007, Pages: 144.
17. Omolola, A.O., A.I.O. Jideani, P. Kapila and V.A. Jideani, 2015. Optimization of microwave drying conditions of two banana varieties using response surface methodology. Food Sci. Technol., 35: 438-444.
18. Thuwapanichayanan, R., S. Prachayawarakorn, J. Kunwisawa and S. Soponronnarit, 2011. Determination of effective moisture diffusivity and assessment of quality attributes of banana slices during drying. LWT-Food Sci. Technol., 44: 1502-1510.
19. Rodriguez-Aguilera, R., J.C. Oliveira, J.C. Montanez and P.V. Mahajan, 2011. Effect of modified atmosphere packaging on quality factors and shelf-life of surface mould ripened cheese: Part I constant temperature. LWT-Food Sci. Technol., 44: 330-336.
20. Jha, S.N., 2010. Colour Measurements and Modeling. In: Nondestructive Evaluation of Food Quality: Theory and Practice, Jha, S.N. (Ed.). Chapter 2, Springer, New York, USA., ISBN-13: 9783642157967, pp: 17-40.
21. Anyasi, T.A., A.I. Jideani and G.R. Mchau, 2017. Effects of organic acid pretreatment on microstructure, functional and thermal properties of unripe banana flour. J. Food Meas. Charact., 11: 99-110.
22. Asaoka, M., J.M.V. Blanshard and J.E. Rickard, 1992. Effects of cultivar and growth season on the gelatinisation properties of cassava (*Manihot esculenta*) starch. J. Sci. Food Agric., 59: 53-58.
23. Asaoka, M., J.M.V. Blanshard and J.E. Rickard, 1993. The effect of pre-harvest pruning on the quality of cassava starch. Ann. Applied Biol., 122: 337-344.
24. Moorthy, S.N., J.E. Wenham and J. Blanshard, 1996. Effect of solvent extraction on the gelatinisation properties of flour and starch of five cassava varieties. J. Sci. Food Agric., 72: 329-336.

25. Perez, E.E., W.M. Breene and Y.A. Bahnassey, 1998. Variations in the gelatinization profiles of cassava, sagu and arrowroot native starches as measured with different thermal and mechanical methods. Starch, 50: 70-72.
26. Morrot, G., F. Brochet and D. Dubourdieu, 2001. The color of odors. Brain Lang., 79: 309-320.
27. Zellner, D.A. and P. Durlach, 2003. Effect of color on expected and experienced refreshment, intensity and liking of beverages. Am. J. Psychol., 116: 633-647.
28. Okaka, J.C. and A.N.C. Okaka, 2001. Food: Composition, Spoilage, Shelf life Extension. 1st Edn., OCJANKO Academic Publishers, Enugu, ISBN: 978-266655-17-7, Pages: 284.
29. Jimoh, K.O., T.O. Olurin and J.O. Aina, 2009. Effect of drying methods on the rheological characteristics and colour of yam flours. Afr. J. Biotechnol., 8: 2325-2328.
30. Akintunde, B.O. and T.Y. Tunde-Akintunde, 2013. Effect of drying method and variety on quality of cassava starch extracts. Afr. J. Food Agric. Nutr. Dev., 13: 8351-8367.
31. Anyasi, T.A., A.I.O. Jideani and G.R.A. Mchau, 2015. Effect of organic acid pretreatment on some physical, functional and antioxidant properties of flour obtained from three unripe banana cultivars. Food Chem., 172: 515-522.
32. Kyere, G., 2015. The effect of various drying methods on drying characteristics, sensory and nutritional qualities of yam. Master's Thesis, Department of Food Science, Kwame Nkrumah University of Science and Technology, Ghana.
33. Akinoso, R. and J.A. Adeyanju, 2012. Optimization of edible oil extraction from ofada rice bran using response surface methodology. Food Bioprocess Technol., 5: 1372-1378.
34. Izydorczyk, M.S. and C.G. Biliaderis, 1995. Cereal arabinoxylans: Advances in structure and physicochemical properties. Carbohydr. Polym., 28: 33-48.
35. Garcia, V., P. Colonna, D. Lourdin, A. Buleon, H. Bizot and M. Ollivon, 1996. Thermal transitions of cassava starch at intermediate water contents. J. Thermal Anal. Calorimetry, 47: 1213-1228.
36. Mahadevamma, S., K.V.H. Prashanth and R.N. Tharanathan, 2003. Resistant starch derived from processed legumes-purification and structural characterization. Carbohydr. Polym., 54: 215-219.
37. Jiang, H., H.T. Horner, T.M. Pepper, M. Blanco, M. Campbell and J.L. Jane, 2010. Formation of elongated starch granules in high-amylose maize. Carbohydr. Polym., 80: 534-539.
38. Da Cruz Francisco, J., J. Silverio, A.C. Eliasson and K. Larsson, 1996. A comparative study of gelatinization of cassava and potato starch in an aqueous lipid phase (L2) compared to water. Food Hydrocolloids, 10: 317-322.
39. Ma, Z. and J.I. Boye, 2017. Research advances on structural characterization of resistant starch and its structure-physiological function relationship: A review. Crit. Rev. Food Sci. Nutr., (In Press). 10.1080/10408398.2016.1230537.
40. Rolland-Sabate, A., T. Sanchez, A. Buleon, P. Colonna and H. Ceballos *et al*., 2013. Molecular and supra-molecular structure of waxy starches developed from cassava (*Manihot esculenta* Crantz). Carbohydr. Polym., 92: 1451-1462.