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Dehydration of Arvi Using Convective Hot air Tray Drying

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Abstract:

The post-harvest losses of about 90% are recorded for colocsaia esculenta (arvi). Thus dehydration of arvi was studied by convective hot air tray drying, using central composite factorial design (3 factors - 5 levels), to reduce the water activity. Response surface methodology (RSM) was the tool to analyze and predict the optimum conditions of convective tray drying. The 3 factor design was aimed to optimized combinations of drying temperature (ºC; A), degree of recirculation (B) and sample thickness (mm; C) which lead to the best results for the responses average drying rate, final moisture content, rehydration ratio and color difference. The optimum drying conditions was drying temperature of 52ºC, degree of recirculation at 3 and sample thickness of 7mm. Validation experiment verifies the second order polynomial model and concludes it to be acceptable.

Keywords: Hot air tray drying; Response surface methodology; Arvi (*Colocasia esculenta*)

Practical Application: Colocasia esculenta commonly known as arvi is highly perishable tuber. It can be dried using this optimized tray drying conditions for temperature, air recirculation ratio inside the dryer and slice thickness. By dehydration one can reduce the bulk for storage with sound quality for the year long use in all types of preparations and also this will lead in minimizing the postharvest losses.

1. Introduction

Arvi (*Colocasia esculenta (L.) Schott*) is a major tuber crop of the tropical and subtropical regions of the world. The tubers are very susceptible to the postharvest rot, leading to large losses. Tubers are known to start rotting as early as two weeks of harvesting. Passam (1982) recorded the post-harvest losses of about 90% during six months of storage [1]. This factor has been suggested by Minagri (1999) as a major contributing factor to the drop in the production of *C. esculenta* [2]. There are various literature on taro flour production [3-4].

This research work aimed at producing flour from arvi to reduce the moisture content to a level which allows safe storage over an extended period. It can serve as starting ingredient for the preparation of various foods which could greatly contribute in resolving the food insecurity problem posed by the postharvest storage problems.

Drying is the most primitive and economical method for processing and preserving of perishable food items. The

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activities of water, microbes as well as enzymes are checked either by natural drying, shade drying or by dehydration (hot air drying) [5]. Also optimization is an essential tool for the efficient operation of processing systems and unit processes yielding a highly acceptable product. The fractional factorial experimental designs of response surface methodology (RSM) approach is a statistical technique mostly used for the optimization experiments [6-10].

In this paper, fresh Arvi (*Colocasia esculenta*) slices were dehydrated using three variables parameters: temperature, air recirculation ratio and slice thickness. The responses variables tested were: average drying rate, final moisture content, rehydration ratio and recirculation ratio. 3 factors - 5 levels fractional factorial design with 20 runs was used as the experimental design.

Later, analysis of variance (ANOVA) was performed and with the second order polynomial (SOP) models response surface and contour plots were generated. Separate validation experiments were conducted at optimum conditions to verify predictions and adequacy of the SOP models.

2. Materials and methods

2.1 Sample preparation

Colocasia esculenta, locally known as arvi was purchased from a fixed vendor in the local market of Mumbai. The tuber was washed thoroughly under running tap water to remove all the dirt. Than it was peeled using the normal kitchen peeler. The peeled arvi was cut into the slices of fixed width using the stainless steel slicer having the provision of adjusting the slice thickness. The slices thus were evenly placed on the tray, before putting them into the dryer.

2.2 Drying apparatus

An experimental hot air dryer, manufactured by Varaj Pvt. Ltd., Pune was used for the study. It essentially consists of three basic units: a heating section, a blower for the provision of air and drying chamber. The construction of dryer is shown in **Error! Reference source not found.**. It is a cross flow laboratory dryer with automated control of temperature, time and air recirculation.

Before each experimental run, the dryer was allowed to run with dummy sample for 1 h to achieve the steady state conditions. The sample tray was then replaced quickly at the start of the drying experiment. The weight loss for first three hours was determined using a laboratory weighing scale place near the dryer. Moisture content of the sample was determined by Moisture meter (M3A; Advance Instrument Company, India).

2.3 Experimental design

To evaluate the effect of three parameters, a central composite factorial experimental design of $2^3 = 8$ plus $2 \times 3 = 6$ start points ($\alpha = 1.682$) and six replicates at the central point for accounting the experimental error, resulting in 20 experiments was used. **Error! Reference source not found.** shows the experimental design for five level-three parameters: temperature (A), degree of recirculation (B) and thickness (C). The decoded values for the independent variables are given in **Error! Reference source not found.**.

The degree of recirculation was adjusted

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by a specific control of the equipment which allows hot air to recirculate for particular time (t_R) and then pump out the air from the drying chamber and vacuum was formed for a time t_c and again fresh air was supplied. The degree of recirculation was calculated as,

$$B = \frac{t_R}{t_C} \quad (1)$$

The rehydration ratio (RR) was measured as the total mass of rehydrated sample per unit dry weight after soaking 2 g of dried sample in 100 ml boiling water for 30 min and determining the weight gain.

The Hunter Lab color parameters L*, a*, b* were determined using Lab Scan XE (LX17375) spectro-colourimeter (USA). The Hunter Lab coordinates shows the degree of brightness (L), the degree of redness (+a) or greenness (-a), and the degree of yellowness (+b) or blueness (-b), respectively. Parameters for each sample were measured in triplicates to determine the average values. The total color difference (ΔE) was defined using the Minotta equation as follows,

$$\Delta L = L - L_0,\ \Delta a = a - a_0,\ \Delta b = b - b_0 \quad (2)$$

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (3)$$

Where L, a, b are the measured values of dried samples and L_0, a_0, b_0 are the values of fresh arvi.

The variables were coded according to the equation 4,

$$x_i = \frac{X_i - X_{cp}}{\Delta X_i}, \quad i = 1, 2, 3, ..., k \quad (4)$$

Where, x_i is dimensionless value of an independent variable; X_i is real value of an independent variable; X_{cp} is real value of an independent variable at the center point; and ΔX_i is step change of real value of the variable i corresponding to a variation of a unit for the dimensionless value of the variable i. The quantitative data obtained from experiments as shown in Table 3 were fitted against second order polynomial equation described in Eq. (5).

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1} \sum_{j=i+1}^{k} \beta_{ij} X_i X_j \quad (5)$$

Where, Y is the predicted transform of response; β_0 a constant; β_i the linear coefficient; β_{ii} the squared coefficient; and β_{ij} the cross-product coefficient, k is number of factors.

2.4 Statistical analysis

The data on hot air drying was then analyzed using Design Expert Version 6.0.10. The second order polynomial coefficients were calculated to estimate the responses of the dependent variable. Response surface plots were also obtained using the same software. The model efficacy was analyzed by using ANOVA i.e. Analysis of Variance suitable for the experimental design used. After each response had analyzed, multiple response optimization was done by numerical tools provided by the Design Expert. Separate experiments were performed to verify the response models at the optimum drying conditions using the same drying apparatus.

The following response variables were

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investigated: average drying rate, final moisture, rehydration ratio and total color difference between dried and fresh arvi sample.

3. Results and discussion

The experimental design and data for response surface analysis of arvi dehydartion are shown in Table 3. The experiments were performed in random order and the relationship of the dependent variables such as average drying rate, final moisture content, rehydration ratio and total color difference, to the independent variables temperature, recirculation ratio and slice thickness was studied. Analysis of variance was performed to determine the lack-of-fit and the significance of the linear, quadratic and cross-product effects of independent variables on the quality attributes (Table 4). The analysis of lack-of-fit was performed on all the dependent variables, and insignificant results were obtained. In the case of the models, high coefficients of determination values ranging from 0.88 to 0.97 (Table 5) were obtained for all these response surface models, i.e. average drying rate, final moisture content, rehydration ratio and total color difference, indicating that high proportion of variability were explained by the data. The response surface models developed were proved to be adequate. An analysis of variance was conducted to assess the significant effects of each independent variable on the responses and which of the responses were significantly affected by the variation of treatment conditions and are shown as in Table 6.

Table 7 shows the regression coefficients for the second order polynomial models of average drying rate, final moisture content, rehydration ratio and total color difference used for predicting the values at optimum conditions (Table 8). The responses of average drying rate, final moisture content and total color difference were found to be affected significantly by independent variables drying temperature and slice thickness; whereas rehydration ratio was affected by all the three independent variables. Response surface plots were generated using significant parameters for each response as shown in Fig 2-5 and parity plots of Predicted versus actual values are as in Fig 6-9.

Fig. 10 shows the rate of drying as a function of time at the optimum drying conditions and confirms that the sample moisture content to be 0.5% after 1.6 hours of drying. It can also be concluded from fig. 11 that initially when moisture content is high the rate of drying is fast and latter due to case hardening the rate of drying is slow.

4. Conclusions

The statistical method, Response Surface Methodology (RSM) was successfully employed for optimizing the dehydration process of arvi. The process parameters *viz.* drying temperature (A), degree of recirculation (B) and sample thickness (C) resulted in the superior product quality. The prediction equations derived for optimization of average drying rate, final moisture content (Xf), rehydration ratio (RR) and total color difference (dE) using RSM were found to be satisfactory. Optimum operating conditions for the hot air tray drying of colocasia were 52°C temperature, 3mm sample thickness and 7 degree of recirculation.

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Table 1: Five level Central Composite design in coded values

A	B	C	Design points	Number
± 1	± 1	± 1	two-level factorial design points	$2^3 = 8$
± 1.682	0	0	Star points	2
0	± 1.682	0	Star points	2
0	0	± 1.682	Star points	2
0	0	0	Center point	1×6 = 6
Total				20

Table 2: Independent variables and their Coded values

Independent variables	Symbol	Coded levels				
		-1.68	**-1**	**0**	**1**	**1.68**
Temperature	A	48.24	53	60	67	71.76
Degree of recirculation	B	1.64	3	5	7	8.36
Thickness	C	4.96	7	10	13	15.04

Table 3: The experimental design and data for the response surface analysis of Arvi

		Factor 1	Factor 2	Factor 3	Response 1	Response 2	Response 3	Response 4
Std	**Run**	**A:Temperature**	**B:Recirculation ratio**	**C:Thickness**	**drying rate**	**Xf**	**RR**	**dE**
12	1	60	8.36	10	1.25	0.06	8.69	2.00
15	2	60	5	10	1.40	0.076	10.49	2.89
16	3	60	5	10	1.49	0.06	10.54	2.66
1	4	53	3	7	1.17	0.07	8.39	1.22
8	5	67	7	13	1.39	0.05	8	3.97
18	6	60	5	10	1.47	0.07	10.5	2.33
14	7	60	5	15.05	0.58	0.09	9.05	2.98
17	8	60	5	10	1.48	0.08	10.38	2.68
7	9	53	7	13	0.70	0.08	10.02	1.80
6	10	67	3	13	1.25	0.05	8.14	3.81
13	11	60	5	4.96	1.63	0.06	10.42	2.02
2	12	67	3	7	1.72	0.03	8.79	3.11
4	13	67	7	7	1.67	0.048	8.68	3.26
3	14	53	7	7	0.94	0.06	11.32	1.20
9	15	48.23	5	10	0.47	0.10	9.13	0.97
5	16	53	3	13	0.63	0.08	8.61	1.87
10	17	71.77	5	10	1.86	0.03	7.21	4.89
20	18	60	5	10	1.44	0.08	10.49	2.15
11	19	60	1.64	10	1.27	0.04	8.76	2.98

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19	20	60	5	10	1.48	0.06	10.54	2.18

Table 4: The ANOVA table for four response variables

Source		Sum of Squares			
	DF[a]	Average Drying rate	Final moisture content	RR	ΔE
Mean	1	32.01	0.083	1770.02	129.82
Linear	3	2.58	5.123E-003	7.42	17.20
2FI	3	0.039	1.968E-004	2.94	0.023
Quadratic	3	0.35	1.036E-003	12.46	0.28
Cubic	4	0.077	4.187E-004	1.25	0.43
Residual	6	6.963E-003	4.840E-004	0.16	0.51
Lack of Fit	5	*0.079*	*5.734E-004*	*1.40*	*0.48*
Pure Error	5	*5.148E-003*	*3.293E-004*	0.017	0.46

a DF: degree of freedom

Table 5: The ANOVA for Response Surface Models

Source	Average Drying rate			Final moisture content			RR			ΔE		
	Mean Square	F Value	Prob > F	Mean Square	F Value	Prob > F	Mean Square	F Value	Prob > F	Mean Square	F Value	Prob > F
Model	0.33	39.43	< 0.0001	7.062 E-004	7.82	0.0017	2.54	17.87	< 0.0001	1.94	20.79	< 0.0001
β_A	1.79	213.44	< 0.0001	4.182 E-003	46.33	< 0.0001	4.64	32.69	0.0002	15.70	167.89	< 0.0001
β_B	1.249 E-003	0.15	0.7074	9.494 E-005	1.05	0.3293	1.16	8.14	0.0171	0.15	1.62	0.2323
β_C	0.79	94.45	< 0.0001	8.462 E-004	9.37	0.0120	1.63	11.47	0.0069	1.35	14.38	0.0035
β_{AA}	0.14	17.17	0.0020	1.677 E-004	1.86	0.2028	8.65	60.98	< 0.0001	0.25	2.68	0.1330
β_{BB}	0.063	7.48	0.0210	8.594 E-004	9.52	0.0115	4.83	34.01	0.0002	7.202 E-003	0.077	0.7870
β_{CC}	0.21	25.04	0.0005	2.259 E-005	0.25	0.6277	0.71	4.99	0.0496	5.182 E-003	0.055	0.8186
β_{AB}	8.591 E-003	1.03	0.3350	1.604 E-004	1.78	0.2121	2.63	18.56	0.0015	0.020	0.21	0.6550
β_{AC}	2.070 E-004	0.025	0.8782	3.617 E-005	0.40	0.5409	7.812 E-003	0.055	0.8192	3.038 E-003	0.032	0.8606

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β_{BC}	*0.030*	*3.56*	*0.08 84*	*2.464 E-007*	*2.730 E-003*	*0.95 94*	*0.30*	*2.12*	*0.17 64*	*2.083 E-004*	*2.227 E-003*	*0.96 33*
R^2	0.9726			0.8756			0.9415			0.9493		

Table 6: The ANOVA table showing the significance of the independent variables on each of the response variables

Source	DF[a]	Sum of Squares			
		Average drying rate	Final moisture content	RR	ΔE
Drying temperature	1	*1.79*	*4.182E-003*	*4.64*	*15.70*
Degree of Recirculation	1	*1.249E-003*	*9.494E-005*	*1.16*	*0.15*
Thickness	1	*0.79*	*8.462E-004*	*1.63*	*1.35*

a DF: degree of freedom

Table 7: The regression coefficients for the second order polynomial models for each of the response Variables

Coefficient[a] (βk)	Average drying rate	Xf	RR	dE
βk0	+1.46	+0.071	+10.48	+2.49
βk1	+0.36	-0.017	-0.58	+1.07
βk2	-9.565E-003	+2.637E-003	+0.29	-0.11
βk3	-0.24	+7.872E-003	-0.35	+0.31
βk11	-0.100	-3.411E-003	-0.77	+0.13
βk22	-0.066	-7.722E-003	-0.58	-0.022
βk33	-0.12	+1.252E-003	-0.22	-0.019
βk12	+0.033	+4.478E-003	-0.57	+0.050
βk13	+5.086E-003	-2.126E-003	-0.031	+0.019
βk23	+0.061	-1.755E-004	-0.19	-5.102E-003

a These are coefficients of Eq. (5), and the numbers 1–3 in the subscripts refer to temperature, air recirculation ratio and slice thickness, respectively.

Table 8: Predicted and observed values for the response variables at optimum conditions

	Temperature	Recirculation ratio	Thickness	average drying rate	Xf	RR	ΔE
Predicted	52.00	3.00	7.00	1.09	0.07	8.51	1.26
Actual				---	0.10	9.12 ± 0.17	2.33

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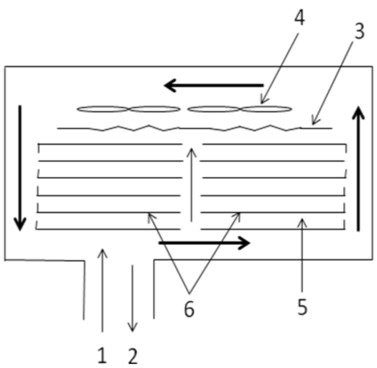
Fig. 1. Schematic model of Tray dryer



1: Air Inlet 2: Air exhaust 3: Heater 4: Blower 5: Drying chamber fitted with trays 6: Trays 7: Exhaust air recycles passage

Fig. 2. Response surface plot for drying rate

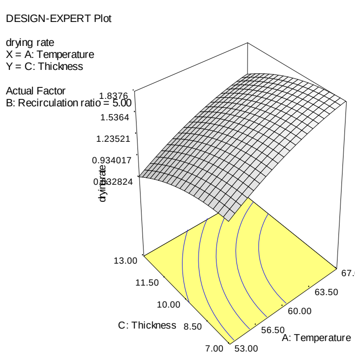


Fig. 3. Response surface plot for final moisture content (Xf)

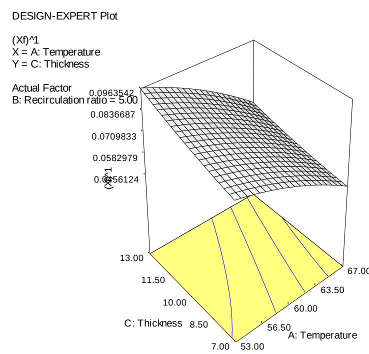


Fig. 4. Response surface plot for rehydration ratio (RR)

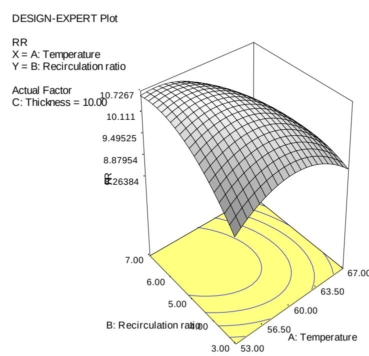


Fig. 5. Response surface plot for total color difference (ΔE)

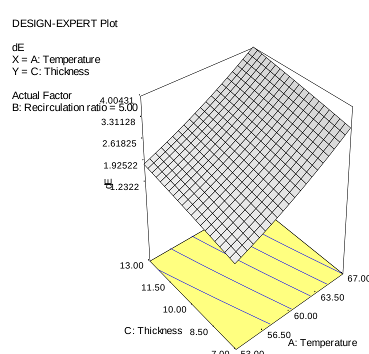


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Fig. 6. Parity plot for drying rate

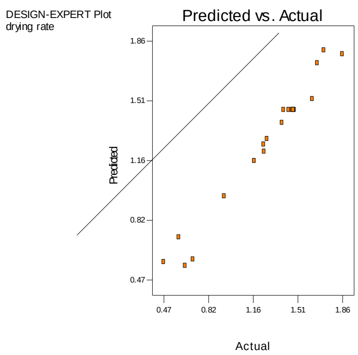


Fig. 7. Parity plot for final moisture content (Xf)

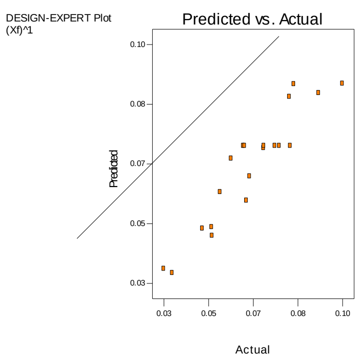


Fig. 8. Parity plot for rehydration ratio (RR)

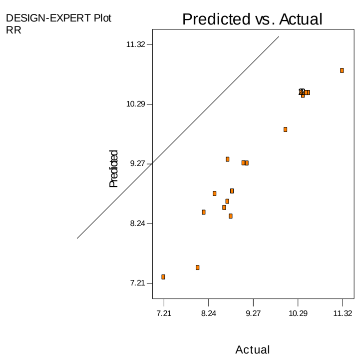


Fig. 9. Parity plot for total color difference (ΔE)

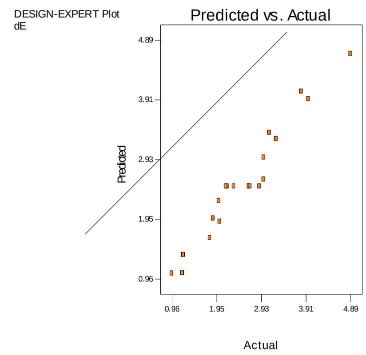


Fig. 10. Moisture profile of Dioscorea at optimum drying conditions
(A: 52°C, B: 3mm, C: 7)

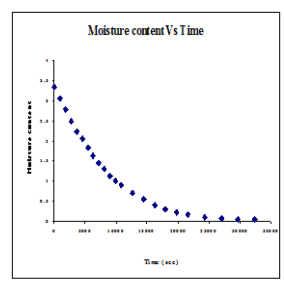
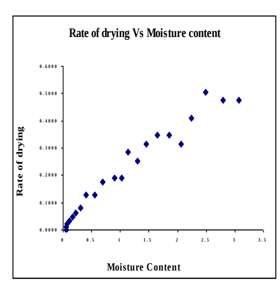


Fig. 11. Graph of Rate of drying Vs Moisture



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