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Influence of Drying Temperature on Drying Characteristics and Moisture Diffusivity of Custard Apple Pulp

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ABSTRACT

Custard apple is multi-nutritional fruit with uncountable benefits to human health as well as honoured with delicious test. The custard apple pulp scooped hygienically from the fruits was dried in a thin layer of 4 mm thickness, temperatures of 50, 55, 60 and 65°C and an air velocity of 2 m/s in a tray dryer. Dehydration characteristics were found in terms of moisture content, dry matter, moisture ratio, drying rate to determine moisture diffusivity and activation energy using standard methodologies. The result data revealed that the custard apple pulp drying process was in falling rate period only. There was a maximum 22.22% decrease in drying time from 60 to 65°C temperature increase while drying rate was recorded to varied from 0.00052 to 0.0008 g water per g dry matter per sec for the selected temperature range. Variation of moisture diffusivity was recorded from 3.20×10^{-9} m^2/s to 4.80×10^{-9} m^2/s, and activation energy for complete drying experiment was noted as 29.436 kJ/mol. The above result show that as the drying temperature increased the effective moisture diffusivity also increased and linear relationship obtained between reciprocal of absolute temperature and logarithm of diffusivity.

Keywords Drying characteristics, Custard apple, Kinetics, Diffusivity, Shelf life, Moisture content.

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INTRODUCTION

Custard apple (*Annona squamosa* L.) commonly known as *sitaphal*, is one of the most important multipurpose plant species of Indian sub-continent and known by several vernacular names such as sugar apple, sweet sop, *sitaphal* and *sharifa* in different part of the country (Khodifad and Kumar 2019). The fruit is rich in free sugars, minerals and vitamins and contains about fifty-three compounds including limonene, alpha-pinene, beta-pinene, germacrene D and bornyl acetate (Pino 1999). Custard apple has medicinal and industrial applications due to properties like anti-oxidant, anti-diabetic, hepato-protective, cyto-toxic, geno-toxic, anti-tumor and anti-lice agent (Sharma and Panesar 2018, Soni *et al.* 2021). Custard apple pulp is being used for production of soft drinks, ice-creams and certain food products. Fruits have short shelf-life and spoiled because of non-availability of proper post-harvest technology (Revathi *et al*. 2022). Dehydrated custard apple powder will inhibit the quality deterioration, browning of pulp and fruit, microbial contamination and increase in shelf life. Spray drying of custard apple pulp was studied by Shashirekha *et al.* (2008), Shrivastava *et al.* (2021), and reported that spray dried powder was free of bitterness, discoloration and off-flavor. Bharadiya and Memon (2010) dried custard apple pulp in freeze dryer. Custard apple pulp freeze dried at (-) 40°C temperature and 20% maltodextrin was reported optimum. Patil (2011) reported that 20% level of maltodextrin and 1% tri-calcium phosphate is optimum for maximum yield of custard apple powder by spray drying. Kumar *et al.* (2015) modeled drying kinetics of custard apple pulp, Drying was carried out at 60–80°C temperatures and thin layer drying models were studied. Moisture diffusivity were ranged from 2.13×10^{-05} to 3.45×10^{-05} m^2/s and activation energy was reported 31.92 kJ/mol and reported optimum temperature reported for tray drying of custard apple pulp was 60°C. Vaccum storage of freeze-dried custard apple powder in poly-ethelene bags was reported optimum by Sondarva *et al*. (2016). Natural circulation solar drying of custard apple pulp was performed by Ojha *et al.* (2018) and reported that whole drying took placed in falling rate only in 29 hrs. Dehydration of custard apple pulp in thin layer foam mats was done by Khodifad and Kumar (2019) and found that 2 mm pulp thickness took drying time 100 to 140 min at 60–75°C temperatures. Only limited research work has been reported related to custard apple dehydration, no literature related to effect of drying parameters on drying characteristics and moisture diffusivity of custard apple powder was available.

MATERIALS AND METHODS

A laboratory model TD 5220 convective tray dryer (Khera Scientific, India) was used for conducting experimental trials on drying of custard apple pulp.100 g custard apple pulp was spread on the preweighed drying trays. These trays were kept in drying chamber. Loss in weight of custard apple pulp was recorded in 5 min interval for first half an hour, at 10 minute intervals for next half an hour, 15 minutes for next one hour and after it at 30 minute intervals for next 3 hrs and finally at one hour intervals until the sample attains constant weight (Kumar *et al*. 2015, Shrivastava *et al.* 2021). Drying experiment was replicated thrice and average value of drying parameters was recorded. As the initial moisture content of samples was known, the moisture content and amount of water removed was determined using mass balance equation.

Drying characteristics

The observed drying data i.e., change of weight of the sample with time during convective drying of custard apple pulp were used to evaluate the moisture content, drying rates and the moisture ratio, as discussed hereunder.

Moisture content

Moisture content of custard apple pulp was found by oven drying method (Ranganna 2002) and was expressed as g water/g dry matter using Eq. 1.

$$\text{Moisture content} = \frac{M_w}{M_d} \quad \ldots (1)$$

Where,

M_w - Weight of water in sample, g
M_d - Weight of dry matter in sample, g

Moisture ratio

The moisture content level at which drying rate ceases and drying experiment cannot be processed further was considered as equilibrium moisture content of custard apple pulp. The moisture ratio (MR) at each moisture content level was calculated by the Eq. 2 (Mudgal and Pande 2007).

$$MR = \frac{(M - M_e)}{(M_0 - M_e)} \quad \ldots (2)$$

Where,

MR - Moisture ratio
M - Moisture content at any time (db)
Mo - Initial moisture content (db)
Me - Equilibrium moisture content (db)

Drying rate

The moisture content data recorded during experiments was analyzed to determine the moisture lost from the dehydrated samples of custard apple pulp in a given period. The drying rate of sample was calculated using Eq. 3 (Kohli *et al.* 2018).

$$R = \frac{WML}{(\text{Time interval} \times DM)} \quad \ldots(3)$$

Where,

R -Drying rate at time t, g/s

WML -Weight of moisture loss, g

DM -Dry matter, g

Estimation of moisture diffusivity

Diffusivity is defined as the moisture flow, in falling rate period water transported from interior to surface of custard apple pulp. Fick's diffusion equation was used to describe falling rate period, Crank (Crank 1975) suggested solution for Fick's diffusion model for different regular shapes viz., rectangular, cylindrical and spherical. Assuming uniform initial moisture distribution with negligible external resistance the form of Eq. 4 can be applicable for custard apple pulp particles with slab geometry.

$$MR_i = \frac{8}{\pi} \sum_{(n=0)}^{\infty} \frac{1}{(2n+1)^2} e - \frac{(2n+1)^2 \pi^2 D_{eff} t}{4L_0^2} \quad \ldots(4)$$

Where,

D_{eff} - Effective moisture diffusivity, m^2/s

L_0 - Half thickness of slab, m

T - Drying time, s

The Eq. 4 was further simplified for longer drying period (Tutuncu and Labuza 1996) and can be written in a logarithmic form as Eq. 5

$$\text{In } MR = \ln \frac{8}{\pi^2} - \frac{\pi^2 D_{eff}}{4L_0^2} \quad \ldots.(5)$$

Diffusivities for each drying experiment was determined by plotting graph between *ln MR* against drying time. The slope of line (m from; y = mx + c) obtained from the graph using Microsoft excel soft ware and multiplied with $\left(\frac{4L_0^2}{\pi^2}\right)$. Result was termed as diffusivity.

Calculation of activation energy

The temperature dependence of the diffusivity was described by an Arrhenius-type relationship (Akgun and Doymaz 2005, Kohli *et al*. 2018) as Eq. 6.

$$D_{eff} = D_0 \, e \left(-Ea \frac{Ea}{RT}\right) \quad \ldots(6)$$

Where,

D_{eff} -Effective moisture diffusivity, m^2/s

D_0 -Pre-exponential factor, m^2/s

E_a -Activation energy, kJ/mol

R -Universal gas constant kJ/mol K,

T -Absolute temperature, K

Activation energy is the minimum energy required to initiate the moisture diffusion process. Its knowledge is necessary for designing and modelling the mass transfer processes such as dehydration and moisture adsorption during storage of any food product. During the drying process and their dependence on factors such as the air temperature and effective moisture diffusivity activation energy for the drying of custard apple pulp of 4 mm thickness at 2 m/s air velocity at temperatures of 50, 55, 60 and 65°C was calculated with help of slope of line obtained by graph between natural logarithmic of effective moisture diffusivity and inverse of absolute temperature as per Eq. 7.

$$\ln D_{eff} = \ln D_0 - \frac{E_a}{RT} \quad \ldots.(7)$$

Above equation is in the form of an inclined line between ln D_{eff} and 1/T with slope (E_a/R) and intercept

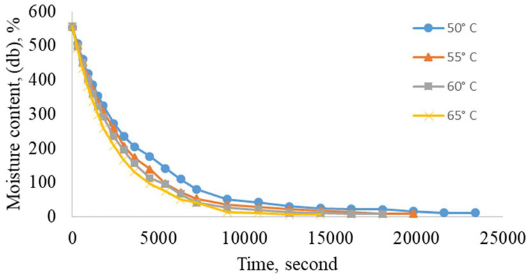

Fig. 1. Variation in moisture content of custard apple pulp with time at various temperatures.

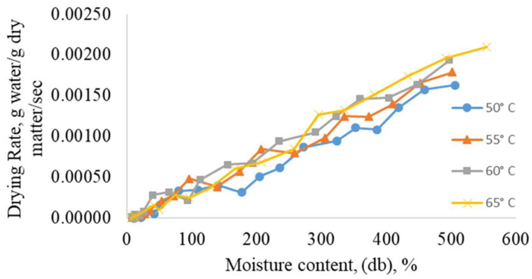

Fig. 2. Variation in drying rate of custard apple pulp with moisture content at various temperatures.

(ln D_0) by using the Microsoft excel software the slope of line was calculated and the value of activation energy was calculated by multiply the slope of above equation with universal gas constant (R). The negative sign of the slope indicates there will be decrease in the log of effective moisture diffusivity with increase of inverse of temperature or vice-versa.

RESULTS AND DISCUSSION

Drying characteristics of custard apple pulp

The dehydration characteristics of convective drying process was described in terms of moisture content versus drying time, moisture content versus drying rate, logarithmic moisture ratio versus drying time for (effective moisture diffusivity) and logarithmic diffusivity versus inverse of temperature for (activation energy) of custard apple pulp at selected temperature.

The custard apple pulp was dried in a thin layer of 4 mm thickness, at temperatures of 50, 55, 60 and 65°C at air velocity of 2 m/s in a tray dryer. The initial moisture content of custard apple pulp was found to be 5.55 g water/g dry matter and final moisture content was found to be as 0.11, 0.09, 0.08 and 0.07 g water/g dry matter for 50, 55, 60 and 65 °C respectively. In the drying process, the moisture content of custard apple pulp was found to be reducing with time at all the temperatures (Fig. 1).

The drying time taken for drying of custard apple pulp with 2 m/s air velocity were 21600, 18000, 16200 and 12600 s at 50, 55, 60 and 65 °C air temperatures, respectively. The average drying time was decreased 16.67, 10.00 and 22.22 for per 5°C temperature increase. It was also found that greater drying effect of 22% reduction in drying time was observed for 60 to 65°C temperature increase. Furthermore, it was recorded that drying time at 65°C was nearly two third of drying time taken for dehydration of custard apple pulp at 50°C. It was inferred from Fig. 1 that the moisture content reduced faster initially, further with increase in time and became very slow in the last phase of drying operation. This may be due to complete exposure of custard apple pulp to the drying environment and high moisture migration in less thickness. As the vapour pressure difference between pulp layer and the drying air inside the dryer was high so the air picked moisture from the pulp fast in initial stage of drying but as the time increased vapour pressure difference decreased which resulted slower drying process.

Similar results have been reported by Kumar *et al.* (2015) for tray drying of custard apple pulp and Shrivastava *et al.* (2021) for drying of foamed custard apple pulp. Drying at higher temperature provided more driving forces for heat transfer, which eventually related to mass transfer (Chantaro *et al.* 2008).

The drying rate for the pulp was estimated from the change in its moisture content in a known time period and expressed as g water evaporated per g dry matter per second. It was observed that drying rate of custard apple pulp was high at higher moisture content i. e., at the begining of drying process and it decreased as moisture content reduced. At the initial stage of drying, moisture content of custard apple pulp was high and more moisture was evaporated from the upper surface of custard apple pulp in further steps. As the drying process proceeded, the moisture on

Table 1. Effect of drying temperature on effective moisture diffusivity.

Sl. No.	Temperature °C	Effective moisture diffusivity (m^2/s)	Linear relationship	R^2 value
1	50	3.20×10^{-09}	y = -0.0002x - 0.3139	0.9607
2	55	3.20×10^{-09}	y = -0.0002x - 0.2948	0.9618
3	60	4.80×10^{-09}	y = -0.0003x - 0.2574	0.9655
4	65	4.80×10^{-09}	y = -0.0003x - 0.1667	0.9751

the surface decreased and hence drying rate reduced with moisture content as shown in Fig. 2. This trend was observed at other tempereture also the drying curves mostly displays a falling rate period only. It was observed that the maximum drying rate was almost double than the average drying rate at initial stage of drying.

The average drying rates for convective tray drying of custard apple pulp at 2 m/s air velocity with 50, 55, 60 and 65°C temperatures were 0.00052, 0.0006, 0.00066 and 0.0008 g water/g dry matter per sec, respectively. During the drying experiment and data were recorded, it was found that highest drying rate during the drying process was about thrice of the average drying time.

It can be inferred from Fig. 2 that drying of custard apple pulp occurred in falling rate period, except a short accelerating period at the begining. It can be due to fast moisture removal from thin surface of pulp. It can be observed that drying rates were significantly higher at higher temperature and moisture content while at lower values of moisture content dryng rates were very low towards end of drying. The main reason of lower drying rates at the end of process was lower moisture migration rate from the inner layer to surface at final stage of drying process.

Effective moisture diffusivity

The results indicated that internal mass transfer resistance controlled the drying time due to which falling rate drying period dominated the drying process. Effective moisture diffusivity (D_{eff}) at various drying temperatures were calculated using Eq. 6 and found to vary from 3.20×10^{-9} m^2/s to 4.80×10^{-9} m^2/s. Table 1 shows the effect of drying air temperature on diffusivity.

It was inferred from Fig. 3 and Table 1 that as the drying temperature increased the effective moisture diffusivity also increased. This could be because of increase in diffusion with the increase in sample temperature (Kohli *et al.* 2018).

Activation energy

Linear relationship obtained between reciprocal of absolute temperature and logarithm of diffusivity at selected temperatures viz. 50, 55, 60 and 65°C were described in Fig. 4. The activation energy was cal-

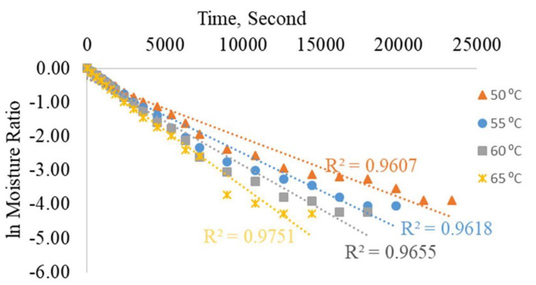

Fig. 3. Variation in moisture ratio with drying time at various drying temperature.

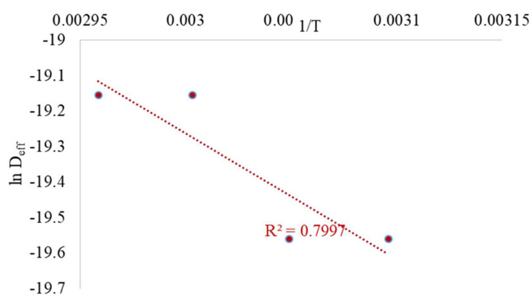

Fig. 4. Variation in effective moisture diffusivity with absolute temperature and 2 m/s velocity of drying air.

culated using Eq. 7. The value of activation energy for the convective tray drying experiment of custard apple pulp was found as 29.436 kJ/mol at an air velocity of 2 m/s.

CONCLUSION

The custard apple pulp was dried in thin layer of 4 mm even thickness at temperature of 50, 55, 60 and 65°C with air velocity of 2 m/s in a tray dryer. The initial moisture content of custard apple pulp was found to be 555% (db) and final moisture content was recorded as 11.45, 9.76, 7.99 and 7.60% (db) for 50, 55, 60 and 65 °C, respectively. The average drying time was decreased 16.67, 10.00 and 22.22% for per 5°C temperature increase. The average drying rates for convective tray drying of custard apple pulp at 2 m/s air velocity with 50, 55, 60 and 65°C temperatures were 0.00052, 0.0006, 0.00066 and 0.0008 g water/g dry matter/sec, respectively. Effective moisture diffusivity (D_{eff}) at 50, 55, 60 and 65°C drying temperatures was found to vary from 3.20×10^{-9} m^2/s to 4.80×10^{-9} m^2/s. The value of activation energy for the convective tray drying experiment of custard apple pulp was found as 29.436 kJ/mol.

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REFERENCES

Akgun NA, Doymaz I (2005) Modeling of olive cake thin-layer drying process. *J Food Engg* 68: 455—461.

Bharadiya NN, Memon KN (2010) Preparation of custard apple powder. A dissertation report submitted to the faculty of agricultural engineering and technology, CAET, JAU, Junagadh.

Chantaro P, Devahastin S, Chiewachan N (2008) Production of antioxidant high dietary fiber powder from carrot peels ! *LWT-Food Sci Tech* 41: 1987—1994.

Crank J (1975) Mathematics of Diffusion. Clarendon Press, oxford, UK.

Khodifad BC, Kumar N (2019) Foaming properties of custard apple pulp and mathematical modelling of foam mat drying. *J Food Sci Tech* DOI: https://doi.org/10.1007/s13197-019-04082-0.

Kohli D, Shahi NC, Kumar A (2018) Drying kinetics and activation energy of Asparagus root (*Asparagus racemosus* Wild.) for different methods of drying. *Curr Res Nutri Food Sci* 6: 191—202.

Kumar S, Kumar N, Seth N, Jethva KR (2015) A study on physical properties and drying characteristics of custard apple. National seminar on emerging trends in food quality and safety. At College of Food Processing Technology and Bio Energy, Anand Agricultural University, Anand, E-Souvenir Oct 15—16.

Mudgal VD, Pande VK (2007) Dehydration Characteristics of Cauliflower. *Int J Food Engg* 3. DOI: 10.2202/1556-3758.1278.

Ojha C, Jain S, Kothari S, Kaushik RA, Panwar NL (2018) Drying kinetics of custard apple pulp in natural circulation solar dryer. *Int J Chem Studies* 6: 939—942.

Patil TB (2011) Standardization of a pre-treatments for liquefaction of custard apple pulp for spray drying. MSc. thesis. Post Graduate Institute Mahatma Phule Krishi Vidyapeeth, Rahuri 413722, Maharashtra, India.

Pino JA (1999) Volatile constituents of custard apple (*Annona Atemoya*). *J Essential Oil Res* 11: 303—305.

Ranganna S (2002) In: Handbook of analysis and quality control for fruits and vegetable products. Tata McGraw Hill. New Delhi.

Revathi S, Jeyanthi J, Suganya R (2022) Phosphating process effluent treatment using activated carbon made from cocopod husk and custard apple seed. *Materials Today*: *Proceedings* 62(6): 4295—4302. https://doi.org/10.1016/j.matpr.2022.04.800.

Sharma HK, Panesar PS (2018) Processing and value addition of custard apple. In: Technologies in food processing. Apple Academic Press Inc, Waretown, USA, pp 265—288.

Shashirekha MN, Revathy B, Rao LJ, Vijayalakshmi MR, Rajarathnam S (2008) Influence of processing conditions on flavour compounds of custard apple (*Annona squamosa* L.). *Swiss Soc of Food Sci Tech LWT* 41: 236—243. https://doi.org/10.1016/j.lwt.2007.03.005.

Shrivastava A, Tripathi AD, Paul V, Rai DC (2021) Optimization of spray drying parameters for custard apple (*Annona squamosa* L.) pulp powder development using response surface methodology (RSM) with improved physicochem ical attributes and phytonutrients, LWT, 151:112091. https://doi.org/10.1016/j.lwt.2021.112091.

Sondarva KN, Cholera SP, Jayswal PS, Bharadiya NN (2016) Preparation of custard apple powder and its packaging for storage. *Agricult Res* 5: 88—97.

Soni N, Mudgal VD, Champawat PS (2021) Post-harvest processing of custard apple (*Annona Squamosa* L.) - a review. *J Postharvest Tech* 09: 96—102.

Tutuncu MA, Labuza TP (1996) Effect of geometry on the effective moisture transfer diffusion coefficient! *J Food Engg* 30: 433—447. DOI: 10.1016/S0260-8774(96)00028-3.