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Drying characteristic of chayote and its effect on rehydration and texture parameters

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Abstract
Chayote (*Sechium edule* sw.) is a common ingredient in ready-to-eat meals because it is high in carbohydrates and other health-promoting elements like salt and phosphorus, and it is low in fat, protein, and vitamin C. Due to the degeneration of vascular and parenchymal tissues brought on by the creation of vascular streaks, chayote has an extremely short shelf life. The current study was conducted to investigate the drying process of chayote slices in an effort to increase their shelf life. In a hot air dryer on a laboratory scale, the properties of hot air drying chayote slices were studied. Three air velocities of 1.0, 1.5, and 2.0 m/s, five air temperatures of 50, 60, 70, 80, and 90 °C, and three slice thicknesses of 5, 10, and 15 mm were used to conduct the thin-layer drying. Regression analysis was performed using the data to determine the associations between several physical transport parameters, such as the mass diffusivity coefficient, drying temperature, air velocity, and sample thickness, which characterize the relationships between the variables during the drying process. Chayote's effective diffusivity was explained by Fick's second law of diffusion.

Keywords: Tray drying, Moisture content, Moisture ratio, Drying Rate

Introduction

Chayote is a type of vegetable that is widely consumed, but the use of squash so far has been limited; it is only used as a vegetable. Chayote has immense potential to generate various products to increase consumption and utilization. Chayote flour is a novel substance that has the potential to become a substitute for traditional foods. A popular base ingredient for healthy food items that can lower blood pressure and glucose levels is squash flour. After harvest, the high moisture content of chayote fosters conditions for chemical and microbial action that cause extensive degradation and loss of the product. However, these losses can be minimised by dehydrating the chayote and converting it into more stable forms. The fundamental goal of preservation by drying is to produce a final product that is stable as a result of a decrease in moisture content. This decrease in moisture also lessens the possibility of physical changes as well as microbial and chemical activities during storage.

Drying characteristics of chayote, different drying characteristics curves were plotted for each set of drying experiment. To analyze the combined effect of drying air temperatures and thickness of slices on drying characteristics, contour surface plots were drawn. The various parameters pertaining to drying characteristics such as drying rate, moisture ratio, etc. were calculated at different time intervals using the standard equations presented below **(Akpinar 2005)** [2].

The moisture content was determined by-

$$M = \frac{W_w - W_d}{W_d} \times 100 \quad (1.1)$$

where,
M = chayote slice moisture content in (% d.b.),
W_w = wet weight in (g) and
W_d= dried weight of the sample in (g).

Drying rate can be defined as-

$$\frac{dM}{dt} = \frac{M_2 - M_1}{\Delta t} \quad (1.2)$$

where,

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Δt = Time interval, min
$M_2 - M_1$ = Change in moisture content (g of water per g of dry matter) in time interval Δt
The moisture ratio (MR) is defined as-

$$MR = \frac{M - M_e}{M_o - M_e} \quad (1.3)$$

where,
M = Average moisture content, (% db) at time t (min) during drying.
M_o = Moisture content, (% db) at the initiation of drying i.e. at zero time.
M_e = Equilibrium moisture content, (% d.b.).
The equilibrium moisture content (EMC) required for calculations of moisture ratio was determined using a method developed by **Henderson and Pabis (1961)** [8]. In this method, last three moisture contents of the drying experiments were considered. Following equation was used-

$$EMC = \frac{\left[M_1 M_3 - (M_2)^2\right]}{\left[M_1 + M_3 - 2M_2\right]} \quad (1.4)$$

where
$M_1 =$ Moisture content (% db) at time t_1
$M_2 =$ Moisture content (% db) at time t_2
$M_3 =$ Moisture content (% db) at time t_3 and
$(t_3\text{-}t_2) = (t_2\text{-}t_1)$

Empirical mass transfer modeling

The calculated moisture ratio values were used to predict the drying model for hot air drying of dried chayote slices. The following models were tried to describe the drying characteristics of chayote **(Erbay and Icier, 2009; Doymaz and Ismail, 2011)** [5, 4].

- **Page model**

$$MR = \frac{M - M_e}{M_o - M_e} = e^{-Kt^N} \quad (1.5)$$

- **Generalized exponential model**

$$MR = \frac{M - M_e}{M_o - M_e} = A.e^{-Kt} \quad (1.6)$$

- **Logarithmic model**

$$MR = \frac{M - M_e}{M_o - M_e} = A + B\,ln(t) \quad (1.7)$$

where,
t = drying time, min
K, N = drying constants
A and B = model constants

Rehydration studies

Based on preliminary experiment, the rehydration tests were carried out in boiling distilled water in mass ratio of 1:40 (dried product : water) for 15, 20 and 30 minutes for 5, 10 and 15 mm slices, respectively. Constant boiling water temperature was maintained using high precision water bath with digital controller. The following terms were calculated during rehydration studies as recommended by **Ranganna (1986)** [13].

1. **Rehydration ratio (RR):** It was estimated using following equation-

$$RR = \frac{W_r}{W_d} \quad (1.8)$$

where,
$W_r =$ *drained weight of rehydrated sample* (g)and

$W_d =$ *weight of dehydrated sample* (g)

2. Percent (%) water in rehydrated sample: It was calculated as-

$$\%\ \text{water in rehydrated sample} = \frac{W_w}{W_{rs}} \quad (1.9)$$

where,
W_w = weight of water rehydrated sample (g) and
W_{rs} = weight of rehydrated sample (g)
3. Coefficient of rehydration (COR): The relationship to estimate COR can be expressed as-

$$COR = \frac{W_r \times [100 - W_i]}{[W_d - W_w]x100} \quad (1.10)$$

where,

$W_r =$ *weight of rehydrated sample*(g)

W_i = weight of raw sample before drying (g)
W_d = weight of dehydrated sample (g), and
W_w = weight of water in the dried sample before rehydration (g)

Textural characteristics

Textural profile analysis (TPA) test was performed on rehydrated chayote slice using texture analyzer (model TA. HD plus, Exponent Stable Microsystems, Software version 3,0,5,0). The specifications of the texture analyzer were: load cell capacity: 5 kg, displacement; 0.1-524 mm and speed: 20-0.01 mm/s to place the sample heavy duty platform (HDP/90) was used. This platform was a base from which many attachments were fitted to the texture analyzer. It ensured the precision alignment of probes and product samples. The platforms were attached with action ratchet screw for ease of installation. The probe adapter was used to connect the probe to texture analyzer. In these experiment AD/100 probe adapter was used to connect the probe to machine. Cylindrical probe (P/75) made of stainless steel, was used through the experiments.

Results and Discussion

Experiments were conducted to characterise the drying behaviour of blanched and chemically treated samples of chayote at various temperatures, air velocities, and thicknesses of slices. Various drying models were evaluated for their suitability in characterising the drying behaviour of the chayote. The moisture content (% d.b.) was calculated using the recorded data of weight loss at regular intervals, and then the moisture ratio and drying rate were calculated. On the basis of moisture loss data, the effective diffusion coefficient was determined. The activation energy was determined to express the temperature dependence of the diffusion coefficient. Predictive models such as Page, generalised exponential, and logarithmic were evaluated for the best predictive model on the basis of the coefficient of determination (R^2). The quality characteristics in terms of texture, rehydration, volumetric shrinkage, browning index, colour, and proximate compositions were evaluated at various stages of the storage period.

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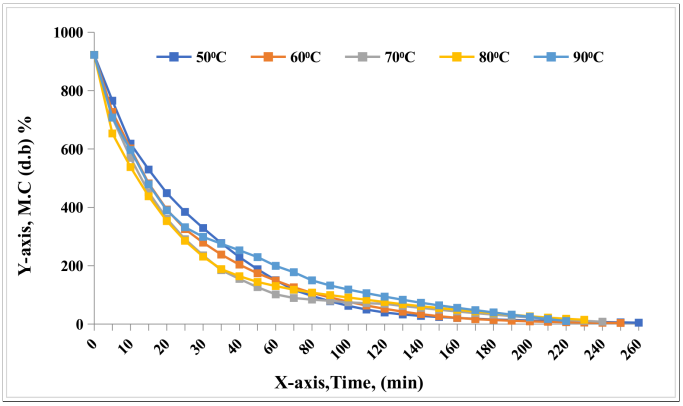


Figure 1. Drying characteristics curve for chayote slices showing variation of moisture content with time at different temperatures (for slice thickness = 0.5 cm and air velocity = 2.0 m/s)

content with time at different slice thicknesses (for temperatures = 70°C and air

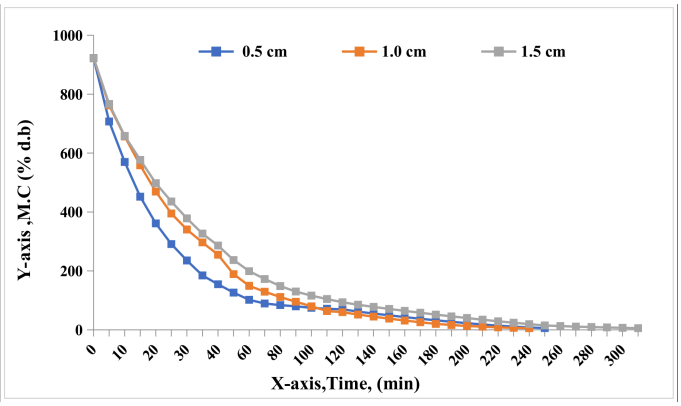


Figure 2. Drying characteristics curve for chayote slices showing variation of moisture

velocity = 2.0 m/s)

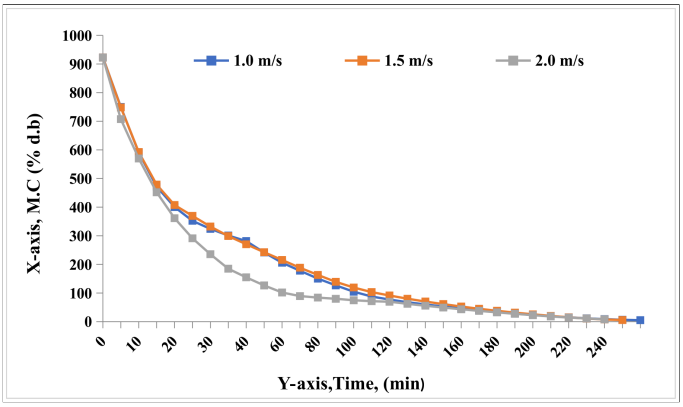


Figure 3. Drying characteristics curve for chayote slices showing variation of moisture content with time at different air velocities (for slice thicknesses = 0.5 cm and temperature = 70°C)

Effect of drying air temperature and slice thickness on total drying time

The contour plot for the total drying time, as shown in the Fig. 1.4, indicated that drying time increased with increasing thickness of chayote slices. Thicker slice sample required a longer drying time due to the increased distance travelled by moisture to the surface **(Kongdej, 2011)** [9]. It was also observed that the total time taken by the slice was less at higher temperature and also for small slice size.

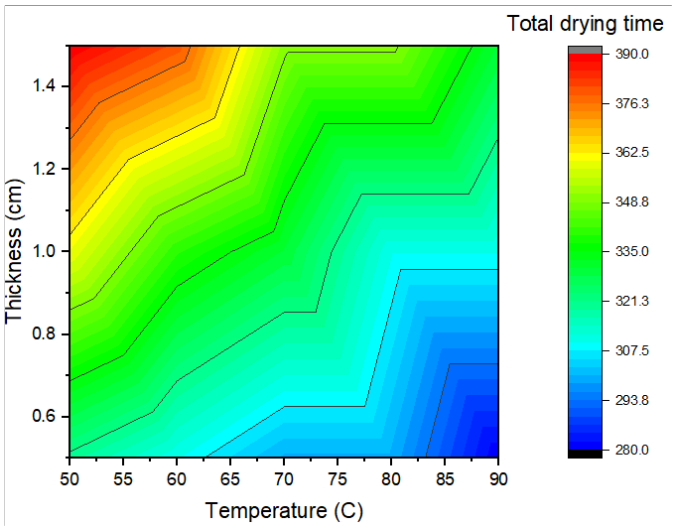


Figure 4. Contour plots showing effect of drying air temperature and slice thickness on the total drying time (min) of the chayote slice during drying at an air velocity of 1.0 m/s.

Effect of drying air temperature and slice thickness on the moisture diffusivity

The contour plot for the variation in moisture diffusivity with drying air temperature and slice

thickness is shown in Fig. 1.5. It was evidenced that the effective moisture diffusivity was found to increase with increasing the drying air temperature as well as slice thickness.

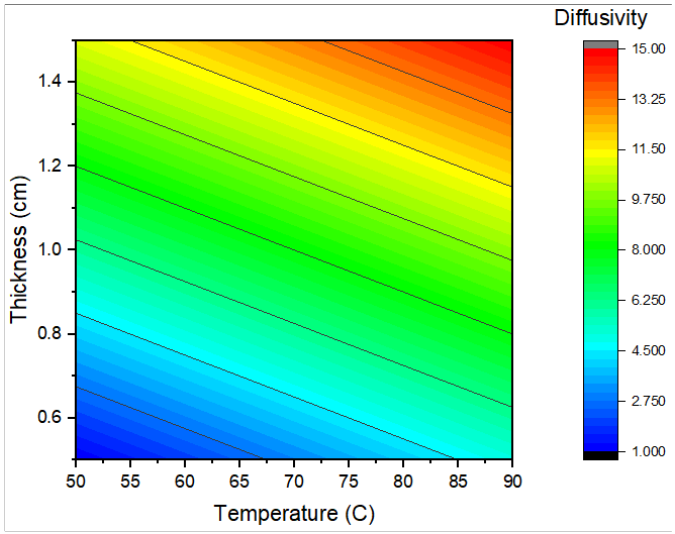


Figure 5. Contour plots showing effect drying air temperature and slice thickness on the moisture diffusivity in the chayote slice during drying at an air velocity of 1.0 m/s.

Empirical modeling

Moisture ratio data were fitted into three models, namely, Page's, generalised exponential, and logarithmic models, in order to select the best predictive model for hot air drying of chayote slices. The experimental data were fitted into the linearized form of these models using the regression technique. The best fit equations for all the three models along with coefficient of determination values .

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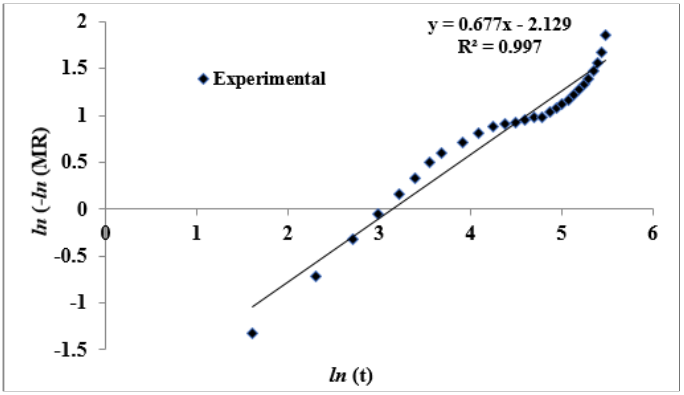


Figure 6. Linear plot for Pages model at 70°C air temperature, 0.5 cm slice thickness and 2.0 m/s air velocity.

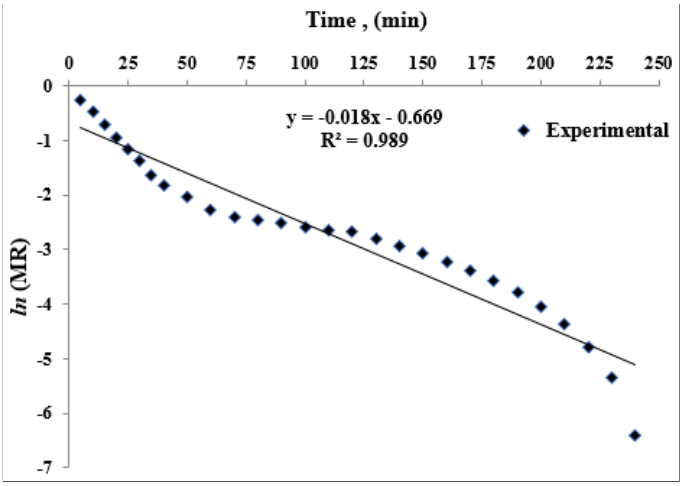


Figure 7. Linear plot for exponential model at 70°C air temperature, 0.5 cm slice thickness and 2.0 m/s air velocity.

Rehydration characteristics

The capacity of the dried chayote slices to revert to their original product properties was used to analyse the rehydration behaviour. The moisture content (MC), coefficient of rehydration (COR), and rehydration ratio (RR) of rehydrated samples are used to express this. At 100 °C, the rehydration kinetics of 0.5 cm, 1.0 cm, and 1.5 cm slices of chayote were examined for 15 minutes, 20 minutes, and 25 minutes, respectively.

Rehydration ratio

The average rehydration ratio ranged from 3.361 to 4.096, 3.357 to 3.604, and 2.991 to 3.588, for 0.5, 1.0, and 1.5 cm slices respectively. In the 1.5 cm-slice scenario, it was lower which is probably more shrinking of the sample in thicker sample.

The sample of 0.5 cm slice dried at 90 °C air temperature and 2.0 m/s air velocity had the highest rehydration ratio (4.096). The chayote slice's rehydrability was impacted by the increased degree of shrinkage caused lower temperature, which requires a longer drying time to reach a given moisture content on rehydration characteristics of chayote revealed that the rehydration ratio (RR) in general increased with increase in temperature in all the sizes of chayote. It was also found that RR was almost same at 50 ℃ and 70 ℃ (Akonor and Tortoe, 2014). RR was slightly higher at higher air velocity. This may be due to the fact that at higher air velocity, the drying rate was faster and the sample took less time to dry to the required moisture level resulting in less shrinkage of the slice.

Coefficient of rehydration

For samples with slice thicknesses of 0.5, 1.0, and 1.5 cm, the coefficient of rehydration (COR) varied from 0.331 to 0.662, 0.550 to 0.601, and 0.296 to 0.604, respectively. At 90 °C, the coefficient of rehydration reached its greatest (0.662) with a 0.5 cm slice and an air velocity of 1.5 m/s. A 1.5 cm thick sample dried at 80 °C and 2 m/s air velocity had the lowest value (0.296).

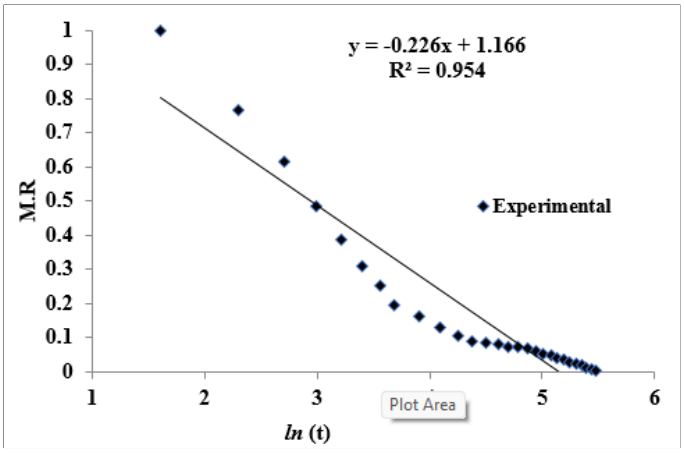


Figure 8. Linear plot for logarithmic model at 70°C air temperature, 0.5 cm slice thickness and 2.0 m/s air velocity.

Moisture content

For 0.5, 1.0, and 1.5 cm slice thicknesses, the moisture content (% w.b.) in rehydrated chayote ranged from 72.6 to 78.0, 72.4 to 74.9, and 69.3 to 75.0, respectively. These discoveries supported the conclusions of earlier researchers that a hard, dense product is produced by delayed dehydration at low temperatures, whereas a more porous product that rehydrates more quickly is produced by using higher temperatures (Talburt and Smith, 1975; Mclaughlin, 1996) [15].

Table 1. Minimum and maximum value of R^2 and SEE for different models

Model	R^2		SEE	
	Minimum	Maximum	Minimum	Maximum
Page Model	0.981	0.999	0.0318	0.1549
Generalized exponential	0.900	0.995	0.1276	0.1624
Logarithmic	0.944	0.970	0.0347	0.0675

Textural parameters

Using a texture analyzer, a texture profile test was performed on fresh, dried, and rehydrated materials. The texture analyzer provides the values for each property and produces the force versus time graph. The structure was weakened, as evidenced by the poorer texture profile analysis and stiffness parameters in the processed samples compared to the fresh samples (Nishinari *et al.*, 2013) [11]. The texture of the dried sample was further enhanced by a similar observation that pretreatments affected the textural qualities of chayote (Breene, 1975) [3]. The gel formed due to partial gelatinization of starch during blanching treatment apparently underwent transformation leading to a partially crystalline structure which further improved the texture of

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the dried sample (Garcia-Alonso *et al.*, 1999) [6]. The textural properties' range is provided in:

Table 2. The effect of temperature, air velocities and slice size on various textural properties

Slice thickness (cm)	Hardness (g)	Adhesiveness	Springiness	Gumminess	Resilience
0.5	3273.024 to 3345.447	-1.253 to -1.135	0.599to 0.688	786.756to 858.017	0.199to 0.267
1.0	4744.712 to 4808.890	-4.760 to -4.975	0.508to 0.590	686.259to 736.135	0.100to 0.187
1.5	6215.186 to 6300.089	-6.021 to -5.201	0.436to 0.500	592.454to 601.599	0.203to 0.234

higher hardness value in the 1.0 cm and 1.5 cm thick slices. This observation is consistent with earlier research (Ahrne *et al.*, 2003) [1], which found that pretreatment with calcium at 20 °C enhanced the hardness of rehydrated apples relative to untreated apples. The hardness was shown to be influenced by the drying temperature, particularly at higher temperatures. The samples dried at 90 °C had less hardness than those dried at 50 °C, but they were not appreciably different from those dried at 80 °C. Raleng *et al.* (2022) [12] reported similar findings when chayote slices were dried. The effect of air velocities was not significant on hardness in 0.5 cm slice. Hardness decreased slightly with increase in temperature in larger slice size (1.5 cm). The effect of slice size on hardness was more pronounced and increased with slice thickness. This observation is in good agreement with the finding of Swasdisevi *et al.* (2007) [14]. This may be because of the fact that the dried samples of 1.5 cm slice had more void space resulting softer compared to small cube size during rehydration.

Adhesiveness increased with increase in temperature in all the sizes, adhesiveness of 0.5 thickness was more compared to the other two sizes. This may be to the reason that more gelatinization took place in smaller size sample, thereby increasing the stickiness on the surface.

Springiness offers a high potential to differentiate the structural natures of different tissues as it recovers instantaneously. Springiness decreased with increase in temperature for all the sizes. It also decreased with increase in air velocity for 1.5 cm-cube while maximum value was observed in 0.5 cm cube size at 1.5 m/s air velocity. However, no significant difference was observed at higher air velocity; 3.5 and 4.5 m/s. Similar trend was observed in cohesiveness decreased with increase in temperature; however, it decreased with air velocity. 0.5 and 1.0 cm slice had no significant difference in cohesiveness as compared to 1.5 cm slice for blanched and treated samples. This observation is in good agreement with finding of Kotwaliwale *et al.* (2007) [10].

Conclusions

In this study, pretreated samples were dried using air temperature (five levels) ranging from 50 to 90°C, 1.0 to 2.0 m/s drying air velocity (three levels), and 0.5 to 1.5 cm slice size (three levels) to achieve a safe moisture content of 5-7% (d.b.) in the dehydrated product. The full three-factorial ANOVA analysis was carried out using a statistical package to check the effect of process variables on the quality parameters. Significant terms of variables were identified based on quality responses, and then the quality response data were fitted into the full second-order model. The adequacy of the model was checked by the coefficient of determination, R^2, and F-value. After establishing the adequacy of the model, it was used to determine the effect of variables on the responses and then optimized. Constant rate drying did not exist and drying of chayote took place in falling rate period. Falling rate drying curve was divided into two periods. During first falling rate period, the rate of drying decreased very rapidly up to about 350% (d.b.) moisture content or 40 min time. During falling rate period, the drying rate decreased gradually then it decreased very slowly. The compromise optimum level of the three variables for samples was found to be 70°C drying air temperature, 2.0 m/s air velocity and 0.5 cm slice thickness.

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Author contributions

Reema: Conceptualization, Formal analysis, Writing – original draft; Ng. Joykumar Singh: Literature collection, Writing – review and editing.

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