International Journal of Agriculture and Food Science 2026; 8(6): 150-157

ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2026): 4.97
IJAFS 2026; 8(6): 150-157
www.agriculturaljournals.com
Received: 26-03-2026
Accepted: 30-04-2026

Subhash Prasad
Dairy Engineering Department, College of Dairy Science, Kamdhenu University, Amreli, Gujarat, India

Tanmay Hazra
Dairy Chemistry Department, College of Dairy Science, Kamdhenu University, Amreli, Gujarat, India

Radhika Govani
Dairy Business Management Department, College of Dairy Science, Kamdhenu University, Amreli, Gujarat, India

Anil Chaudhari
Dairy Engineering Department, College of Dairy Science, Kamdhenu University, Amreli, Gujarat, India

Rohit Sindhav
Dairy Technology Department, College of Dairy Science, Kamdhenu University, Amreli, Gujarat, India

Corresponding Author:
Subhash Prasad
Dairy Engineering Department, College of Dairy Science, Kamdhenu University, Amreli, Gujarat, India

Mathematical modeling and dimensional analysis of hot-air tray drying kinetics of Khoa

Subhash Prasad, Tanmay Hazra, Radhika Govani, Anil Chaudhari and Rohit Sindhav

DOI: https://www.doi.org/10.33545/2664844X.2026.v8.i6b.1589

Abstract
This study investigates the transport phenomena and drying kinetics of *khoa* (heat-coagulated milk solids) during hot-air tray drying to produce a shelf-stable *khoa* powder. Experiments were conducted at three drying temperatures (55°C, 60°C and 65°C) at a constant air velocity of 2.0 m/s with a 0.5 cm product thickness. The results indicated a non-linear decrease in moisture content over time, showing that the dehydration occurred entirely within the falling-rate period. Elevating the temperature from 55°C to 65°C significantly accelerated the moisture removal rate, reducing the total drying time from 6.0 hours to 5.0 hours, and yielding a final moisture content ranging from 4.83% to 3.17% (dry basis). To predict drying behavior, moisture ratio (MR) data were fitted to two semi-empirical models: Henderson and Pabis, and Wang and Singh. The Wang and Singh model demonstrated superior predictive accuracy, achieving the highest correlation coefficient (R^2=0.998). Using Fick's second law of diffusion, the effective moisture diffusivity (D_{eff}) was determined to increase with temperature, ranging from 1.11×10^{-9} m^2/s at 55°C to 1.55×10^{-9} m^2/s at 65°C. Dimensional analysis validated these transport mechanisms; the mass transfer Biot numbers (Bi_m) exceeded 9.0×10^6, confirming that internal moisture diffusion, rather than surface evaporation, is the process bottleneck. Furthermore, mass transfer Fourier numbers (Fo_m) surpassed the critical threshold of 0.2 within 1.0 to 1.5 hours, indicating a rapid progression of the drying front to the core of the product. These universal dimensionless parameters offer a robust foundation for scaling up and optimizing industrial *khoa* drying operations.

Keywords: Khoa powder, tray drying, drying kinetics, effective moisture diffusivity, biot number, fourier number

1. Introduction

Drying has remained a popular method for preserving dairy and food products for many years. The drying process involves reducing the water content of the product to an acceptable level for marketing, storage or processing. Drying is usually done by vaporizing water from the product. Thus, the latent heat of evaporation must be supplied. Air flow is also necessary to remove the vapor from the product. The lower the humidity of the hot air supplied to the drying chamber, the better the drying speed, as the less humid air can transport more moisture from the product surface than the more humid air. In general, increasing temperature and the speed of air reduces drying time. However, high temperatures in heat-sensitive products such as dairy and food reduce the quality of products. In this case, low temperature and humidity drying is required to maintain the fresh colour of the product (Sato *et al*., 1997) [17]. The dryers that are commonly used are tray, tunnel, drum, fluidized bed, spray, flash, rotary, belt, vacuum and freeze dryers. Tray dryer is the widely used because of its simple and economic. Normally, the moisture content is determined by using an electronic balance to get the difference between the final and initial mass of the product. (Bakhshipour *et al*., 2012) [3].

Khoa, a traditional dairy product in South Asian cuisine, is a heat-coagulated milk solid prized for its granular texture and rich, milky flavor. Despite its cultural and economic importance as a primary ingredient in numerous sweet and savory dishes, *khoa* is highly perishable. Its high moisture content makes it an ideal medium for microbial spoilage and chemical deterioration, limiting its shelf life to only a few days under ambient conditions (Meena *et al*., 2021) [11].

To address these stability issues and facilitate large-scale distribution, the dairy industry frequently employs dehydration to transform fresh *khoa* into a shelf-stable *khoa* powder. Drying it into a powder or shelf-stable concentrate is challenging due to its high fat (20-30%) and protein content. These components create a complex food matrix that resists moisture migration. Among various industrial dehydration technologies, tray drying remains the most extensively utilized method due to its simplistic design, economic viability, and operational flexibility (Chaudhari *et al*., 2022) [4].

Drying kinetics study the rate of moisture removal as a function of time and drying conditions. The efficiency of this process is governed by drying kinetics. During the initial constant rate period, evaporation occurs freely from the saturated surface. However, as the process transitions into the falling rate period, internal mass transfer becomes the limiting factor (Sarkar *et al*., 2023) [16]. To optimize dryer performance must develop robust mathematical models. However, the interplay of variables including air density, viscosity, thermal conductivity, mass diffusivity and characteristic length presents a high degree of complexity. However dimensionless number comes in it groups variables like air velocity, temperature and moisture diffusivity into ratios that remain valid regardless of the dryer's size. By reducing the physical problem to universal parameters such as the Biot and Fourier number of mass transfer of researchers can generalize drying behavior across different scales and equipment geometries. This research aims to apply the principles of dimensional analysis to the tray drying of *khoa* to better understand the underlying transport phenomena. This study seeks to model the relationship between processing parameters (temperature, air velocity) and drying kinetics.

2. Material and methods

2.1 Raw material and Equipment

Tray dryer has a heating element of 1.0 kW capacity for air heating was used to drying of *khoa* to make *khoa* powder in this study. The tray was made up of stainless steel (AISI-316). The balanced draught fan (forced and induced fans) were used to proper speed regulator. During the experiment blower speed was controlled by a regulator to regulate the air flow rate. The tray dryer was connected with the energy meter to measure energy consumption. The inlet, inside and exit air temperatures of tray dryers were measured using a calibrated copper constantan thermocouple digital temperature indicator (accuracy:±0.1%). The inlet and outlet air velocity of the tray dryer was measured with an electronic digital anemometer (least count of 0.1 m/s with an accuracy of ±2% on the full-scale range of 0.2 m/s to 30.0 m/s).

2.2 Methodology

2.2.1 Khoa preparation

Khoa was prepared by traditional *khoa* making process in manner as described in the flow chart given below (Aneja *et al.,* 2002) [1].

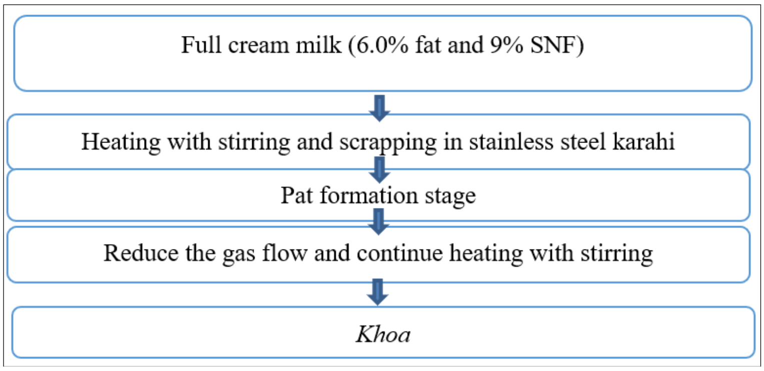

Fig 1: Flow diagram of khoa making

2.2.2 Working principle of khoa drying

The khoa was dried with the help of hot air circulation in a tray dryer. Forced convection heating took place to remove moisture from the *khoa*. *Khoa* was taken in clean stainless steel (AISI-316) trays and uniformly spread in a layer about 0.5 cm thick layer. The tray dryer was turned on and temperature and time in the tray dryer were recorded. Inlet and exit fan (blower) knobs were adjusted to control the air flow rate. After reaching the set temperature, trays were loaded into the tray dryer and mass of partially dried *khoa* lumps were manually mixed and re-spread at every 30-minute interval. The weight of *khoa* mass (kg) was recorded until the equilibrium relative humidity achieved. The air temperature was established at 55, 60, and 65°C with velocity of air drying was established at 2.0 m/s (Prasad *et al*., 2024) [14]. The tests were replicated 3 times for each experimental, and the average values were reported. *Khoa* were uniformly positioned on the tray (40 x 30 cm) in a thin layer with a loading rate of 2.0 kg/m^2.

2.2.3 Drying kinetics

The drying kinetics of *khoa* were described as a decrease in moisture ratio (MR) versus drying time (t). Moisture Ratio (MR) is a dimensionless number that represents the amount of removable moisture remaining in the product at any given time relative to the initial moisture content. The MR was analysed using using equation (1) (Jahanbakhshi *et al*, 2020) [8].

$$MR = \frac{M_t}{M_i} \text{ ………. (1)}$$

where,

MR: Moisture ratio in dimensionless value

M_t: Moisture content at any time t (% wb)

M_i: The initial moisture content (% wb)

Variations of the drying rate of *khoa* (kg moisture.h^{-1}.m^{-2}) at different temperatures with drying time were evaluated (Sekar *et al*., 2023b) [18]. The drying rate for *khoa* was determined using Equation (2)

$Dr = \frac{M_w}{A.t} \dots$ (2)

where,
D_r: Drying rate of *khoa*, kg.h^{-1}.m^{-2}
M_w: Mass of moisture evaporated, kg
A: Area of the tray for the spread of *khoa* for drying, m^2
t: Time taken for drying of *khoa*, h.

2.2.4 Mathematical modelling of drying kinetics

Table 1 shows the equations used to determine the best model for explaining the *khoa* drying curve. Two semi-empirical drying equations were operated to describe the *khoa* drying kinetics and calculate the Drying Rate Constant (k) in this investigation (Darvishi *et al*., 2013) [5].

Table 1: Mathematical models of drying kinetics

No.	Models' name	Models' equation	Ref.
1	Henderson and Pabis	MR=a.exp(-kt)	Henderson and Pabis, 1961
2	Wang and Singh	$MR=1+at+bt^2$	Wang and Singh, 1978

2.2.5 Dimensionless Number of *khoa* drying

The evaluated of effective moisture diffusivity (D_{eff}) for *khoa* during tray drying by plotting ln (MR) vs time for a thin layer drying as a semi-infinite medium. The calculation according to Fick's Second Law of Diffusion (Equation 3).

$\ln(MR) = \ln(8/\pi^2) - [\pi^2 D_{eff}/4\,L^2\,]t$ ………………….(3)

The resulting straight line has a slope (S):

$S = -\,\pi^2 D_{eff}/4\,L^2$ …………………………………. (4)

$D_{eff} = -\,S.4\,L^2/\,\pi^2$ …………………………………. (5)

L as the full thickness if drying from one side only
To validate your D_{eff} value for *khoa* tray drying, we use Biot (Bi) and Fourier (Fo) numbers.

Biot Number for Mass Transfer (Bi_m): The Biot number determines if the "bottleneck" of drying is inside the *Khoa* or at the air-surface interface.

$Bi_m = h_m.\,L/D_{eff}$ ………………………………….(6)

Where,
h_m: Convective mass transfer coefficient (m/s).
L: Characteristic length (m) (for a tray, this is the thickness of the Khoa layer).
D_{eff}: Effective moisture diffusivity (m^2/s).
Fourier number for mass transfer (Fo_m): The Fourier number represents "dimensionless time". Calculating the Fourier Number for Mass Transfer for drying *khoa* in a tray dryer helps you understand how deep or how fast moisture is diffusing through the layer of *khoa* relative to the drying time.

$Fo_m = D_{eff} \times t/L^2$ …………………………………….(7)

Where,
t: Drying time (s).
L: Characteristic length (m).
D_{eff}: Effective moisture diffusivity (m^2/s).

2.3 Statistics

Statistical processing was conducted via one-way ANOVA (IBM SPSS v.20), and results are reported as mean ± SE from triplicate runs. Duncan's Multiple Range Test was employed to identify significant differences ($P < 0.05$) among samples. The drying kinetics models were validated based on their goodness-of-fit, where the most suitable model was identified by maximizing the correlation coefficient (R^2).

3. Result and discussion

3.1 Moisture evaporation rate of khoa at different drying temperatures

The moisture evaporation rate (kg moisture.m^{-2}.h^{-1}) of *khoa* at three different temperatures (55°C, 60°C and 65°C) was estimated, having the *khoa* drying area 0.12 m^2 and fixed mass of *khoa* (0.625 kg) were fixed. The temperature and velocity (2 m/s) of air were fixed during the period. During drying, the process of changing of mass of *khoa* (g) over time was recorded. The mass of *khoa* was taken at different temperatures, with an interval of half hour (Prasad *et al.*, 2024) [14]. Drying ends at 6, 5.5 and 5 hours for drying temperatures of 55, 60 and 65 °C, respectively. Drying of *khoa* was continued up to equilibrium conditions and recorded mass change of full cream based *khoa* (Figure 2). Sanika *et al.* (2021) [15] reported that nonlinear decrease of moisture with the time progressing of tray-dried peanut milk residue. Author reported that the time taken to reach EMC decreases with increase in temperature; which supports findings of the current investigation for the trends obtained. Korotkiy *et al.* (2023) [9] reported that the time duration (h) required for complete drying of bananas at 50 °C, 60 °C and 70 °C were 12, 9 and 9 h in tray dryer.

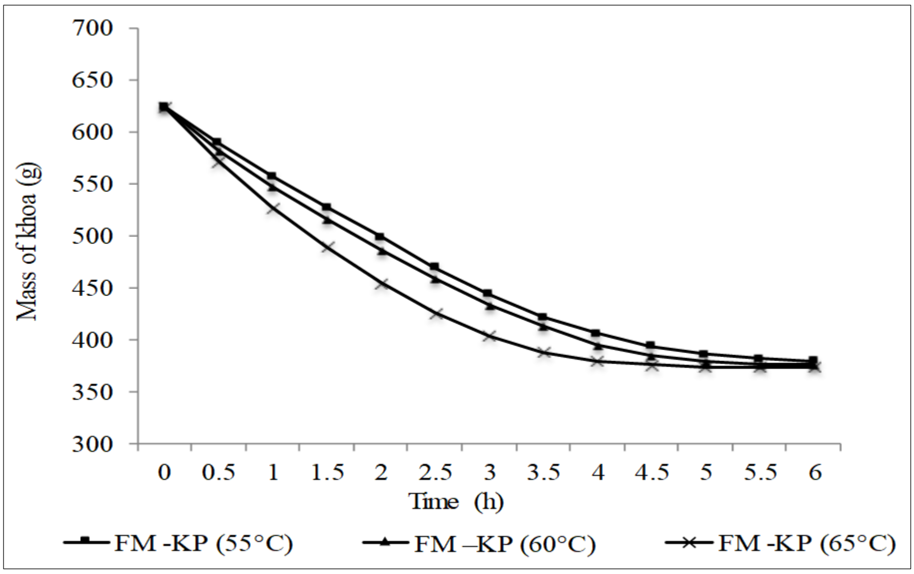

Fig 2: Changes in mass of full cream milk based khoa during drying at different temperatures

The change of moisture content (%, dry basis) of full cream milk based FM *khoa* with time (h) at three different drying temperatures (55, 60 and 65 °C) in tray dryer are shown in Figure 3. A nonlinear decrease in moisture content (dry basis) with time (h) was observed.

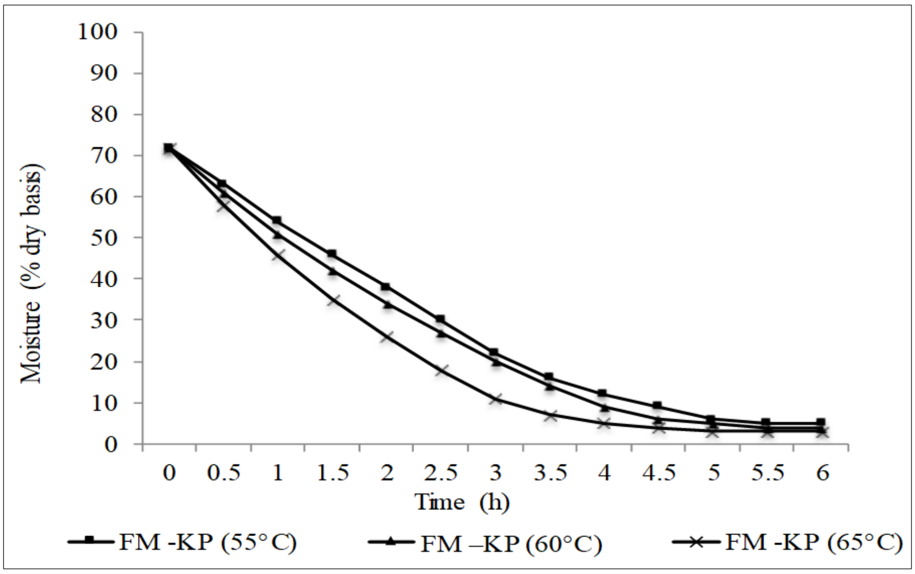

Fig 3: Moisture (%, dry basis) during drying of full cream milk khoa at different temperatures

The rate of removal of moisture increased with drying temperature. The time to reach the equilibrium moisture content decreased with the increase in temperature. When *khoa* is dried at 65ºC, it takes about 5 hours to reach the equilibrium condition. However, at 55 and 60 ºC, thorough drying took 6 and 5.5 hours, respectively. For *khoa*, the final moisture content (%, dry basis) of *khoa* powder obtained at 55, 60 and 65 °C were 4.83, 4.00 and 3.17% respectively. Moisture carrying capacity of air increases with temperature rise. The low relative humidity of air in the tray dryer caused drying in less time. At higher air drying temperatures in tray dryer for drying of quinces to make quince powder, the gradient potential was high which led to a reduction in drying time Tzempelikos *et al*., (2014) [19]. Arulkumar *et al.* (2023) [2] reported that the range of equilibrium moisture content (% wb) of tray dried paneer cube samples (8 cm^3) at 50, 55 and 60 °C were 15.26 to 16.64, 14.65 to 16.59 and 12.46 to 15.89%, respectively; shows similar trends of current investigation, higher drying temperature recorded lower equilibrium moisture content. According to Sanika *et al.* (2021) [15], tray-dried peanut milk residue at 60, 70, and 80°C required 9, 7, and 5 hours, respectively, to reach equilibrium moisture content (EMC); these results are consistent with our observations.

3.2 Variation of drying rate of *khoa* with respect to drying time

Khoa (0.625 kg) was evenly distributed in a tray with a bed thickness of about 0.5 cm and the area of tray used for this study was 0.12 m^2. The moisture evaporation per unit area per unit time (kgmoisture.h^{-1}.m^{-2}) vs. time (h) relationship for drying rate of full cream milk (FM) *khoa* is depicted in Figure 4. At the commencement of the *khoa* drying process, the water content of the *khoa* was significantly greater, hence the drying rate faster. Increasing the temperature resulted increase in the drying rate and hence water content in the material decreased. As temperature rises, the diffusivity of water increases both on the *khoa* surface and within the mass, which results in faster drying rate. Figure 4 shows the full cream milk based *khoa* drying at a temperature of 65ºC gives a higher drying rate than at 60 ºC and 55 ºC.

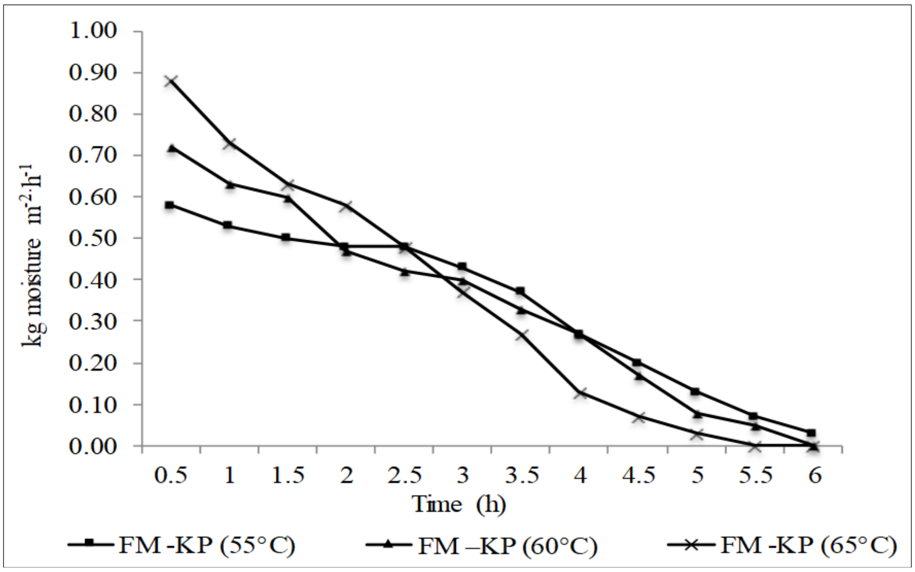

Fig 4: Drying rate of full cream milk based khoa at different temperatures

At the starting (0.5 h) of full milk based *khoa* (FM-*Khoa*) drying, drying rates (kg moisture.$h^{-1}.m^{-2}$) at 55, 60 and 65°C were obtained as 0.58, 0.72 and 0.88 kg moisture.$h^{-1}.m^{-2}$, respectively. Drying rate (kg moisture.$h^{-1}.m^{-2}$) of FM-*Khoa* at 55, 60 and 65°C were ceased at 6, 5.5 and 5.0 h, respectively. The average drying rate (kg moisture.$h^{-1}.m^{-2}$) of FM-*khoa* during the drying period at 55, 60 and 65°C were at 0.34, 0.38 and 0.42 kg moisture.$h^{-1}.m^{-2}$, respectively. Arulkumar *et al.* (2023) [2] reported maximum drying rate (g/g.h) for tray drying of paneer cube samples (8 cm^3) at 50, 55 and 60°C as 0.2080, 0.3352 and 0.3213 kg moisture.$kg^{-1}.h^{-1}$, respectively.

Drying rate best fitting equation at 55°C, 60 and 65°C (shown in equation 8 to 10) with R^2 values 0.95, 0.99 and 0.97 respectively.

Dr (at 55°C) = -0.052t + 0.6771 ………………………(8)

Dr (at 60°C) = -0.0657t + 0.7723 ………………………(9)

Dr (at 65°C)= -0.0844t + 0.8964 ………………………(10)

3.3 Modelling of drying curves

Moisture ratio (MR) is defined as the ratio of moisture percent in the product at a particular time to initial moisture content. The moisture ratio (%) of full cream based *khoa* (Figure 5) with respect to drying time (h) at three different drying temperatures (55, 60 and 65 °C) in tray dryer. The moisture ratio (%) decreased with time. The FM *khoa* (FM-KP) at 55°C was the slowest. The final moisture ratio (%) of full cream milk based *khoa* powder at 55, 60 and 65 °C were 6.67, 5.52 and 4.38 respectively. According to Sanika *et al.* (2021) [15], tray-dried peanut milk residue's moisture ratio dropped over time and showed that it fell inside the falling rate zone, which is consistent with current findings.

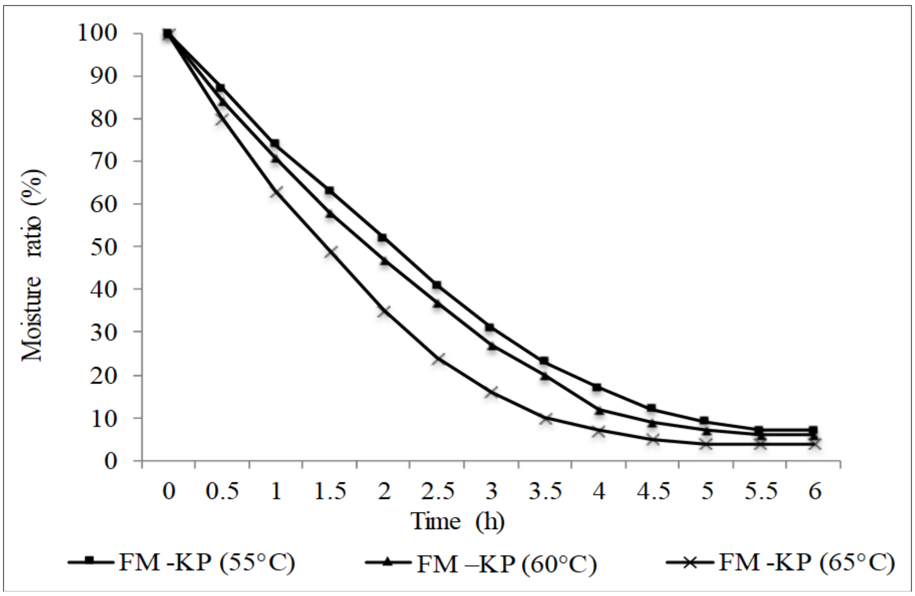

Fig 5: Moisture ratio of full cream based khoa with drying time

Table 2 shows the statistical measurements of data goodness of fit to drying equations. Both equations exhibited the high (R^2) values than 0.95, could equitably represent the drying behaviour.

Table 2: Statistical variables were found from the fitting of thin-layer equations

Drying Temp. (°C)	Henderson and Pabis		Wang and Singh	
	Equation	R^2	Equation	R^2
55	$MR(\%) = 154.77\ e^{-0.246t}$	0.985	$MR(\%) = 0.611t^2 - 16.57t + 117.73$	0.999
60	$MR(\%) = 153.79\ e^{-0.265t}$	0.981	$MR(\%) = 0.716\ t^2 - 17.96t + 117.84$	0.999
65	$MR(\%) = 144.75e^{-0.309t}$	0.974	$MR(\%) = 0.994\ t^2 - 21.57t + 119.25$	0.998

3.4 Dimensionless Number of *khoa* drying

Figure 6 shows ln (MR) vs time for a thin layer *khoa* drying at three different temperature as a semi-infinite medium. Factors that will change your result include temperature of drying, composition of *khoa* and shrinkage of *khoa* during drying. Evaluation of effective moisture diffusivity (D_{eff}) for khoa, according equation 3 to 5. Ndukwu *et al.* (2017) [13] reported that effective moisture diffusivity (D_{eff}) value for cocoyam slices found from 3.37 x10^{-10} to 1.13 x10^{-10} for drying temperature 50-70°C. As the drying temperature was stepped up from 55°C to 65°C, the negative slope of the drying curves accelerated significantly from -0.3958 to -0.5533. Correspondingly, the D_{eff} values increased from 1.11 x 10^{-9} m²/s to 1.55 x 10^{-9} m²/s. Elevating the drying temperature imparts greater kinetic energy to the water molecules within the *khoa* matrix. This structural collapse accounts for the slight non-linearities and the constant intercept of -0.21 observed in the regression models.

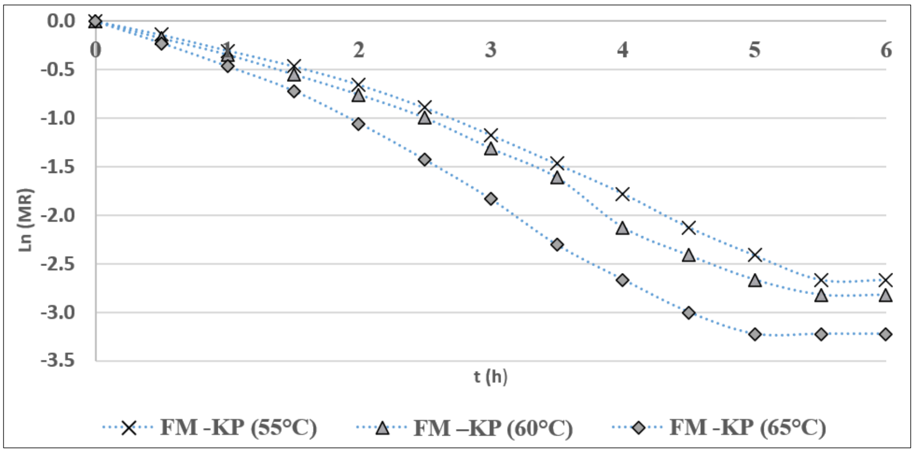

Fig 6: Logarithmic of moisture ratio (MR) vs time (hour) graph for khoa drying at different temperature

Table 3: Best fit equations and D_{eff} values of khoa drying at different temperature

Temperature (°C)	Best fit equation	Slope (S)	L (m)	D_{eff} (m²/s)	R^2
55	Ln (MR)55 = -0.3958 t-0.21	-0.3958	0.005	1.11 ×10^{-9}	0.933
60	Ln $(MR)_{60}$ = -0.4405 t-0.21	-0.4405	0.005	1.24 ×10^{-9}	0.942
65	Ln $(MR)_{65}$ = -0.5533 t-0.21	-0.5533	0.005	1.55 ×10^{-9}	0.959

3.4.1 Biot Number for Mass Transfer (Bi_m)

The Biot numbers for mass transfer were determines using equation 6. Table 4 shows the Biot numbers for mass transfer during khoa drying at different drying temperature. Here, Bi_m > 40: Internal resistance controls the process. Fick's Second Law is highly accurate here because the surface dries almost instantly, and the core moisture struggles to reach the surface. The calculated mass transfer Biot numbers (Bi_m > 9.0x 10^6) mathematically confirmed that internal mass transfer resistance vastly dominates over surface convective resistance. Since *khoa* is dense and sticky, you will likely find Bi_m is very high, validating that internal diffusion is indeed the limiting factor. Mondal and Das (2017) [12] reported that mass transfer biot number of frying of *Chenna jhilli* from 4.21 to 4.286 for frying temperature (125-145°C).

Table 4: Biot numbers for mass transfer during khoa drying at different drying temperature

Temperature (°C)	L (m)	H_m (m/s)	D_{eff} (m²/s)	Bi_m
55	0.005	2	1.11 x10^{-9}	9.0 ×10^6
60	0.005	2	1.24 x10^{-9}	10.12 ×10^6
65	0.005	2	1.55 x10^{-9}	12.57 ×10^6

3.4.2 The Fourier Number for Mass Transfer (Fo_m)

The mass transfer Fourier number is a dimensionless quantity that characterizes transient mass diffusion, representing the ratio of the moisture transport rate to the rate of moisture storage within the food matrix. Essentially, it is a dimensionless time variable that tells you how far along the internal moisture diffusion process is according to equation 7. Table 5 shows the Fourier numbers for mass transfer during khoa drying at different drying temperature. At all evaluated drying temperatures, the Fo_m values exhibited a strict, progressive increase with drying time. For instance, at a drying temperature of 55°C, Fo_m increased from 0.079 at 0.5 h to 0.950 at 6.0 h. The highly regular increments over time indicate that the internal resistance to moisture movement remains governed by a steady diffusion mechanism during these drying stages for all three temperature. Franklin *et al*. (2014) [6] reported that mass transfer Fourier number of frying of *Gulab jamun* from 0.29 to 0.51 for frying temperature (135-155°C).

Fourier numbers (Fo_m) crossed the critical threshold of 0.2 within the first 1.0 to 1.5 hours, showing that the drying front rapidly advanced from the surface down to the core of the 0.5 cm khoa layer. A Fourier number approaching or exceeding 1.0 indicates that the mass transfer process is deeply developed and moving toward equilibrium conditions throughout the entire thickness of the material. At 65°C, the Fo_m crossed the unity threshold quite rapidly, reaching 1.106 at 5.0 h. In contrast, at 55°C and 60°C, the Fo_m values remained below unity even at 5.0 h (0.792 and 0.885, respectively), failing to reach advanced equilibrium states within that time frame.

Table 5: Fourier numbers for mass transfer during khoa drying at different drying temperature

T (h)	Fo_m (at 55°C)	Fo_m (at 60°C)	Fo_m (at 65°C)
0.5	0.079	0.088	0.111
1	0.158	0.177	0.221
1.5	0.238	0.266	0.332
2	0.317	0.354	0.442
2.5	0.396	0.443	0.553
3	0.475	0.531	0.664
3.5	0.554	0.620	0.774
4	0.634	0.708	0.885
4.5	0.713	0.797	0.995
5	0.792	0.885	1.106
5.5	0.871	0.974	1.217
6	0.950	1.062	1.327

4. Conclusion

This study applied dimensional analysis and thin-layer modeling to evaluate the hot-air tray drying kinetics of *khoa*. Drying occurred entirely within the falling-rate period. Increasing the drying temperature from 55°C to 65°C enhanced the effective moisture diffusivity (D_{eff}) from 1.11×10^{-9} m²/s to 1.55×10^{-9} m²/s. This structural change effectively shortened the total drying time by 16.7% (from 6.0 hours to 5.0 hours) and decreased the final moisture content from 4.83% to 3.17% (dry basis). Among the mathematical models tested, the Wang and Singh equation provided the best fit for predicting moisture ratio (MR) behavior ($R^2 = 0.998$). The calculated mass transfer Biot numbers ($Bi_m > 9.0 \times 10^6$) mathematically confirmed that internal mass transfer resistance vastly dominates over surface convective resistance. Fourier numbers (Fo_m) crossed the critical threshold of 0.2 within the first 1.0 to 1.5 hours, showing that the drying front rapidly advanced from the surface down to the core of the 0.5 cm *khoa* layer. Ultimately, these scale-independent dimensionless numbers (Bi_m and Fo_m) offer universal transport parameters that can be directly applied to optimize industrial equipment design, control energy consumption, and scale up shelf-stable *khoa* powder manufacturing.

References

1. Aneja RP, Mathur BN, Chandan RC, Banerjee AK. Technology of Indian dairy products. A Dairy India Publication. 2002;56(3):122-125.
2. Arulkumar M, Pandian NK, Murugan B, Nambi VE, Sivaranjani S, Baskaran D, *et al*. Drying kinetics, effective moisture diffusivity, and activation energy of osmotic pretreated hot-air-dried paneer cubes. Journal of Food Processing and Preservation. 2023;2023(1):7685192.
3. Bakhshipour A, Jafari A, Zomorodian A. Vision based features in moisture content measurement during raisin production. World Appl Sci J. 2012;17(17):860-869.
4. Chaudhari M, Pinto S, Ankamanal V. Development of reduced fat paneer from reconstituted milk. Asian Journal of Dairy and Food Research. 2022;41(3).
5. Darvishi H, Asl AR, Asghari A, Azadbakht M, Najafi G, Khodaei J. Study of the drying kinetics of pepper. Journal of the Saudi Society of Agricultural Sciences. 2014;13(2):130-138.
6. Franklin ME, Pushpadass HA, Ravindra Menon R, Rao KJ, Nath BS. Modeling the heat and mass transfer during frying of gulab jamun. Journal of Food Processing and Preservation. 2014;38(4):1939-1947.
7. Henderson SM, Pabis S. Grain drying theory. 1. Temperature effect on drying coefficient. J Agric Eng Res. 1961;6(3):169-174.
8. Jahanbakhshi A, Kaveh M, Taghinezhad E, Rasooli Sharabiani V. Assessment of kinetics, effective moisture diffusivity, specific energy consumption, shrinkage, and color in the pistachio kernel drying process in microwave drying with ultrasonic pretreatment. Journal of Food Processing and Preservation. 2020;44(6):e14449.
9. Korotkiy I, Neverov E, Gorelkina A, Korotkaya E, Zadesenets A. The dehydrator parameters for convective drying of food products. BIO Web of Conferences. 2023;64:01023.
10. Limpaiboon K. Effects of temperature and slice thickness on drying kinetics of pumpkin slices. Walailak Journal of Science and Technology (WJST). 2011;8(2):159-166.
11. Meena M, Prajapati P, Ravichandran C, Sehrawat R. Natamycin: A natural preservative for food applications—a review. Food Science and Biotechnology. 2021;30(12):1481-1496.
12. Mondal IH, Dash KK. Textural, color kinetics, and heat and mass transfer modeling during deep fat frying of Chhena Jhili. Journal of Food Processing and Preservation. 2017;41(2):e12828.
13. Ndukwu MC, Dirioha C, Abam FI, Ihediwa VE. Heat and mass transfer parameters in the drying of cocoyam slice. Case Studies in Thermal Engineering. 2017;9:62-71.
14. Prasad S, Shah BP, Ahuja KK. Energy-efficient solar-assisted drying of Khoa: optimization of drying parameters and powder properties. Chemical Science Review and Letters. 2024;13(52):245-259.
15. Sanika B, Poojitha P, Gurumoorthi P, Athmaselvi KA. Drying kinetics and quality of tray dried peanut milk residue. Food Research. 2021;5(2):106-112.
16. Sarkar T, Salauddin M, Chakraborty R. Optimization of tray drying kinetics and quality parameters of concentrated ethnic dairy products using dimensional empirical equations. LWT - Food Science and Technology. 2023;174:114412.
17. Sato K, Katahira M, Toji E. Drying characteristics of raw bulb and dehumidified air and moisture content

distribution of different bulb parts. Journal of Japanese Society of Agricultural Machinery, Tohoku Branch. 1997;44:43-46.
18. Sekar SD, Sekar S, Rajesh S, Kumar PJL, Kumar SB, Vinosh M. Performance analysis of thin layer drying of okra (*Abelmoschus esculentus*). AIP Conference Proceedings. 2023;2914(1):020003.
19. Tzempelikos DA, Vouros AP, Bardakas AV, Filios AE, Margaris DP. Case studies on the effect of the air drying conditions on the convective drying of quinces. Case Studies in Thermal Engineering. 2014;3:79-85.
20. Wang CY, Singh RP. A single layer drying equation for rough rice. ASAE paper. 1978:33.
21. Yashkumar DS, Srilatha P. Optimization of drying parameters for cactus fruit in hot air tray drier. The Pharma Innovation J. 2023;12(3):128-134.