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Energy-Efficient Solar-Assisted Drying of Khoa: Optimization of Drying Parameters and Powder Properties

Subhash Prasad[1]*, B.P. Shah[2] and Kunal Kumar Ahuja[1]

[1]College of Dairy Science, KU, Amreli, Gujarat
[2]SMC College of Dairy Science, Anand, Gujarat

Abstract

In this study, the hot air convective drying method was used to dry the khoa. The khoa was made traditionally from full cream milk (FM) and dried in electrical heated tray dryer coupled with solar PTC air heater at 55°C, 60°C and 65°C. Using the response surface methodology (RSM) of Design-Expert®V-10 software drying temperature (°C) and batch size of khoa (g) were optimized keeping lowest possible energy requirement (ER/MO), maximizing total solids (TS) in khoa powder and minimizing the browning index (BI) as constraints. Optimized parameters were lot size: 621.6 g and dying temperature: 65 °C. The average moisture, fat, protein, total carbohydrate and ash content of solar assisted tray dried khoa powder at optimized temperature (65°C) were 2.60, 39.00, 20.44, 32.12 and 5.84%, respectively. The average bulk density, tapped density, porosity, Carr's index, Hausner ratio, angle of repose, water activity, L*, a*, b* and browning index of khoa powder at optimized temperature were 502 kg/m^3, 675 kg/m^3, 60.66%, 27.85, 1.39, 41.80°, 0.34, 72.43, 3.06, 31.67 and 58.54, respectively. The solar PTC air heater has the potential to be used for the heating of air and for drying khoa to make khoa powder.

Keywords: Khoa powder, solar assisted, browning index, energy requirement, porosity, bulk density

***Correspondence**
Author: Subhash Prasad
Email: sp@kamdhenuuni.edu.in; subhashprasad85@gmail.com

Introduction

India is the world's largest milk producer with annual production of 230.58 million tonnes and contributing approximately 24.64% of total milk production in year 2022-23[1]. The industries that process milk and milk products use more energy and their production capacities are increasing continuously [2]. Energy is the major cost contributor in the dairy process industry [3]. Milk and milk products are best preserved by drying. It reduces water activity and thus slows down the deterioration in quality. The improved solar assisted tray drying methods can be used for the preparation of milk products like khoa.

Tray drying refers to dehydrating small pieces or granular particles of food by exposing them to the source of hot dry air until dry enough to store them at ambient temperature with minimal spoilage. Controlled tray drying equipment entails a cabinet fitted with shelves of solid or perforated trays, a device for air heating and a fan or blower to circulate hot air to remove moisture from the product. Khoa cannot be stored for more than 5 days at room temperature without spoilage. Dried khoa i.e. khoa powder has advantages such as improved shelf life, significant savings in storage space and lower shipping cost as well as can be used to prepare various convenience formulations. The use of solar energy is a novel way to increase the shelf life of khoa to make khoa powder. Solar thermal energy is one of the viable potential renewable energy resources in dairy and food processing applications. Solar air and water heating systems are efficient way of converting solar energy into thermal energy. Solar thermal conversion has an efficiency of about 70%, but solar electrical conversion efficiency only around 17% [4]. Indirect solar drying systems have several advantages over direct solar drying, like precise control, running at higher temperatures, superior product quality and good drying rate and efficiency [5]. In the direct convective drying process, hot air is used as working fluid most commonly because it is a simple, efficient and low-cost process [6].

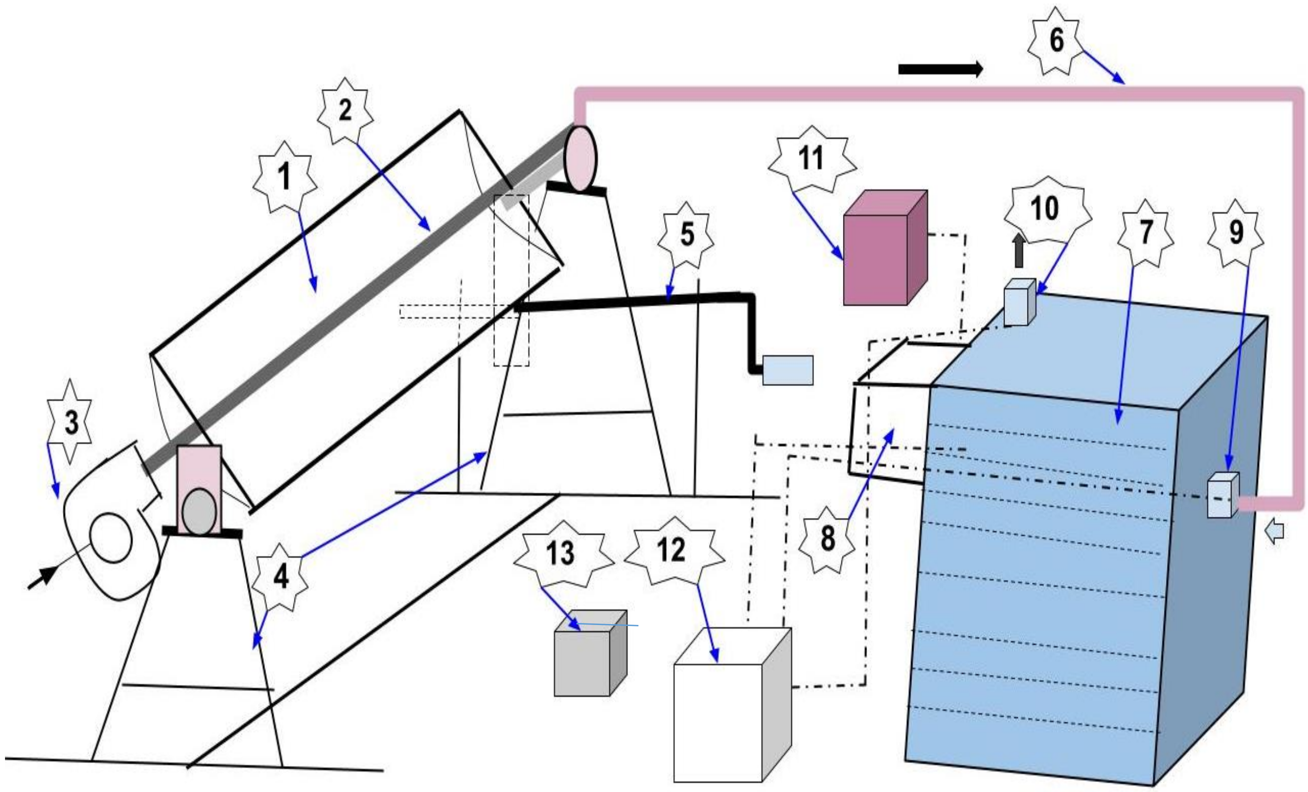
In this study, the hot air convective drying method is used to dry the khoa. The hot air enters the tray dryer and heats the surface of the khoa, and then heat gently transferred to the inside of the khoa lumps. As a result, the moisture formed on the surface of the khoa is pulled away as vapour by the surrounding flowing hot air. Moisture within the khoa begins to migrate to its surface by combinations of transport processes such as liquid diffusion, differential hydrostatic pressure, vapour diffusion or capillary flow. Removing of moisture from khoa continues until the vapour pressure comes in equilibrium that of ambient hot air. The khoa and drying air reach equilibrium and the moisture content of the product at that point is known as equilibrium moisture content [7].The manufacture of khoa powder has tremendous scope for its commercial viability. Earlier, some successful efforts were made for the manufacture of khoa powder. Therefore, there is a great opportunity to use solar assisted tray drying system for drying of khoa for making khoa powder. The present research work was aimed to making energy-efficient solar-assisted drying of khoa by optimization of drying parameters and powder properties.

Materials and Methods

Raw material and instruments for the Preparation of khoa and khoa powder

Milk (full cream milk and standardized milk). Water activity meter (LabSwift aw, Novasina, Switzerland). Energy meter (Parameter measurand: Power factor, current, voltage, power, frequency and energy consumptions; Make-Jeevyee), multi-channel temperature monitor (12-Point temperature monitor with thermocouple temperature sensors; Make: DIGIQUAL, Chennai, India).

The schematic experimental setup (**Figure 1,2**) and photograph (**Figure 3**) of the solar-assisted tray dryer system is given. Tray dryer available at the Department of Dairy Engineering of the College was used to assemble with solar PTC air heater and drying of khoa to make khoa powder in this study. The tray dryer has a heating element of 1.0 kW capacity for air heating to ensure uniform heat in the working chamber. A PT-100 type temperature sensor fitted inside the tray dryer with a wide range and resolution of 0.1°C. The tray dryer was provided with an HMI interface screen to control various parameters such as date, time, temperature, fan speed, etc. The tray dryer was connected with the energy meter to measure energy consumption. Energy meters can record the reading of kW, kVA, power factor, frequency, voltage (volt) and current (Ampere). Silicone two-layer duct pipe (length 5 m, ID 51 mm) was used as a hot air conveying duct and it was linked between the receiver's outputs and the tray dryer's intake duct using other accessories.



1: PTC reflector; **2:** Receiver; **3:** In-line blower; **4:** Support structure; **5:** Manual tracking system; **6:** Air conveying duct; **7:** Tray dryer; **8:** HMI interface of tray dryer; **9:** Inlet air duct with fan; **10:** Outlet air duct with fan; **11:** Energy meter; **12:** Multi-channel data logger and **13:** Weighing balance

Figure 1 Schematic diagram of solar assisted tray dryer

Khoa Powder Preparation from Khoa

Khoa preparation

Khoa was prepared by traditional khoa making process in manner as described in the flow chart given in Figure 2.

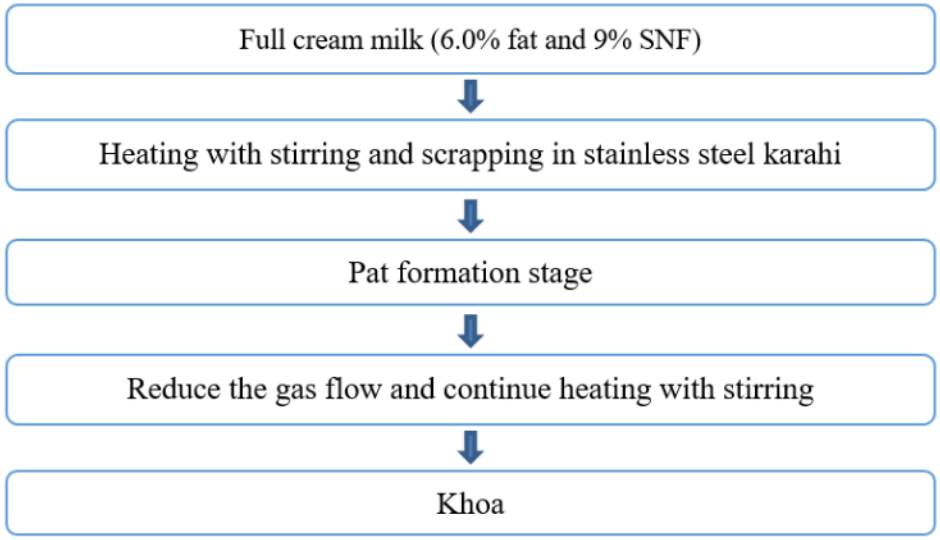


Figure 2 Flow diagram of khoa making

Figure 3 Photograph of assembled solar PTC air heater assisted tray dryer system

Preparation of khoa powder

Khoa was taken in clean stainless steel (AISI-316) trays and uniformly spread with 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 two consecutive reading differences is less than 0.1g, and considered as drying end point. The inlet, inside and exit air of tray dryer temperatures were measured by calibrated copper constantan thermocouples digital temperature indicator (accuracy: ± 0.1%). Relative humidity (% RH) of inlet and outlet air was measured using a humidity measurement sensor (range 0-100 % and resolution 0.1%). Khoa and khoa powder weight was measured by digital weighing balance having a least count of 0.001 g. The dried khoa lumps were ground in a grinder to a fine powder. The khoa powder thus obtained was loaded in desiccators and stored in air tight containers till further use. Process parameters were varied by three different drying temperatures i.e. 55°C, 60°C and 65°C. Based on the best product quality, the temperature was selected.

Analysis of khoa powder

The khoa powder was made from full cream milk khoa in solar-assisted tray dryer at three different temperatures i.e. 55°C, 60°C and 65°C. Khoa powder samples were coded based on a temperatures shown in **Table 1**.

Table 1 Coding of different khoa powders prepared using solar assisted mode at different temperatures

Code	Type of milk	Mode of heating	Temperature (°C)
KP-FMS55	FM	Solar assisted tray dryer	55
KP-FMS60	FM	Solar assisted tray dryer	60
KP-FMS65	FM	Solar assisted tray dryer	65

FM: Full cream milk, KP-Khoa Powder, S-Solar assisted tray dryer

In chemical composition analyses moisture, fat, protein, lactose and ash percentage were studied.In physical and engineering properties of khoa powder i.e. bulk density (kg/m^3), tapped density (kg/m^3), particle density (kg/m^3), porosity (%), Carr's index (CI), Hausner ratio (HR), angle of repose (°) and water activity (a_w) were studied.Colour value (L*, a*, b*) and colour indices i.e. chroma (C*), yellowness index (YI), whiteness index (WI) and browning index (BI) were also studied.

Chemical composition

The chemical composition of khoa powder including moisture was determined by the gravimetric method, fat was determined by the Mojonnier fat extraction tube method, the protein was determined by the Kjeldahl method and ash was determined as per the method mentioned in BIS: SP18, Part XI (1981) [8]. The total carbohydrate content of khoa powder was determined by difference methods.

Physical, engineering and rheological properties

Angle of repose: The angle of repose was determined by the angle of inclination (in degree) of the heap height (mm) to heap radius (mm) of the product. Measures of heap height and heap base radius with the help of simple scale. It is one of the engineering parameters of granular or powdery materials that specify the inter-particulate friction and varies from 0° to 90° [9].The formula to calculate the angle of repose is given below

$$Angleofrepose\ (\theta_r) = tan^{-1}\left(\frac{H}{R}\right) \qquad (1)$$

where, H: Heap height (mm),R: Heap radius (mm)

Bulk (ρ_b) and tapped (ρ_t) density**:** Bulk and tapped densities were determined as per the method described by Salooja and Balachandran [10].

Particle density (ρ_p):The particle density was calculated based on milk component particle densities using the following equation

$$\rho_p = \frac{1}{\sum\frac{M_x}{\rho_x}} = \frac{1}{\frac{m_w}{998.2}+\frac{m_f}{918}+\frac{m_p}{1400}+\frac{m_c}{1780}+\frac{m_a}{1850}} \qquad (2)$$

where,m_x= Mass fraction of component, ρ_x= Density of component, m_w= Mass fraction of moisture,m_f= Mass fraction of Fat, m_p= Mass fraction of protein, m_c= Mass fraction of carbohydrate or lactose, m_a= Mass fraction of ash

Porosity (ε):The porosity of the khoa powder at different moisture contents was calculated using the relationship between the tapped (ρ_t) and particle (ρ_p) densities of the powder as shown below:

$$\%\ Porosity\ (\%\ \varepsilon)=(1-\frac{\rho_t}{\rho_p})\ x\ 100 \qquad (3)$$

Flowability and cohesiveness:Flowability and cohesiveness of the khoa powder was evaluated in terms of Carr's Index (CI) [11] and Hausner Ratio (HR)[12], respectively. Both CI and HR were calculated from the bulk (ρ_b) and tapped (ρ_t) densities of the powder as shown below.

$$\%\ Carr's\ Index\ (CI)=\frac{\rho t-\rho b}{\rho t}\ x\ 100 \qquad (4)$$

$$Hausner\ Ratio\ (HR) =\frac{\rho_t}{\rho_b} \qquad (5)$$

Classification of the Flowability based on CI value and cohesiveness based on HR values are presented in (**Table 2**).

Table 2 Flowability based on CI value and cohesiveness based on HR values

(A) Carr's Index (CI), %	**Flowability**
Less than 15	Very good
15to 20	Good
20 to 35	Fair
35 to 45	Poor
Greater than 45	Very poor
(B) Hausner Ratio (HR)	**Cohesiveness**
Less than 1.2	Low
1.2 – 1.4	Intermediate
More than 1.4	High`
Source: Prakash [13]	

Water activity (a_w): Water activity is defined as the ratio of food water vapour pressure to pure water vapour pressure under identical conditions. The water activity of khoa powder was estimated by a Water activity meter (LabSwift aw, Novasina, Switzerland) at 25 °C.

Colour and colour indices measurement

Color and various colour indices of khoa powder and gulabjamun mix were analysed in terms of CIELAB parameters using a colour spectrophotometer model (Color Flex EZ, Hunter Lab, Virginia, USA). Direct reading of CIELAB coordinates (L*, a*, and b*) was done. L* is the lightness index, and the parameter a* has positive values for reddish colours and negative values for greenish colours, whereas b* has positive values for yellowish colours and negative values for bluish colours.Different colour indices like chroma (C*), whiteness index (WI), browning index (BI), yellowness index (YI) and color difference (ΔE) were calculated.

Chroma (C*):The quantitative measure of colorfulness, known as chroma (C*), quantifies how much a hue differs from a grey colour at same luminance. The higher the Chroma values, the higher the color intensity of samples perceived by humans [14]. Chroma (C*) was calculated using Eq.6, as shown below.

$$C^* = \sqrt{a^{*2} + b^{*2}} \qquad (6)$$

Whiteness index (WI): The whiteness index (WI) specifies the degree of whiteness and mathematically combines brightness and yellow-blue into a single term. It was measured using the Eq.7, as under [15].

$$WI = 100 - \sqrt{(100 - L^*)^2 + a*^2 + b^{*2}} \qquad (7)$$

Browning Index (BI): The browning index (BI) is one of the frequent indicators of browning in milk products containing sugar. Browning index (BI) was calculated using Eq. 8, as under.

$$BI=100\left(\frac{\frac{a*+1.75L*}{(5.645L*+a*-3.012b*}-0.31}{0.17}\right) \qquad (8)$$

Yellowness Index (YI):The browning index and the yellowness index (YI) are related colour metrics. The yellowness index (YI was calculated Eq. 9 as shown below.

$$YI= 142.86\frac{b*}{L*} \qquad (9)$$

Statistical Analysis

Statistical analysis was performed using IBM SPSS @ 20.0, the level of difference was calculated by Duncan's multiple comparison test ($p<0.05$). The difference was considered highly significant when ($P \leq 0.01$), significant when ($0.01 > p \leq 0.05$) and not significant when ($p > 0.05$). The mean ± standard error (SE) was used to represent the results.

Results and Discussion

Chemical composition and colour parameters of khoa

Khoa samples were prepared from full cream milk (6 % fat and 9.0% SNF). Khoa was prepared by continuous desiccation of milk in an open pan until a desirable consistency was achieved as per the procedure mentioned by Aneja *et al.*[16]. The average chemical composition of khoa of full cream milk (FM) is summarized in **Table 3**.

Table 3 Chemical composition of FM based khoa

Khoa	Moisture (%)	Fat (%)	Protein (%)	Lactose (%)	Ash(%)
FM	30.65±2.39	27.76±0.97	14.56±0.50	22.88±0.78	4.16±0.14

Data are expressed as mean ± standard error (n = 3); FM: full cream milk based khoa

It was observed that the average moisture, fat, protein, lactose and ash of FM khoa were 30.65, 27.76, 14.56, 22.88 and 4.16%, respectively (Table 3). Chemical constituents for the *khoa p*repared from buffalo milk were evaluated by Aggarwal *et al.*[17], the average fat, protein, moisture, lactose and ash content were observed as 35.24, 17.60, 21.76, 21.13 and 2.74%, respectively. The variation in the chemical composition of khoa samples was due to the initial composition of milk and the final consistency of khoa.

Average colour value (L*, a* & b* scale) and colour indices viz., Chroma (C*), yellowness index (YI), whiteness index (WI) and browning index (BI) are summarized in **Table 4**. Walstra *et al.* [18] reported that the differences in colour value (L*, a* and b*) of product variances due to several variables i.e., heating temperature and holding time and composition of components due to the formation of brown pigments, which statement was an agreement to the intermediate Maillard reaction product formed during the heat treatment. Morales and van-Boekel [19] reported that the Maillard reaction led to changes in food colour. Patange *et al.*[20] also reported that the L* value of cow and buffalo milk ranged from 43.99- 49.50 and 60.50 -68.77, respectively. Prasad *et al.*[21] reported that on average L*, a*, b*, chroma (C*), whiteness index (WI), browning index (BI) and yellowness index (YI) of thabdi peda had 37.74, 9.12, 13.56, 16.35, 35.63, 61.50 and 51.33, respectively. Results reported by Aggarwal *et al.*[17] for L*, a* and b* values of buffalo milk khoa were 59.05, -0.39 and 22.5, respectively.

Table 4 Colour values and different colour indices of khoa

Colour parameters	FM khoa
L*	68.88±0.20
a*	1.16±0.07
b*	19.52±0.03
C*	19.55±0.03
YI	40.48±0.10
WI	63.25±0.16
BI	34.18±0.51

Data are expressed as mean ± standard error (n = 3); FM khoa: full cream milk based khoa

Chemical Composition, Physical and Engineering Properties, and Colour Parameters of Khoa Powder

The khoa powder was made from full cream milk khoa in an solar assisted tray dryer at three different temperatures i.e. 55°C, 60°C and 65°C. Khoa powder samples have been coded based on variety of khoa, heating methods and drying temperatures as shown in Table 1. Proximate chemical composition, physical and engineering properties and colour attributes of different types of khoa powder made from FM-khoa in solar-assisted tray dryers at three different temperatures (55, 60 & 65°C) are summarized in **Table 5**.

Chemical composition of khoa powder

The average moisture content (%) of different types of khoa powder ranged from 2.6% to 4.22%. Vasiljevic *et al.* [22] reported that powdered milk and milk products must contain less than 5% moisture; khoa powder prepared under the experiment contains less than 5% moisture, which is within the prescribed value. The moisture content of khoa powder was decreased with the increase in temperature. Ranganadham [23], reported that moisture content of khoa powder made from standardized milk (5% fat and 9% SNF) khoa in tray dryer at 70 °C was 3.98 %; which is well within the range in present results.The average fat content (%) of different types of khoa powders was obtained between 38.37% to 39.00%. The fat content was increased with the increase in temperature of khoa powder, due to final moisture content of milk powder decreased with temperature. The average protein content (%) of experimental khoa powders in the range was obtained between 20.11% to 22.56%. The average ash content (%) of solar assisted tray dried khoa powder at three different drying temperatures (55, 60 & 65°C) ranged was found between 5.74% to 5.84%. The ash content was increased with the increase in temperature for same types of khoa powder, due to moisture content lower for high temperature drying of khoa powder. According to [23], the average chemical composition of khoa powder produced in a tray dryer from milk (5% fat and 9% SNF) was 3.98, 31.17, 26.73, 32.98, and 5.14% for moisture (%), fat (%), protein (%), lactose (%), and ash (%); which are consistent with current research findings.

Table 5 Chemical composition, physical and engineering properties and colour parameters of khoa powder made from full cream milk based khoa using solar assisted tray dryer

Khoa powder	KP-FMS55	KP-FMS60	KP-FMS65
Chemical composition			
Moisture (%)	4.22±0.14[b]	2.85±0.10[a]	2.6±0.03[a]
Fat (%)	38.33±0.17[a]	38.92±0.08[b]	39±0.14[b]
Protein (%)	20.11±0.01[a]	20.38±0.01[b]	20.44±0.04[b]
Lactose (%)	31.6±0.02[a]	32.03±0.02[b]	32.12±0.07[b]
Ash (%)	5.74±0.00[a]	5.82±0.00[b]	5.84±0.01[b]
Physical and Engineering Properties			
BD (kg/m^3)	502±3[b]	491±2[a]	487±2[a]
TD (kg/m^3)	704±5[b]	683±2[a]	675±2[a]
PD(kg/m^3)	1232±2[a]	1235±2[a]	1238±3[a]
Porosity (ε,%)	59.23±0.26[a]	60.24±0.13[b]	60.66±0.12[b]
CI (%)	28.68±0.06[c]	28.15±0.06[b]	27.85±0.10[a]
HR	1.40±0.00b	1.39±0.00[a]	1.39±0.00[a]
Angle of Repose(°)	44.40±0.09[c]	42.52±0.03[b]	41.80±0.12[a]
Water activity (a_w)	0.56±0.01[c]	0.38±0.00[b]	0.34±0.00[a]
Colour value and colour indices			
L*	70.81±0.12[a]	71.58±0.03[b]	72.43±0.05[c]
a*	3.55±0.06[c]	3.3±0.08[b]	3.06±0.05[a]
b*	33.24±0.05[c]	32.3±0.13[b]	31.52±0.16[a]
C*	33.43±0.05[c]	32.47±0.13[b]	31.67±0.16[a]
YI	67.07±0.19[a]	64.46±0.23[b]	62.17±0.35[c]
WI	55.61±0.10[a]	56.85±0.08[b]	58.01±0.15[c]
BI	65.00±0.24[c]	61.53±0.26[b]	58.54±0.46[a]

Data are expressed as Mean ± SE (n = 3);[a-c]means with different superscripts within a row differs significantly (p< 0.05);KP-FMS55, KP-FMS60 and KP-FMS65 represents, khoa powder made from full cream milk based khoa in solar assisted tray dryer at 55°C, 60°C and 65°C, respectively.

Physical and engineering properties of different types of khoa powder

The average bulk density (kg/m^3) of different types of solar assisted tray-dried khoa powder at three different drying temperatures ranged from 487±2 to 502±3 kg/m^3. Ranganadham [23] reported that the bulk density of khoa powder made from milk (5% fat and 9% SNF) in a atmospheric pressure tray dryer at 70°C was 450 kg/m^3, which was lower than our findings. The average tapped density (kg/m^3) of different khoa powder at different drying temperatures ranged 675±2 to 704±5kg/m^3. BD and TD of khoa powder were higher than WMP; loose bulk density of 461 kg/m^3, while tapped density values of 541 kg/m^3 were reported by Szulc *et al.*[24]. Pugliese *et al.*[25]reported that the ratio of tapped to bulk density was around 1.40; however, our findings indicates that the ratio varies between 1.30 and 1.41. The particle density depends on the composition of the product. The average calculated particle density (kg/m^3) of different khoa powder at different drying temperatures ranged 1232 to 1238 kg/m^3.According to Westergaard [26], the particle density of WMP containing 26% fat was measured as 1280 kg/m^3. Fitzpatrick *et al.*[27] also reported that the particle densities of spray- dried milk powder ranged from 1130 to 1180 kg/m^3. In the current study, khoa powder increases bulk and tapped density when tray drying temperature increased and resulted decrease in moisture content.

The porosity is defined as the percentage by volume of the powder mass occupied by air surrounding the individual particles. The porosity of food powder depends on various factors like moisture content, processing method and process conditions [28]. The average porosity (%) of khoa powders at three different temperatures ranged 59.23%to 60.66%. In the present study, tray-dried khoa powder shows increase in porosity with increasing drying temperature.Melter [29] stated that the porosity of WMP made in a spray drier was found as 42 and 50% for output air temperatures of 90°C and 113°C, respectively; which support our findings. The higher porosity of khoa powder at high temperatures was due to particle irregularity based on their texture and structure.

The compressibility index (sometimes referred to as Carr's index) measures the ability to reduce the volume of khoa powder by tapping. Low CI and HR of a khoa powder was an indicator of better flow properties. Powders with large agglomerates and larger size particles have good flow properties reported by Sharma *et al.*[30], as larger size powder particles have lower cohesive force and lesser friction and lower Vander Walls forces reported by Ilari and Mekkaoui [31]. Sanika *et al.*[32] reported that milk-based powder had good acceptability based on flowability. Due to the matrix structure of milk powder containing lactose, casein and fat obtained by spray drying tend to caking and have poor flowability resulting in solid bridges between the particles. Koç *et al.*[33] reported that the flowability of milk powders was influenced by composition at the surface of the particle, with higher levels of oiling off resultant poor flowability; in line with the current study, khoa powder after grinding and mixing tended to stick together and form lumps giving poor flowability. A Carr Index value indicated that powder had very poor (>45.0), poor (35.0 to 45.0), fair (20 to 35.0) and good (less than 20.0) flowability [13]. However, in solar assisted tray drying of different khoa powder produced in this study, the CI value ranges from 27.85±0.10to 28.68±0.06which shows fair flowability. The average Hausner Ratio (HR) of khoa powder made from FM and SM khoa ranged 1.39 to 1.40which was lower than whole milk powders (1.59) reported by Ilari and Mekkaoui [31]. A high HR value (1.2 to 1.4) indicated that khoa powder shows intermediate cohesiveness, resulting in poor flowability. The Hausner's Ratio (HR) and Carr's Index (CI) of different types of tray-dried khoa powder were found to decrease with an increase in drying temperature and decreased with final moisture content, indicating flowability of khoa powder improved at higher drying temperature.

The lower the angle and hence the free-flowing, the more easily the powder flowed. The average angle of repose (θr) of different types of khoa powder at different temperatures ranged between 41.80° to 44.40°. The angle of repose (degree) of khoa powder decreased with the increased drying temperature. The angle of repose of khoa powder was higher because of the high moisture content of all varieties of tray-dried khoa powder.According to Tuochy [34], the angle of repose for SMP ranged from 33° to 38° and for fat-containing milk powders from 40° to 58°. Water activity (a_w) highly influences the shelf life of dairy products. Water activity highly influences the mole fraction of solute concentration and free water content of the dried milk products. The average water activity of different khoa powders ranged between 0.34 to 0.56. Ranganadham [23] reported that the water activity of khoa powder made from milk (5% fat and 9% SNF) in an atmospheric pressure tray dryer at 70°C was0.42;which was in range of our findings (0.310 to 0.561). Pugliese *et al.*[25] reported that water activity of SMP and WMP ranged from 0.237 to 0.303 and 0.249 to 0.329; which were in accordance with the trends of our observations. Water activity of khoa powder was decreased with drying temperature; due to moisture content of khoa powder reduces at higher temperature.

Colour values and colour indices of solar assisted tray dried khoa powder

The changes in the physico-chemical properties of milk products, colour coordinates and colour indices were chosen as indicators. Walstra *et al.*[18] reported that the variations of colour value (L*, a* and b*) were due to affecting variables like drying type, drying medium, drying temperature and formation of the amounts of brown pigments by Maillard reactions during the heat treatment. Ryan *et al.*[35] reported that the colour variation parameter (L*, a* and b*) of milk products during storage time had very useful information related to quality and duration of shelf life of products. The lightness (L*) value was related to colour brightness by which we can perceive light and dark colours. At three different temperatures, the average lightness (L*) of various types of khoa powder ranged 70.81 to 72.43. The average redness (a*) values ranged from 3.06 to 3.55 for different types of khoa powder at three different temperatures. The average yellowness (b*) value ranged of different types of khoa powder at three different temperatures was found between 31.52 to 33.24. Nanua *et al.* [36]reported that the average L* value of WMP was 95.96, which was higher than that of the current findings of khoa powder. Pugliese *et al.* (2017) reported that average colour values (L*, a* and b*) for SMP and WMP were 96.94, -2.32, 11.12 and 96.1, -1.74, 14.45, respectively.

The average chroma (C*) ranged in different types khoa powder at three different temperatures from 31.67±0.16to 33.43±0.05. The average yellowness index (YI) for various types of khoa powder at three different temperatures ranged from 62.17±0.35to 67.07±0.19. The average whiteness index (WI) of various khoa powders at three different temperatures ranged from 55.61 to 58.01.

The browning index (BI) is used to characterise the overall changes in browning colour. It is defined as brown colour purity and is one of the most common indicators of browning in food products containing sugar. Browning index (BI) is a critical factor in the quality of khoa powder, if high browning index of khoa powder reproduce the functional and reconstitution properties lower. Higher browning index of khoa powder found to possess on undesirable after taste.The average browning index (BI) of khoa powder at three different temperatures ranged from 58.54 to 65.00. Fematt-Flores *et al.*[37] also reported WI of casein (maximum) had 95.04. Le *et al.* (2013) reported that the Maillard products in the later stage had an initiator for cross-linking of proteins in powdered milk products. Arulkumar *et al.* [38] found that the average WI values of tray dried-paneer cube samples at 50, 55, and 60 °C were 62.33 to 77.03, 5.33 to 67.03 and 57.16 to 59.35, respectively.

Optimization of Processing Parameters for Making Khoa Powder in solar Assisted Tray Dryer

Optimization was done to determine the best possible combination of air temperature and batch size that would lead to the most acceptable product in terms of energy requirement, final total solid and browning index of khoa powder. The goals that were set for obtaining the best combination are shown in **Table 6**. The data were analyzed using Design-Expert®V-10 software. Considering the constraints and their limits, the RSM has suggested the most suitable solution.

Table 6 Process optimization criteria for drying of khoa in tray dryer

Parameters	Constraints	Goal	Lower Limit	Upper Limit
Variables	Lot size (g)	In range	400	1000
	Air Temperature (°C)	In range	55	65
Responses	ER/MO(kWh/kg)	Minimize	2.08	4.03
	TS (%)	Maximize	94.8	97.9
	Browning index	Minimize	51.26	60.12

The Response surface method (RSM) was used to analyse the data from the khoa drying experiment. Thirteen alternative combinations of the RSM were carried out and performed, as indicated in **Table 7**. In order to determine the best possible combination of air velocity, batch size and input air temperature that would result in the most acceptable energy efficiency, RSM optimised the drying of khoa in a fluidized bed dryer [39]. An important factor in drying process is energy. The coefficient of determination (R^2) which reflects the proportion of variability in data explained or accounted by the model for ER/ MO, total solid (TS) and Browning index (BI) for drying of khoa were 0.979, 0.960 and 0.926 respectively. A large R^2 value near 1.0 indicates a better match for the quadratic model. The appropriate precision number will be higher than 4.0. In the present study, the adequate precision value for ER/MO, Total solid (TS) and Browning index (BI) for drying of khoa were greater than 4.0, underlining the suitability of the model to navigate the design shown in (**Table 8**).

Table 7 Effect of lot size and drying temperature on energy requirement, total solids and browning index

Run order	Lot size (g)	Drying temperature (°C)	ER/MO (kWh/Kg)	Total Solid (%)	Browning Index (BI)
1	700	60	2.86	97.12	54.73
2	275.7	60	3.24	97.46	53.23
3	700	67.1	2.12	97.45	51.26
4	700	60	2.73	97.12	54.23
5	700	52.9	4.03	94.80	60.12
6	1000	65	2.08	97.46	52.18
7	400	55	3.86	96.75	57.07
8	700	60	2.96	97.05	54.18
9	1000	55	3.68	95.04	56.83
10	400	65	2.24	97.90	52.84
11	700	60	2.78	97.35	54.34
12	1124.3	60	2.65	95.75	55.87
13	700	60	2.88	96.95	54.22

Table 8 Coefficients of selected models for drying of khoa

Response	Suggested model	Intercept	Model F-value	Adequate precision	R^2
ER/MO(kWh/kg)	Quadratic	2.84	64.70	25.74	0.979
TS (%)	Quadratic	97.12	33.23	17.12	0.960
Browning index	Quadratic	54.39	17.49	13.38	0.926

Table 9 ANOVA and partial coefficient of regression equations of suggested Models for drying of khoa

Factors		ER/MO	TS	BI
Model		1.69**	1.69**	1.69**
Linear level	A	-0.001*	-0.012**	0.005
	B	-0.656**	1.911**	-3.258**
Interactive effect	A X B	<0.0001	0.0002*	<0.0001
Quadratic level	A2	<0.0001	<0.0001	<0.0001
	B2	0.004	-0.016**	0.023

*Significant at 5% level (P< 0.05); **Significant at 1% level (P< 0.01); A= Lot size, B= Air temperature

Effect of Process Conditions on Different Responses

Energy requirement (kWh/ kg moisture) of khoa drying in tray dryer

From Table 7, it was observed that energy requirement (kWh/ kg moisture) of khoa drying in tray dryer is decreasing with increasing drying air temperature and lot size of khoa. This was due to the fact that higher drying air temperature resulted in a larger temperature gradient between the wet khoa bits and the hot drying air, ensuring greater rate of heat and mass transfer, so lesser time to complete the drying process. Chaudhary *et al.*[39] studied khoa drying to make khoa powder in a fluid-bed dryer at different temperatures, and find that the energy requirement per kg of moisture removed is 1.74 kWh/kg moisture at 70°C and 6.38 kWh/kg moisture at 60°C. The value of R^2 was 0.979 and the adequate precision value was 25.74. Multiple regression equation to predict ER/ MO for drying of khoa affected by different actual factors is as follows.

$$ER/\ MO\ (kWh/kg) = 2.842-0.147A-0.74B+0.005AB+0.04A^2+ 0.105B^2 \quad (10)$$

The Energy requirement was significantly affected by the lot size of khoa (linear term) and air temperature in tray dryer (linear term). The interactive effects of the factors were non-significant (P< 0.05). The coefficient estimates of energy requirement per unit moisture evaporation (ER/ MO) from khoa in tray drying model showed that the lot size of khoa(P< 0.01) and air temperature in tray dryer (P< 0.05) had a negative effect on ER/MO (**Table 9**). It can be seen from **Figure 4** that by increasing of air temperature, ER/MO was decreased up to 2.08 (kWh/kg moisture) with air temperature 65° C for 1000 g lot size of khoa.

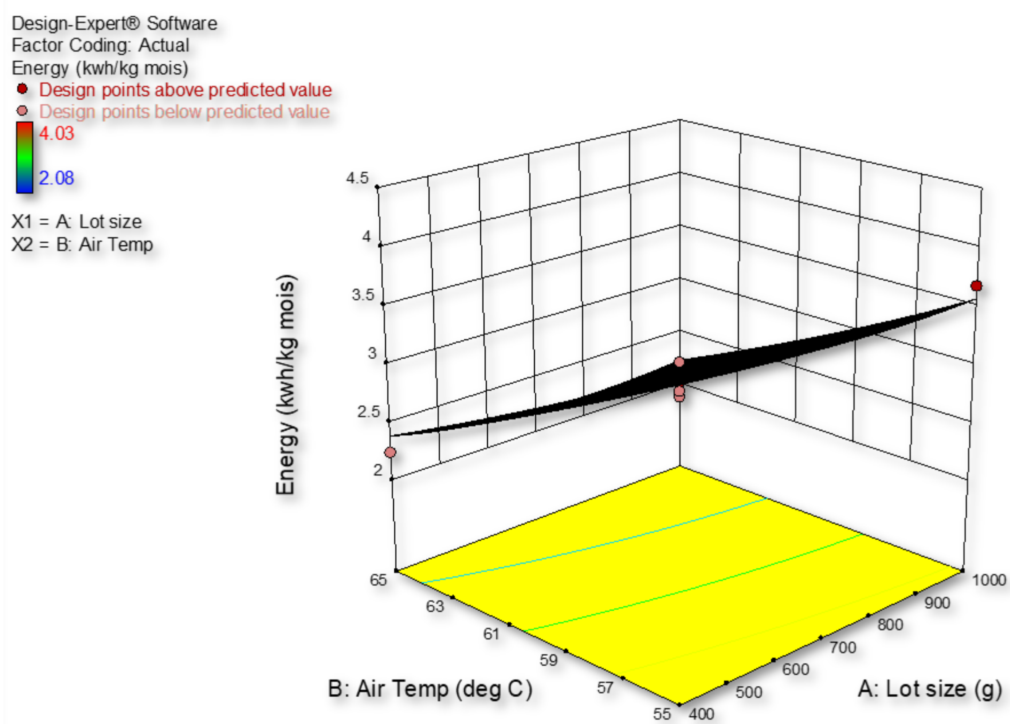


Figure 4 Response surface plot of ER/MO (kWh/kg) for khoa drying as influenced by air temperature and lot size

Total solid (TS) content of milk powder

From Table 7, it was observed that the total solid content of khoa powder increased with increasing drying air temperature and decreasing lot size. This was due to the fact that higher drying air temperature resulted in a larger temperature gradient between the wet khoa bits and the hot drying air, ensuring greater rate of heat transfer to the khoa. This provided better driving force for evaporation of moisture. Thus, higher inlet temperature produced powders with lower moisture content. Schuck *et al.*[40] reported that the moisture content of skim milk powder reduced from 5.2 to 4.5% with increase in outlet air temperature from 77 to 87°C. Multiple regression equation to predict TS of khoa powder for drying of khoa affected by different actual factors is as follows.

$$TS\ (\%) = 97.118-0.571A+0.915\ B+0.317AB-0.151A^2-0.391\ B^2 \qquad (11)$$

The total solid of khoa powder was significantly affected by the lot size of khoa (linear term) and air temperature in tray dryer (linear and quadratic term). The interactive effects of the factors were significant ($P< 0.05$). The coefficient estimates of total solid(% TS) ofkhoa powder model showed that the lot size of khoa($P< 0.05$)had negative effect
and air temperature in tray dryer ($P< 0.05$) had a positive effect on TS content of khoa powder. It can be seen from **Figure 5** that by increasing air temperature, TS was increased up to 97.90 % for air temperature 65° C and lot size of khoa 400 g.

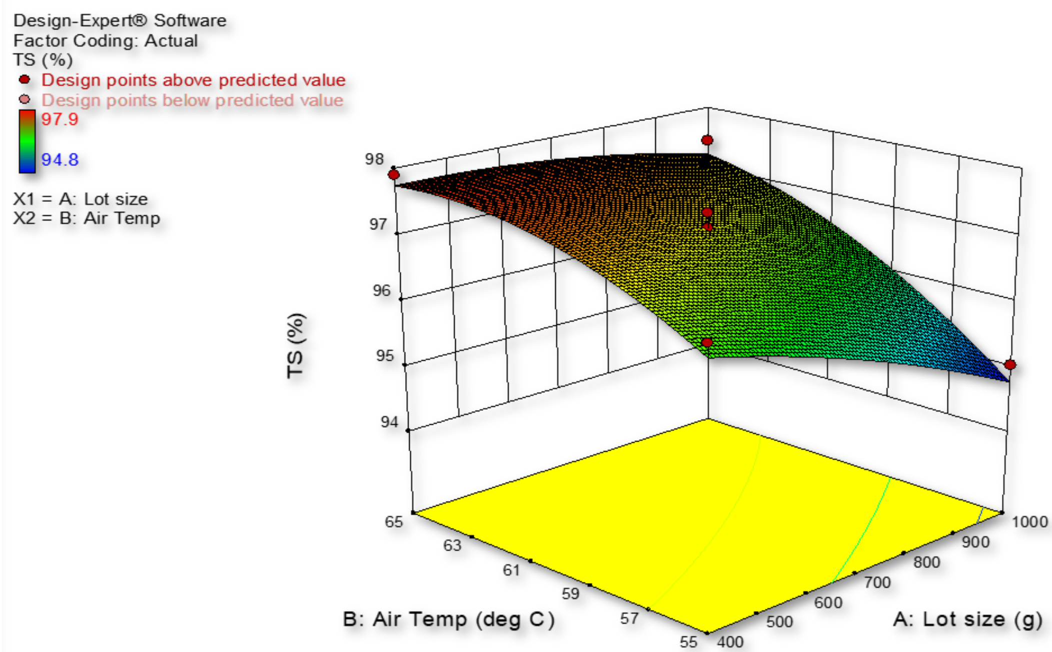


Figure 5 Response surface plot of final total solid content for dried khoa as influenced by air temperature and lot size

Browning index (BI) of khoa powder

From Table7, it was observed that the browning index (BI) of khoa powder decreased with increasing drying air temperature and decreasing with lot size. The value of R^2 was 0.926 and the adequate precision value was 13.38. Multiple regression equation to predict BI of khoa powder for drying of khoa affected by different actual factors is as follows.

$$BI= 54.34+0.354A-2.676B-0.105AB+0.007A^2+0.0578\ B^2 \qquad (12)$$

The browning index (BI) of khoa powder was significantly affected by the air temperature in tray dryer (linear term). The interactive effects of the factors were non-significant ($P< 0.05$). The coefficient estimates of browning index (BI) of khoa powder model showed that the lot size of khoa had positive effect and air temperature in tray dryer ($P< 0.01$) had a negative effect on TS content of khoa powder. It can be seen from **Figure 6** that by increasing of air temperature, BI was decreased up to 52.18 for air temperature 65° C and lot size of khoa 1000 g.

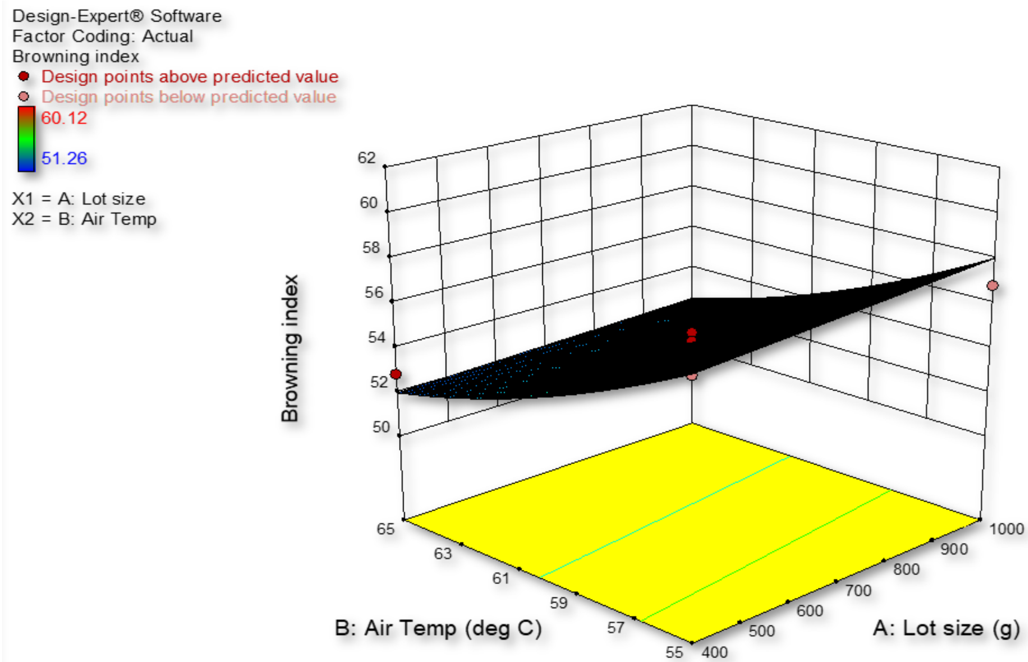


Figure 6 Response surface plot for browning index for dried khoa as influenced by air temperature and lot size

Based on the data of energy requirement per kg moisture evaporation (kWh/kg moisture), the final total solid and browning index for drying of khoa with different combinations the lowest possible energy requirement per kg moisture evaporation, highest possible total solid (% TS) content of khoa powder and lowest possible browning index (BI) would be a solution from Response surface methodology. The lot size of drying of khoa 621.6 (g) and air temperature in tray drying maintained at 65 °C (**Table 10**) of optimized solution for khoa powder properties.

Table 10 Optimized solution for drying parameters

Lot size (g)	Drying Temperature (°C)	ER/MO (kWh/kg)	TS (%)	BI	Desirability
621.6	65	2.25	97.70	52.18	0.915

Conclusion

Solar energy is the energy of the current era and has potential to combat the shortage of primary energy sources like coal, gas and oil. It is undoubtedly playing a critical role in producing the necessary energy to fulfill the rising energy demands. The use of solar energy is a new approach and can be used in assistance with other conventional system. In present study shelf life of khoa was extended by drying and converting it to powder using solar PTC air heater assisted tray dryer system.

Optimized parameter obtained by response surface methodology (RSM) through numerical optimization was lot size of drying of khoa 621.6 g and the dying temperature 65°C. The average moisture, fat, protein, total carbohydrate, ash, L*, a* and b* of the experimental full cream milk (FM)khoa were 30.65%, 27.76%, 14.56%, 22.88%, 4.16%, 68.88, 1.16 and 19.52, respectively. The average moisture, fat, protein, total carbohydrate and ash content of solar assisted tray dried khoa powder at different temperature (55, 60 and 65°C) ranged 2.6 to 4.22%, 38.33 to 39.00%, 20.11 to 20.44%, 31.60 to 32.12% and 5.74 to 5.84%, respectively. The average bulk density, tapped density, porosity, Carr's index, Hausner ratio, angle of repose, water activity, L*, a*, b* and browning index of khoa powder at different temperature ranged 487 to 502 kg/m^3, 675 to 704 kg/m^3, 59.23 to 60.66%, 27.85 to 28.68, 1.39to 1.40, 41.80 to 44.40°, 0.34 to 0.56, 71.81to 72.43, 3.06 to 3.55, 31.67 to 33.24 and 58.54 to 65.00, respectively.

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