**Physico-Chemical and Engineering Properties of Cow and Buffalo Milk based *Khoa* Powder: A Comparative Study.**

**ABSTRACT**

|  |
| --- |
| The study was focused on the evaluation of different Physico-chemical and engineering properties of cow and buffalo milk based solar assisted tray drying *khoa* powders. The fresh buffalo milk (BM) and cow milk (CM) were collected from local dairy farms. The cow and buffalo milk *khoa* were prepared following the traditional *khoa* making process. The *khoa* powder from *khoa* was make with the help of hot air circulation in a solar assisted tray dryer. The temperature inside the tray was 65°C to ensure that the *khoa* was dried at the appropriate rate. Obtained buffalo and cow milk *khoa* powders were analyzed for chemical composition (moisture, fat, protein, ash and carbohydrate), physical and engineering properties (bulk density, tapped density, porosity, Carr’s index, Hausner ratio, angle of repose, water activity) and colour parameters (L\*, a\*, b\*, chroma, yellowness index, whiteness index and browning index). The average bulk density, tapped density, porosity, carr’s index, Hausner ratio, angle of repose, water activity, L\*, a\*, b\* and browning index of buffalo and cow milk based *khoa* powder were 589 kg/m3, 709 kg/m3, 0.47, 16.91 %, 1.204, 42.7°, 0.28, 68.72, 1.37, 22.47, 40.11 and 551 kg/m3, 643 kg/m3, 0.56, 14.32 %, 1.167, 43.2°, 0.32, 80.92, -0.68, 24.19, 33.96, respectively. *Khoa* powder is used in various Indian sweets and desserts, to provide a rich, creamy texture and enhance the flavor of these. Therefore, there is a further scope for improvement in the flavour and texture of the *khoa* based product by incorporating *khoa* powder in the commercial mix. |

*Keywords: Khoa powder, Cow milk, Solar, Green energy, Porosity, browning index, tapped density*

1. **INTRODUCTION**

India is the world’s largest milk producer, producing around 239.30 million metric tonnes in the year 2023-24 (FAO, 2024), with buffalo milk share around 45%. Cow milk is the most produced type of milk worldwide, with an annual production of approximately 552 million metric tons (MMT) in the year 2024. Cow milk is versatile and it’s used to produce a variety of dairy products such as fluid milk, chhana based sweet, cheese, butter, yogurt and milk powder. Buffalo milk the world's second-largest milk supply after cows' milk with production of 127.34 million metric tonnes (FAOSTAT, 2018). Buffalo milk has higher fat, protein, lactose, and mineral contents (Abesinghe et al., 2020 ) making it ideal for producing high-quality dairy products like mozzarella cheese, *khoa* based sweets and *paneer*.  Buffalo milk is suitable for a wide range of dairy products production (Khedkar et al., 2003). Although buffalo milk was preferred for to manufacture of many dairy products due to its high SNF and fat content, but use in the production of dried milk products was limited. Milk powder made from buffalo milk had poor solubility, high free fat liberation and high fat oxidation problems (Murtaza et al., 2017).

Raw milk production is subject to seasonality, which makes it difficult to continuity of production of milk based products (Felfoul et al., 2021). Drying of milk and milk products was considered the best way to preserve the milk solids. Drying is the process wherein moisture is removed from the food material as a result of concurrent heat and mass transfer (Sontakke and Salve, 2015). In the direct convective drying process, hot air is used as a working fluid most commonly because it is a simple, efficient and low cost process (Violidaki et al., 2017).

Tray drying techniques have been used in homes and by small commercial growers worldwide for millennia. In improved drying technologies of milk products like *khoa* drying tray dryer an option. 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 ambient temperature with minimal spoilage. Generally, tray drying equipment entails a cabinet fitted with shelves of solid or perforated trays, a way to heat the air and a usually a fan or blower to circulate moisture away from the product, unless the environment is arid enough to allow convection alone to circulate air. The Parabolic trough collector (PTC) system occupies less space and produces higher thermal efficiency compared to the flat plate collector solar heating system (Jamadi *et al.,* 2017). Based on this solar air heaters can be designed at a lower cost and minimum amount of material. The popular use of PTC air heaters is due to lower fabrication cost, higher efficiency and can easily assemble with tray dryer (Gupta and Kaushik, 2009).

Converting liquid milk into heat-desiccated traditional Indian dairy products was one method of preserving milk solids for direct human consumption. Among heat desiccated milk product, *khoa* and *khoa* based products have a longer shelf-life than raw milk (Asgar and Chauhan, 2017). *Khoa* is a major intermediate product base for variety of milk sweets, i.e., gulabjamuns, kalajamun, burfi, kalakand, peda and their variants. *Khoa* powder is a desiccated product that potentially offers an economically attractive long-life product that can supplement the traditional, perishable *khoa*. Under the sub-tropical conditions prevailing in India the shelf life of *khoa* can be extended only to a limited period. The prevailing methods cannot help in flush season, till the one set of lean months, i.e. for about six months. The manufacture of *Khoa* powder has tremendous scope; some efforts were made for the manufacture of *khoa* powder (Khatkar, 2007). *Khoa* powders possess various physico-chemical and engineering properties which are important to both industrial and consumer. The characteristics of any food product are very important parameters for food processing operation, and design of the process, modeling and optimization. Therefore, there is further scope for improvement in the flavour and texture of the *khoa* based product by incorporating *khoa* powder in the commercial mix. In the present investigation a comparative study of physico-chemical and engineering properties of cow and buffalo milk *khoa* powder made in solar assisted tray drying**.**

**2. MATERIALS AND METHODS**

**2.1 Location and Period of Study**

The present work was conducted at the Department of Dairy Engineering, College of Dairy Science, Kamdhenu University, Amreli, Gujarat, India from February 2022 to January 2024.

**2.2 *Khoa* Preparation**

Fresh buffalo milk (BM) and cow milk (CM) were collected from local dairy farms at Amreli. The cow and buffalo milk *khoa* were prepared by following the traditional *khoa* making process as described in the flowchart (Figure 1). When the desired consistency has been achieved, the heating is stopped and the product is allowed to cool to room temperature (Aneja et al., 2002).

Cow or Buffalo milk

Heating with stirring and scrapping in stainless steel karahi

Pat formation stage

Reduce the gas flow and continue heating with stirring

Khoa

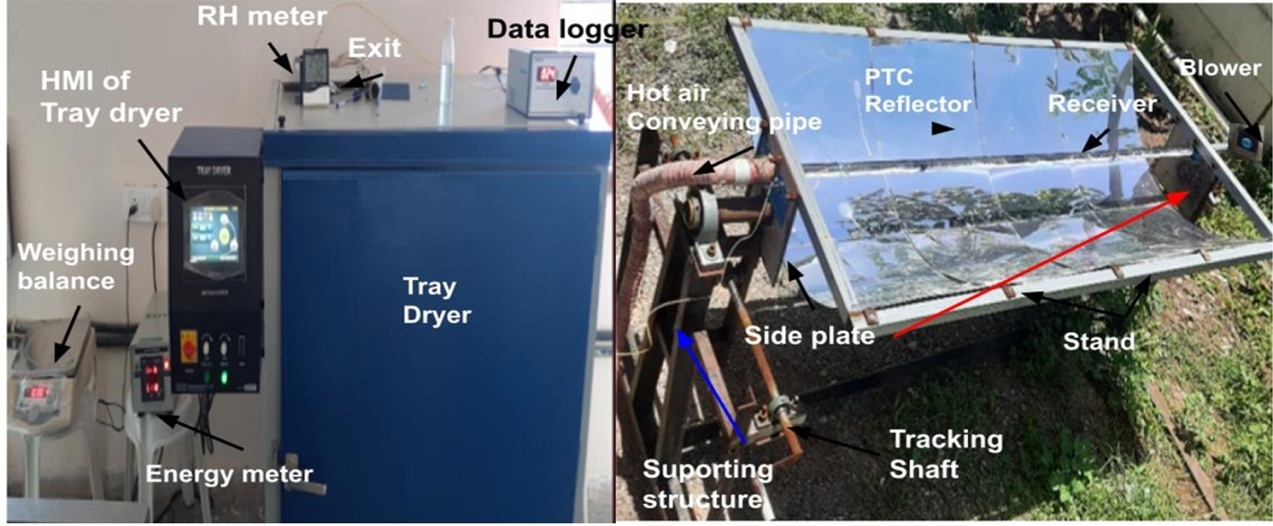
**Figure 1: Flow diagram of *khoa* making**

**2.3 Sample Preparation for *Khoa* Drying**

*Khoa* was taken in a tray, manually broken into small particles and spread in the tray (AISI-316) up to 0.5 cm bed thickness. The *khoa* was dried with the help of hot air circulation in a tray dryer. Forced convection heating removed moisture from the *khoa*. The temperature inside the tray was controlled (65°C) to ensure that the *khoa* was dried at the appropriate rate.

**2.4 Experimental Set-up and Instrumentation**

The schematic experimental setup (**Figure 2**) of the solar-assisted tray dryer system is given. A 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. *Khoa* and *khoa* powder weight measured by digital weighing balance of 20 kg capacity (model TJ-6000, Scaletech, made in India) having a least count of 0.001 g. Temperatures, relative humidity and weighing sensor attached with data logger to take data. A water activity meter (LabSwift aw, Novasina, Switzerland) and multi-channel temperature monitor (12-point temperature monitor with thermocouple temperature sensors; Make: DIGIQUAL, Chennai, India) were used in this experiment.



**Figure 2** **Schematic diagram of solar assisted tray dryer**

**2.5 Preparation of *Khoa* Powder**

For the preparation of *khoa* powder, *khoa* was manually broken into small particles and spread in a tray with the help of a fork and aluminum foil up to 0.5 cm thick layer. The tray was loaded into the drier and the heater was started. *Khoa* powder was obtained through a solar assisted tray drying system at an optimized temperature of 65°C up to equilibrium moisture content (Prasad *et al*., 2024). Mass of partial drying *khoa* powder taken in intervals of 30 minutes. After the drying period, the tray was taken out of the drier and allowed to cooling to ambient temperature. The dried *khoa* particles were ground in a mixer to a fine powder. The *khoa* powder thus obtained was stored in desiccators till further use.

Khoa (made from cow or buffalo milk) taken in tray

Khoa uniformly spreeded with about 0.5 cm thickness in tray

Tray dryer on and temperature was set 65 °C

Partially dried khoa lumps were manually mixed at every 30 minutes interval

Drying upto EMC

Khoa powder stored at air tight container

**Figure 3: Flow diagram of *khoa* powder preparation in solar assisted tray dryer**

* 1. **Methodology/ Experimental Observations**

Experiments have been performed at the College of Dairy Science, Amreli. Cow and buffalo milk to prepare *khoa* powder were triplicated.

**2.7. Analysis of *Khoa*/*Khoa* Powder**

The moisture content of *Khoa* / *khoa powder* was determined by the gravimetric method, fat was determined by the Mojonnier fat extraction tube method, protein was determined by the kjeldhal method and ash by as per ISI: SP18, Part XI (1981). The lactose content of *Khoa*/ *khoa powder* was determined by the difference method, i.e., Lactose = 100- (moisture + fat + protein + ash).

The angle of repose measures the angle of inclination of the free surface to the horizontal of a bulk solids pile. It is one of the primary parameters of granular materials that indicate inter-particulate friction. It is related to the particle density, size, surface area, shape and coefficient of friction (Littlefield *et al*., 2011). Calculation of the angle of repose (by

Where,

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

The loose bulk density and tapped density was determined as per the method described by Reddy et al. (2014).

The particle density (**ρp**) was calculated based on the milk component

- - - - **(2)**

where,

Mx= Mass fraction of component, ρx= Density of component, mw= Mass fraction of moisture., mf= Mass fraction of fat, mp= Mass fraction of protein, mc= Mass fraction of carbohydrate or lactose and ma= Mass fraction of ash,

The porosity (ε) of the *khoa* powder was calculated using the relationship between the tapped (ρt) and particle (ρp) densities of the powder as shown below:

***% Porosity (% ε)=(1- ) x 100***  ----------------**(3)**

Flowability and cohesiveness of the *khoa* powder were evaluated in terms of the Carr Index (CI) (Carr, 1965) and Hausner Ratio (HR) (Hausner, 1967), respectively. Both CI and HR were calculated from the bulk (ρb) and tapped (ρt) densities of the *khoa* powder as shown below.

***% Carr’s Index (CI)= x 100***  - - - - - - **(4)**

***Hausner Ratio (HR) =***  - - - - - - **(5)**

Classification of the flowability (< 15: very good, 15-20: good, 20-25: fair, 35-45: bad > 45: very bad) and as cohesiveness (< 1.2: low, 1.2-1.4: intermediate and > 1.4: high) of the *khoa* powder based on the CI and HR values, respectively (Prakash, 2016).

**Water activity (aw):** 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:-** Colour of *khoa*/ *khoa* powder was evaluated using a colour spectrophotometer model name colour Flex EZ in terms of CIELAB parameters. The parameter L\* was measured lightness value, a\* takes positive values for reddish colours and negative values for greenish ones, whereas b\* takes positive values for yellowish colours and negative values for bluish ones. Researchers frequently use the L\*a\*b\* system if they were looking at the “true” human eye perception of color (Leon et al, 2006).

Colour indices are shown in Table1. Chroma (C\*) considered the quantitative attribute of colorfulness, was used to determine the degree of difference of a hue in comparison to a grey Colour with the same lightness (Bermúdez-Aguirre et al, 2009). Whiteness index (WI)was indicates the degree of whiteness and mathematically combines lightness and yellow–blue into a single term. The browning index (BI) was defined as brown color purity and is one of the most common indicators of browning in food products containing sugar. The yellowness index (YI) was used as a color measurement related to browning index.Colour difference (), Color changes can be measured as total color deference. Total color difference indicates the magnitude of colour difference between two samples, if ∆E > 3, colour differences that could be perceptible to the human eye (Quintanilla et al., 2019).

**Table 1: Colour indices and mathematical equations**

|  |  |  |  |
| --- | --- | --- | --- |
| S.N. | **Colour indices** | **Equations** | **References** |
| 1 | Chroma (C\*) | **C\* =( a\*2 + b\*2)0.5** | Bermúdez-Aguirre et al, 2009 |
| 2 | Whiteness index (WI) | **WI= 100-((100- L\*)2+ a\*2 + b\*2)0.5** | Vargas *et al.,* 2008 |
| 3 | Browning index (BI) | **BI=100(**) | Erbay and Koca, 2015. |
| 4 | Yellowness index (YI) | **YI= 142.86 b\*/L\*** |  |
| 5 | Colour difference () | **= [∆L\*2 +∆a\*2 +∆b\*2]0.5** | Fernandez-Avila et al., 2017 |

**2.8 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 mean ± standard error (SE) was used to represent the results.

**3. RESULTS AND DISCUSSIONS**

**3.1 Analysis of *Khoa***

The average chemical composition and colour values of *khoa* of the two varieties of milk i.e. buffalo milk (BM) and cow milk (SM) are summarized in Table 2.

**Table 2: Chemical composition and colour value of *khoa*.**

|  |  |  |  |
| --- | --- | --- | --- |
| **SN.** | ***Khoa* characteristics** | **BM *khoa*** | **CM *khoa*** |
| **1** | Moisture (%) | 32.20±1.40 | 29.23±3.02 |
| **2** | Fat (%) | 29.03±1.65 | 22.40±1.01 |
| **3** | Protein (%) | 13.57±0.50 | 16.93±0.17 |
| **4** | Lactose (%) | 21.32±0.78 | 26.80±0.27 |
| **5** | Ash (%) | 3.88±0.14 | 4.64±0.06 |
| **6** | L\* | 60.68±1.53 | 72.86±0.52 |
| **7** | a\* | 2.03±0.19 | -0.34±0.01 |
| **8** | b\* | 18.24±0.18 | 21.43±0.14 |
| **9** | Chroma (C\*) | 18.35±0.16 | 21.43±0.14 |
| **10** | Yellowness index (YI) | 42.94±0.67 | 42.02±0.05 |
| **11** | Whiteness index (WI) | 56.61±1.32 | 65.41±0.32 |
| **12** | Browning index (BI) | 37.45±0.94 | 33.59±0.05 |

Data are expressed as mean ± standard error (n = 3); BM: Buffalo milk; CM: Cow milk

It was observed that the average moisture, fat, protein, lactose and ash of buffalo milk (FM) *khoa* were 32.20, 29.03, 13.57, 21.32 and 3.88 %, respectively whereas those for cow milk (CM) *khoa* were 29.23, 22.40, 16.93, 26.80 and 4.64%, respectively (Table 2). Results reported by Srinivasan & Anantkrishnan (1964) gross chemical composition (%) i.e. moisture, fat, protein, lactose and ash for cow milk *khoa* were found of 30.4, 22.2, 18.8, 24.9 and 3.7 %, respectively. Chemical constituents for the khoaprepared from buffalo milk were evaluated by Aggarwal *et al.* (2019), 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*.

According to Granato and Masson (2010), L\* represents luminosity, which lies between black and white. Walstra *et al.* (2006) reported that the differences in colour value (L\*, a\* and b\*) of product variances due to several variables i.e., heating temperature- time combination and composition of components due to the formation of brown pigments or intermediate Maillard reaction product formed during the heat treatment. The buffalo milk *khoa* were found to have more a\* and YI, BI but less L\*, b\*, C\* and WI compared to cow milk *khoa* may be due to variation of milk solid composition and moisture content of *khoa*. Results reported by Aggarwal *et al.* (2019) for L\*, a\* and b\* values of buffalo milk *khoa* were 59.05, -0.39 and 22.5, respectively. Adekante et al. (2010) divided perceivable colour differences into three categories, highly distinct (∆E > 3 ) , distinct (1.5<∆E < 3 ) and small difference (∆E < 1.5 ).

**3.2 Analysis of *Khoa* Powder**

**3.2.1 *Chemical composition and colour of khoa powder*.**

The average colour difference of cow and buffalo milk base *khoa* powder is shown in Table 3.

**Table 3: Chemical composition and colour indices of *khoa* powder.**

|  |  |  |  |
| --- | --- | --- | --- |
| **SN.** | ***Khoa* characteristics** | **BM *khoa*** | **CM *khoa*** |
| **1** | Moisture (%) | 1.90±0.59 | 2.83±0.24 |
| **2** | Fat (%) | 42.47±0.76 | 28.40±0.98 |
| **3** | Protein (%) | 19.47±0.60 | 24.27±0.16 |
| **4** | Lactose (%) | 30.40±0.68 | 38.02±0.22 |
| **5** | Ash (%) | 5.36±0.19 | 6.47±0.12 |
| **6** | L\* | 68.72±0.22 | 80.92± 0.37 |
| **7** | a\* | 1.37±0.02 | -0.68± 0.03 |
| **8** | b\* | 22.47±0.16 | 24.19±0.13 |
| **9** | Chroma (C\*) | 22.51±0.16 | 24.20±0.13 |
| **10** | Yellowness index (YI) | 46.72±0.18 | 42.71±0.03 |
| **11** | Whiteness index (WI) | 61.46±0.09 | 69.18±0.13 |
| **12** | Browning index (BI) | 40.11±0.16 | 33.96±0.06 |

Data are expressed as mean ± standard error (n = 3); BM: Buffalo milk; CM: Cow milk

Cow milk *khoa* powder, a pale yellow tinge of brown, smooth and compact fine grains, pleasantly sweet. Contributes a firmer texture due to less fat content than buffalo milk *khoa* powder. Buffalo milk *khoa* powder, dull white, soft and loose body, slightly heated flavour. Contribute oily and greasy appearance due to less fat content than buffalo milk *khoa* powder. The average chemical composition of BM and CM *Khoa* powder is represented in Table 3. The moisture content of CM *khoa* powder (2.83%) was higher than BM *khoa* powder (1.90 %). Vasiljevic *et al.* (2021) reported that powdered milk and milk products must contain less than 5% moisture; *khoa* powder prepared in the experiment contains less than 5% moisture, which is within the prescribed value. Freeze-dried yogurt powder without any additives has a moisture level of 4.25%, as evaluated by Ismail *et al.* (2020). In fat analysis, fat content was found higher in buffalo milk *khoa* powder (42.47%) than in cow milk *khoa* powder (28.40 %), due to cow milk content lower amount of fat than buffalo milk. The protein content of cow milk based *khoa* powder was higher than buffalo milk-based *khoa* powder, due to the difference in protein content of the two types of milk. The lactose content of cow *khoa* powder was higher than buffalo milk *khoa* powder, due to the fat content (%) of full cream milk being higher than standardized milk. The ash content of CM *khoa* powder was higher than BM *khoa* powder, due to the difference in the mineral and fat content of the two types of milk. According to Ranganadham (1988), 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. The moisture, fat and ash content of cow and buffalo milk based *khoa* powder were reported to be 3.0,31.3,4.80 and 2.9,33.90,5.30%, respectively (Thompkinson and De, 1981)

The changes in the physico-chemical properties of milk products, colour coordinates and colour indices were chosen as indicators. Walstra *et al.* (2006) reported that the variations of colour value (L\*, a\* & b\*) were due to affecting variables like drying type and drying medium. Ryan *et al.* (2020) reported that the colour variation parameter (L\*, a\* and b\*) of milk products during storage time had very useful information related to the quality and duration of shelf life of products. The lightness (L\*), redness (a\*), and yellowness values (b\*) of buffalo and cow milk *khoa* powder were found 68.72 ±0.22, 1.37± 0.02, 22.47± 0.16 and 80.92± 0.37, -0.68± 0.03, 24.19± 0.13, respectively (Table2). The L\*, a\* and b\* values depend on different sources of milk, chemical composition, *khoa* powder process such as the type of dryer and drying conditions during their manufacture (Meena et al., 2017). Maillard reactions lead to changes in *khoa* powder colour. Temperature can also be a potential reason for different results in colour. Milovanovic *et al.* (2020) reported that lightness (L\*), redness (a\*) and yellowness (b\*) values of cow milk powder were 88.6 ± 10.1, 0.2± 6.8, 11.8 ± 6.1, respectively, which showed more L\* and b\* values and whereas of a\* value is within the range in current findings. Patange *et al.* (2022) also reported that the a \* and b\* values of cow and buffalo milk ranged from 2.57 to 2.82, 1.73 to 2.88, 16.49 to 18.59 and 6.52 to 8.82, respectively. 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 also concluded that higher L\*and lower a\* and b\* for SMP than WMP.

Various colour indices of cow and buffalo milk based tray-dried *khoa* powder i.e. chromaticity (C\*), yellowness index (YI), whiteness index (WI) and browning index (BI) were calculated by mean values of L∗, a∗, and b∗ values of the sample (Table 1). The chromaticity (C\*), yellowness index (YI), whiteness index (WI) and browning index (BI) of buffalo and cow milk *khoa* powder were found 22.51±0.16, 46.72±0.18, 61.46±0.09, 40.11±0.16 and 24.20±0.13, 42.71±0.03, 69.18±0.13, 33.96±0.06, respectively (Table2). Chromaticity (C\*) may describe colorfulness and represent the colour sensation; when colour is fully saturated. Chroma value found in CM *khoa* powder (24.20±0.13) was higher than BM *khoa* powder (22.51±0.16), therefore saturation or vividness of colour in CM *khoa* powder higher than BM *khoa* powder. Browning index (BI) is defined as brown color purity and is one of the most common indicators of browning in food products containing sugar.BI value was found in CM *khoa* powder (33.96±0.06) lower than BM *khoa* powder (40.11±0.16). Al-Hilphy et al. (2022) reported that maximum C\*, WI and BI values of concentrated milk were 20.12, 74.26 and 28.11, respectively. Fematt-Flores *et al.* (2022) also reported WI of casein (maximum) had 95.04. Arulkumar *et al.* (2023) 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, concerning Chroma (C\*) is used to determine the degree of difference of a hue in comparison to a grey colour with the same lightness.

This difference in the ∆E value may be attributed to the heat treatment for *khoa* powder at different temperatures. Al-Hilphy *et al.* (2022) reported the maximum and minimum of ∆E between concentrated and unconcentrated milk. ∆E of cow and buffalo milk based *khoa* powder obtained was 12.49.

**3.2.2. Physical and Engineering properties of *khoa* powder.**

**Table 4**: **Avarage values of physical and engineering properties of *khoa* powder.**

|  |  |  |  |
| --- | --- | --- | --- |
| **SN.** | ***Khoa* powder types** | **BM *Khoa* powder** | **CM *Khoa* powder** |
| **1** | Bulk density (kg/m3) | 589±9 | 551±27 |
| **2** | Tapped density( kg/m3) | 709±8 | 643±40 |
| **3** | Particle density(kg/m3) | 1337±15 | 1452±19 |
| **4** | Porosity (ε) | 0.47±0.00 | 0.56±0.03 |
| **5** | Angle of repose (degree) | 42.7±0.5 | 43.2±0.9 |
| **6** | Carr Index(% CI) | 16.91±0.4 | 14.32±1.2 |
| **7** | Hausner Ratio (HR) | 1.204±0.006 | 1.167±0.016 |
| **8** | Water activity (aw) | 0.28±0.03 | 0.32±0.04 |

**Mean±SE; n=3**

Powder parameters like HR, CI, Loose and tapped density were used for quantitative analysis of the flowability of food powder (Juliyano et al., 2006). Milk powder having low density was undesirable due to increases in the cost of packing, storage and transportation (Schuke and Qwest,2011). Table 4 shows that bulk density of BM *khoa* powder (589±9 kg/m3) was higher compared to CM *khoa* powder (551±27 kg/m3). The variation of bulk density of the different *khoa* powders was due to the amount of air including moisture content and amount of interstitial air between powder particles, shape, size and size distribution of the particles themselves. Ranganadham (1988) reported that the bulk density of *khoa* powder made from milk (5% fat and 9% SNF) in an atmospheric pressure tray dryer at 70°C was 450 kg/m3, which was lower than our findings. Tapped density was higher than bulk density because as tapping was applied, smaller particles rolled between these voids to reach a dense packing condition. The average tapped density (kg/m3) of buffalo milk and cow milk tray-dried *khoa* powder were found 709±8 kg/m3 and 643±40 kg/m3, respectively. Pugliese *et al.* (2017) reported that the ratio of tapped to bulk density was around 1.40; however, our findings indicate that the ratio in case of buffalo milk *khoa* powder and cow milk *khoa* powder was 1.20 and 1.17, respectively. However, the particle density was largely unaffected by moisture content due to the dependence on only a fraction of the components of milk. The particle density of BM *khoa* powder was (1337 kg/m3) lower than and CM *khoa* powder (1452 kg/m3). According to Westergaard (1994), the particle density of WMP (containing 26% fat), nonfat milk solids and spray dried whey powder were measured as 1280, 1520 and 1580 kg/m3, respectively. Barbosa-Cánovas *et al.* (2005) reported that the bulk density of whey powder was 530 kg/m3 and particle density of whey powder was 1,400 kg/m3, which was higher than BD and PD of tray dried *khoa* powder due to the higher percent of lactose content in whey powder. Fitzpatrick *et al.* (2004) also reported that the particle densities of spray- dried milk powder ranged from 1130 to 1180 kg/m3.

The porosity of food powder depends on various factors like moisture content, processing method and process conditions (Krokida and Maroulis, 2000). The porosity of CM *khoa* powder (0.56 ) was higher than BM *khoa* powder (0.47). Powders with large agglomerates and larger size particles have good flow properties reported by Sharma *et al.* (2012), as larger size powder particles have lower cohesive force and lesser friction and lower Vander Walls forces reported by Ilari and Mekkaoui (2005). Sanika *et al.* (2021) reported that milk-based powder had good acceptability based on flowability. The compressibility index (sometimes referred to as Carr’s index) measures the ability to reduce the volume of *khoa* powder by tapping. 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 (Prakash, 2016). Carr’s Index (CI) of *khoa* powder was found from 14.32 to 16.91 % which shows good flow. Hausner’s Ratio (HR) of BM *khoa* powder was (1.204±0.006) higher than CM *khoa* powder (1.167±0.016). Lower CI and HR of a powder material was an indicator of better flow property.

As the particulates imbibed water and underwent swelling, adhesion between particulates increased due to liquid-liquid bridges and interlocking forces, decreasing the ability of the powder to flow as seen by the increase in the angle of repose. Angle of repose of CM *khoa* powder (43.2°) is higher compared to BM *khoa* powder (42.7°). According to Tuochy (1989), the angle of repose for SMP ranged from 33° to 38° and for fat-containing milk powders from 40° to 58°. Bastıoğlu *et al. (*2016) reported higher moisture content in melon seed milk spray dried powder had a higher angle of repose; which supports our findings. Walstra et al., (1999), reported that the angle of repose for WMP and SMP were 46.5 and 46.0°, respectively.

Water activity was the key factor of milk powder stability as it determines the glass transition temperature (Tg), which controls caking and lactose crystallization properties (Fournaise et al., 2020). Water activity (aw) highly influences the shelf life of dairy products. Lin *et al*. (2020) reported that the water activity of dairy products is linked to powder stability. Water activity highly influences the mole fraction of solute concentration and free water content of the dried milk products. Ranganadham (1988) 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 was 0.42; which was in the range of our findings (0.28 to 0.561). Pugliese *et al.* (2017) 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.

**4. CONCLUSION**

The study focuses on drying *Khoa* in a tray dryer in forced convection mode, and evaluation of different compositional, physical, rheological and engineering properties of *khoa* powders. This study was planned to assess the feasibility of tray dryer with hot air drying of *khoa* powder and also estimate the moisture evaporation rate during *khoa* drying. The average moisture, fat, protein, lactose and ash content of buffalo milk (FM) *khoa* powder were 1.90, 42.47, 19.47, 30.40 and 5.66 %, respectively whereas those for cow milk (CM) *khoa* powder were 2.83, 28.40, 24.27, 38.02 and 6.47%, respectively. Lightness (L\*), redness( a\*), and yellowness (b\*) values of buffalo’s and cow’s milk *khoa* powder were 68.72 ±0.22, 1.37± 0.02, 22.47± 0.16 and 80.92 ± 0.37, -0.68± 0.03, 24.19± 0.13, respectively. Chroma value found in CM *khoa* powder (24.20±0.13). Browning index (BI) value was found in CM *khoa* powder (33.96±0.06) lower than BM *khoa* powder (40.11±0.16). The bulk and tapped density of buffalo milk *khoa* powder were higher than cow milk based *khoa* powder but the particle density of BM *khoa* powder was (1337 kg/m3) lower than CM *khoa* powder (1452 kg/m3). The porosity of *khoa* powder ranged from 0.47 (BM *khoa* powder) to 0.56 (CM *khoa* powder). Carr’s Index (CI) of *khoa* powder was found from 14.3 to 16.91 % which shows good flow. The angle of repose of CM *khoa* powder (43.2°) was higher compared to BM *khoa* powder (42.7°).

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (Chat GPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

**REFERENCES**

Abesinghe, A. M. N. L., Vidanarachchi, J. K., Islam, N., Prakash, S., Silva, K. F. S. T., Bhandari, B. & Karim, M. A. (2020). Effects of ultrasonication on the physicochemical properties of milk fat globules of Bubalus bubalis (water buffalo) under processing conditions: A comparison with shear-homogenization. *Innovative Food Science & Emerging Technologies*, *59*, 102237.

Adekunte, A., Tiwari, B., Cullen, P., Scannell, A. & O’Donnell, C. (2010). Effect of sonication on colour, ascorbic acid and yeast inactivation in tomato juice. *Food Chemistry*, 122(3), 500–507.

Aggarwal, A., Seth, R., Gandhi, K. & Wangdare, S. (2019). Physico-chemical properties of *khoa* prepared from lactose hydrolyzed buffalo milk. *Journal of Food Science and Technology,* 56(6), 3067–3076.

Al-Hilphy, A.R., Ali, H.I., Al-IEssa, S.A., Gavahian, M. & Mousavi-Khaneghah, A. (2022). Assessing compositional and quality parameters of unconcentrated and refractive window concentrated milk based on color components. *Dairy*, 3, 400–412.

Aneja, R.M., Mathur, B.N., Chandan, R.C. & Banerjee, A.K. (2002).Desiccated milk based products in technology of Indian milk products. Dairy India Yearbook, Delhi (India): 122-125.

Arulkumar, M., Pandian, K.S.N., Murugan B., Eyarkai N.V., Sivaranjani, S., Baskaran, D., Pugazhenthi, T. R., Kishore, G.S. & Pandiselvam, R. (2023). Drying kinetics, effective moisture diffusivity, and activation energy of osmotic pretreated hot-air-dried *paneer* cubes. *Journal of Food Processing and Preservation,* 1-17.

Asgar, S. & Chauhan, M. (2017). Contextualization of traditional dairy products of India by exploring multidimensional benefits of heating. *Trends in Food Science and Technology*. 88 (3), 243-250.

Barbosa-Cánovas, G.V., Ortega-Rivas, E., Juliano, P. & Yan, H.  (2005). Food powders: physical properties, processing, and functionality. New York: Kluwer Academic/Plenum Publishers.

Bastioglu, A.Z., Tomruk, D., Koç, M. & Ertekin, F.K. (2016). Spray dried melon seed milk powder: physical, rheological and sensory properties. *Journal of Food Science and Technology*, 53(5):2396-2404

Bermúdez-Aguirre, D., Mawson, R., Versteeg, K. & Barbosa-Cánovas, G.V. (2009). Composition properties, physicochemical characteristics and shelf life of whole milk after thermal and thermo-sonication treatments. *J. Food Qual.* 32, 283–302.

Carr, R. L. (1965). Evaluating flow properties of solids. Chemical Engineering, 69-72. Hausner, H. H. 1967. Friction conditions in a mass of metal powder.Int. J. Powder Met., 3 (4), 7-13.

Erbay, Z. & Koca, N.(2015). Effects of whey or maltodextrin addition during production on physical quality of white cheese powder during storage. *J. Dairy Sci.*, 98, 8391–8404.

Faostat. (2018). Livestock primary. Food and Agriculture Organization of the United Nations (FAO) statistical database.

Felfoul, I., Burgain, J., Perroud, C., Gaiani, C., Scher, J., Attia, H. & Petit, J. (2021). Impact of spray-drying conditions on flow properties of skim dromedary and cow’s milk powders using the FT4 powder rheometer. *J. Food Process. Preserv*. 45

Fematt-Flores, G.E., Aguiló-Aguayo, I., Marcos, B., Camargo-Olivas, B.A., Sánchez-Vega, R., Soto-Caballero, M.C. & RodríguezRoque, M.J. (2022). Milk protein-based edible films: Influence on mechanical, hydrodynamic, optical and antioxidant properties. *Coatings*, 12, 196.

Fernandez-Avila, C., Gutierrez-Merida, C. & Trujillo, A.J. (2017). Physicochemical and sensory characteristics of a UHT milk-based product enriched with conjugated linoleic acid emulsified by Ultra-High-Pressure Homogenization. *Innov. Food Sci. Emerg. Technol.* 39, 275–283.

Fitzpatrick, J.J., Iqbal, T., Delaney, C., Twomey, T. & Keogh, M.K. (2004). Effect of powder properties and storage conditions on the flowability of milk powders with different fat contents. *Journal of Food Engineering,* 64(4), 435-444.

Food & Agriculture Organization (FAO)-UN.(2024). Dairy Market Review Emerging trends and outlook -2024.

Fournaise, T., Burgain, J., Perroud, C., Scher, J., Gaiani, C. & Petit, J. (2020). Impact of formulation on reconstitution and flowability of spray-dried milk powders. *Powder Technol.* 372:107–116.

Granato, D. & Masson, M. L. (2010). Instrumental color and sensory acceptance of soy-based emulsions: a response surface approach. *Ciênciae Tecnologia de Alimentos*, 30(4), 1090–1096.

Gupta, M. K.& Kaushik, S. C. (2009). Performance evaluation of solar air heater for various artificial roughness geometries based on energy, effectiveness and exergy efficiencies. *Renewable Energy*, 34(3), 465-476.

Gupta, P.R. (2007). Dairy India published by Dairy India Yearbook, New Delhi.

Ilari, J.L., & Mekkaoui, L. (2005). Physical properties of constitutive size classes of spray-dried skim milk powder and their mixtures. *Dairy Science and Technology (former Lait),* 85, 279-294

ISI: (SP: 18). 1981. “ISI Handbook of Food Analysis, Part XI: Dairy Products,” Indian Standards Institution, New Delhi.

Ismail, E.A., Aly, A.A. & Atallah, A.A. (2020). Quality and microstructure of freeze-dried yoghurt fortified with additives as protective agents, *Heliyon,* 6, e05196

Jamadi, F., Arabpour, M. & Abdolzadeh, M. (2017). Performance comparison of parabolic and lat plate solar collectors utilizing in the heating system of a room-an experimental investigation. *International Journal of Renewable Energy Research*, 7(4), 1836-1849.

Juliano, P., Muhunthan, B. & Barbosa-Ca´novas, G.V. (2006). Flow and shear descriptors of preconsolidated food powders. *Journal of Food Eng*ineering, 72, 157-166

Khatkar, B.S. (2007). *Food Science and Technology*. Daya Publishing House, Delhi 114-116

Khedkar, C. D., Khedkar, G. D., Patil, M. R., & Kalyankar, S. D. (2003). Buffalo milk. In B. Caballero, L. Trugo, & P. M. Finglas (Eds.), Encyclopedia of food sciences & nutrition (2nd edn., pp. 705-709), Maryland, USA.

Krokida , M.K. and Maroulis , Z.B. (2000). Quality Change During Drying of Food Materials. *In Drying Technology in Agriculture and Food Sciences; Mujumdar, A.S.; Ed* , Enfield, NH : Science Publishers, Inc.

Leon, K., Mery, D., Pedreschi, F. & Leon, J. (2006). Color measurement in L\*a\*b\* units from RGB digital images. Food Res. Int. 39, 1084–1091.

Lin, R., Wang, Y. & Selomulya, C. (2020). Analytical methods: Physical properties of dairy powders. *Encyclopedia of Dairy Science*. L.H. McSweeney, McNamara, P. (chief eds). 3rd Edition. Academic Press. 1-17

Littlefield, B., Fasina, O. O., Shaw, J., Adhikari, S. & Via, B. (2011). Physical and flow properties of pecan shells-particle size and moisture effects. *Powder Technology, 212(1),* 173-180.

Meena, G.S., Singh, A.K., Arora, S., Borad, S., Sharma, R. & Gupta V.K. (2017). Physico-chemical, functional and rheological properties of milk protein concentrate 60 as affected by disodium phosphate addition, diafiltration and homogenization. *J. Food Sci. Technol.* 54:1678–1688

Murtaza, M. A., Pandya, A. J., & Khan, M. M. H. (2017). Buffalo milk utilization for dairy products. In Y. W. Park, G. F. Haenlein, & W. L. Wendorff (Eds.), Handbook of milk of non-bovine mammals (pp. 284-343).

Niro Atomizer. (1978c). Determination of wettability. In: Sørensen, I.H., Krag, J., Pisecky J., and Westergaard, V., (eds.), Analytical Methods for Dry Milk Products (4th ed, pp 26-27), Copenhagen, Denmark.

Prakash, A.K. (2016). Evaluation and optimization of spray drying Performance of milk-barnyard millet food and characterization of product quality:Ph.D. thesis. Sothern regional station. ICAR-NDRI, Bengaluru.

Prasad, S., Shah, B.P. & Ahuja, K.K. (2024). Energy-Efficient Solar-Assisted Drying of *Khoa*: Optimization of Drying Parameters and Powder Properties. *Chemical Science Review and Letters*, 13 (52), 245-259

Pugliese, A., Cabassi, G.,Chiavaro, Paciulli, M., Carini, E. & Mucchetti, G. (2017). Physical characterization of whole and skim dried milk powders. *Journal of Food Science and Technology*, 54(11), 3433-3442.

Quintanilla, P., Beltran, M.C., Molina, A., Escriche, I. & Molina, M.P. (2019). Characteristics of ripened Tronchon cheese from raw goat milk containing legally admissible amounts of antibiotics. J. Dairy Sci., 4, 2941–2953.

Ranganadham, M. (1988). Process innovatin in the manufacturing of *khoa* powder. Ph.D. Thesis, Kurukshetra University,Kurukshetra.

Reddy, R.S., Ramachandra, C.T., Hiregoudar, S., Nidoni, U., Ram, J., Kammar, M. (2014). Influence of processing conditions on functional and reconstitution properties of milk powder made from osmanabadi goat milk by spray drying. *Small Rumin. Res.* 119, 130–137.

Ryan, J., Hutchings, S.C., Fang, Z., Bandara, N., Gamlath, S., Ajlouni, S. & Ranadheera, C.S. (2020). Microbial, physico-chemical and sensory characteristics of mango juice-enriched probiotic dairy drinks. *International Journal of Dairy Technoogy,*73, 182-190.

Salooja, M. K. & Balachandran, R. (1988). Physical properties of spray-dried malted milk powder. *Indian Journal of Dairy Science*, 41(4), 456-461.

Sanika,B., Poojitha, P., Gurumoorthi, P. & Athmaselvi (2021).Drying kinetics and quality of tray dried peanut milk residue. *Food Research,* 5 (2), 106- 112.

Schuck, P., & Ouest, A. (2011). Milk powder: physical and functional properties of milk powders. In: Fuquay JW, Fox PF, McSweeney PLH (eds) Encyclopedia of dairy sciences. Academic Press, San Diego, 117–12

Sharma, A., Jana, A.H. & Chavan, R.S. (2012). Functionality of milk powders and milk-based powders for end user applications-a review. *Comprehensive Review in Food Science and Food Safety,* 11, 518-528.

Sontakke, M.S. & Salve, P. (2015). Solar drying technologies: A review. *International Journal of Engineering Science,* 4:29-35.

Srinivasan, M. R. & Anantakrishnan, C. P. (1964). Milk products of India.ICAR Publication No.4, KrishiBhavan, New Delhi, India.

Thompkinson, D.K.&  De, S. (1981). Utilization of dried *khoa* for peda making. *Journal of food science and technology*. 18(6), 259-260.

Tuohy, J. J. (1989). Some physical properties of milk powders. *Irish Journal of Food Science and Technology,*13(2),141-152.

Vargas, M., Chafer, M., Albors, A., Chiralt, A. & Gonzalez-Martinez, M. (2008). Physicochemical and sensory characteristics of yoghurt produced from mixtures of cows’ and goats’ milk. Int. J. Dairy Technol. 18, 1146–1152.

Vasiljevic, T., Toebes, A. & Huppertz, T. (2021).Moisture sorption by dairy powders studied by low-field NMR.*International Dairy Journal*, 119, 105062

Violidakis, I., Drosatos, P. & Nikolopoulos, N. (2017). Critical review of current industrial scale lignite drying technologies. Low-rank coals for power generation, fuel and chemical production. *Woodhead Publishing*,. 41–71.

Walstra, P., Geurts, T.J., Noomen, A., Jelemma, A. & Van Bockel, M.A.J.S. (1999). Heat treatment. In: Dairy Technology: Principles of Milk Properties and Processes. Marcel Dekker Inc., New York, 189-239.

Walstra, P., Wouters, J.T.M. and Geurts, T.J. (2006). Dairy science and technology. CRC Press*,* Boca Raton

Westergaard, V. (1994). Milk powder technology: Evaporation and spray drying. *Niro A/S Copenhagen*, Denmark, 832-98.