DETERMINATION OF PHYSICAL AND ENGINEERING PROPERTIES OF TOUKIR AND ITS APPLICATION IN THE PREPARATION OF GULABJAMUN

THESIS SUBMITTED TO THE
NATIONAL DAIRY RESEARCH INSTITUTE
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MASTER OF TECHNOLOGY
IN
DAIRYING (DAIRY ENGINEERING)

BY
BRAJ KUMAR
B. Tech. (DAIRY TECHNOLOGY)

SOUTHERN REGIONAL STATION
NATIONAL DAIRY RESEARCH INSTITUTE
(ICAR)
BANGALORE- 560030, INDIA
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Regn. No. 2041205


Heartfully
Dedicated to my
beloved Parents
and Teachers
and Friends

SOUTHERN REGIONAL STATION
NATIONAL DAIRY RESEARCH INSTITUTE
(Deemed University)
Indian Council of Agricultural Research
BANGALORE-560030 (KARNATAKA), INDIA

Date:

Dr. P. Heartwin Amaladhas
Senior Scientist (Dairy Engineering)
Southern Regional Station
NDRI, Bangalore

CERTIFICATE

This is to certify that the thesis entitled **"DETERMINATION OF PHYSICAL AND ENGINEERING PROPERTIES OF TOUKIR AND ITS APPLICATION IN THE PREPARATION OF GULABJAMUN",** submitted by **Mr. BRAJ KUMAR** towards the partial fulfilment for the award of the degree of **MASTER OF TECHNOLOGY** in **DAIRYING (DAIRY ENGINEERING)** of the **NATIONAL DAIRY RESEARCH INSTITUTE (Deemed University)**, Karnal (Haryana), India, is a bonafide research work carried out by him under my supervision and guidance, and no part of the thesis has been submitted for any other degree or diploma.

Dr. P. Heartwin Amaladhas
Major Advisor (Guide)

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Approved By

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(External Examiner)	**Dr. P. Heartwin Amaladhas**
	(Major Advisor)

Members of Advisory Committee

1. Er. Chitranayak
Senior Scientist, Dairy Engineering ----------

2. Dr. M. Manjunatha
Scientist, Dairy Engineering ----------

3. Dr. K. Jayaraj Rao
Principal Scientist, Dairy Technology ----------

4. Dr. B. Surendra Nath
Principal Scientist, Dairy Chemistry ----------

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Abstract

Curcuma angustifolia Roxb. (*Zingiberaceae*) produces edible rhizomes that are rich in starch called 'Toukir'. This starch is an important ingredient in the preparation of khoa-jalebi, a popular dairy product of central India. The objectives of the present work were to investigate the physico-chemical, thermal and microstructural properties of toukir at different moisture contents (3, 6, 9 and 12% d.b.), moisture sorption isotherms at three different temperatures (10, 25 and 40ºC) and rheological properties at different temperatures and concentrations. The bulk and tapped densities of toukir decreased from 630 to 530 kg/m^3 and from 930 to 750 kg/m^3 with increase in moisture content. True density (2424 kg/m^3) was not affected by change in moisture content. The angle of repose values at moisture contents of 3, 6, 9 and 12% were 50.02, 54.49, 55.55 and 56.16°, respectively. Colour of toukir, measured using Minolta CM5 spectrophotometer in terms of L*, a* and b* values, were 95.74, -0.01 and 3.30, respectively. The volumetric specific heat, thermal conductivity, and thermal diffusivity increased from 1466.1 to 1645.1 kJ/m^3.K, 0.141 to 0.158 W/m.K, and 0.08 to 0.09×10^{-6} m^2/s as moisture content increased from 3 to 12%. The thermal resistivity decreased from 7.07 to 6.31 K.m/W. Scanning electron microscopic analysis of toukir showed that the granules were tetrahedral in shape. The increase in moisture content increased the particle size from 17.33 to 19.99µ as moisture in toukir increased from 3 to12%. The T_g decreased linearly form 70.15°C at 3% to 64.65°C at 12% moisture content (R^2=0.985). Moisture sorption isotherm of toukir powder presented a sigmoidal shape, and belonged to type II of BDDT classification.

The particle size parameters such as, d(0.1), d(0.5) and d(0.9) increased from 9.511 to 9.709µ, 15.568 to 16.792µ and 178.631 to 226.360µ, respectively with increase in moisture content. WAI and WSI of toukir were ranged from 2.01 to 2.069g.g^{-1} and 0.028 to 0.031g.g^{-1}, respectively. However, 81 % of dispersibility was recorded with toukir powder. Proximate composition of toukir added (6, 12 and 18%) gulabjamun includes moisture (20.84 to 20.07%, w.b.), protein (11.67-14.12%), ash (3.0 to 3.81%), fat (26.88 to 29.63%) and carbohydrate (31.60, 33.26 and 36.38%) was determined and found their dependence over change in toukir percentage in dough. Similarly, geometric mean dia. and sphericity was ranged between 28.41 to 29.26 mm and 0.97 to 0.985, respectively. The dough expansion was 1.255 to 1.221 with the porosity value between 18.21 to 34.34%. Corresponding percent volume change was 25.11, 17.68, 24.60 and 21.91%. L* (26.22, 28.09 and 29.01) and a* (29.51, 31.56 and 34.48) and b* (29.51, 31.56 and 34.48) values were determined for toukir at 6, 12 and 18%.

Noticeable changes in thermal conductivity (0.256, 0.245, 0.260 and 0.265 W/m.K), volumetric specific heat (2.101, 1.769, 2.049 and 2.192 kJ/m^3.K), thermal diffusivity (0.120, 0.125, 0.128 and 0.152 m^2/s) and thermal resistivity (3.927, 4.097, 3.869 and 3.817, K.m/W) at 0, 6, 12 and 18% of toukir added gulabjamun was observed. Similarly increase in toukir percentage (6, 12 and 18%) increased gulabjamun hardness (7.41, 8.12 and 12.36N) cohesiveness (-0.35, -1.93, -2.07 and -4.94) with springiness and gumminess values as 78.39, 81.38, 80.70% and 3.67, 4.97, 4.54%, respectively. Rheological study showed that 4% toukir solution displayed Newtonian behaviour at all temperatures while 8 to 20% concentrations were fitted to the non-Newtonian power law model (n= 0.1 to 0.7). Sensory evaluation by fuzzy logic ranked different treatments as Control ≈ Sample 3 (12% toukir) > Sample 2 (6% toukir) > Sample 4 (18% toukir).

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˚Brix	-	Degree Brix
AOAC	-	Association of Official Analytical Chemists
BIS	-	Bureau of Indian Standards
CIELAB	-	Commission Internationale de L'Eclairage
d.b.	-	Dry basis
Dpi	-	Dot per inch
M	-	Molarity
m.c.	-	Moisture content
mJ	-	Milli-Joule
mbar	-	Milli-bar
N	-	Normality/ Newton
Pa	-	Pascal
rpm	-	Revolution per minute
RH	-	Relative humidity
w.b.	-	Wet basis
w/w	-	Weight by weight
w/v	-	Weight by volume

1. Introduction

India is the leading milk producing country of the world, accounting for more than 13% world's total milk production. Indian milk production is estimated as 132 million tonnes in 2013-14 (NDDB, 2013). Only 20% of the total milk produced in India is handled by the organized sector. Nearly, 7% of India's total milk production is converted into heat-desiccated milk products and 3% into heat and acid-coagulated milk products (Gupta, 2007). The strength of the traditional Indian dairy products sector is the richness of the wide variety of sweets and there is a steady and rapidly growing demand for these products. However, there is a need to ensure good and uniform quality products throughout the nation, all year round.

Toukir, (*Curcuma angustifolia* Roxb., family Zingiberaceae), is a tuber commonly found in the hilly tracts of Central India, West Bengal and in some of the lower Himalayan ranges. It is also known as East Indian arrowroot. The plant mostly grows wild in the moist and cool areas but is also cultivated to a smaller extent (Rani and Chawhaan, 2012). The rhizomes produced contain mostly starch. The rhizomes are processed to obtain the starch called as toukir. The starch is similar to arrow root, and is taken as a dietary aid in gastrointestinal disorders. It is also used as an ingredient in traditional local medicine. It is considered a cardiac tonic, diuretic and is good for peptic ulcers because of its soothing effect (Kumari *et al.,* 2012). The leaves of the plant also yield volatile oil, which possess antimicrobial properties (Rani and Chawhaan, 2012).

Knowledge of physical and thermal properties and their dependence on moisture content is useful in the design and development of processing methods and equipment. Many researchers have studied the effect of moisture content on the properties of different starch-based products such as rice flour extrudates (Hagenimana *et al.,* 2006), wheat extrudates (Ding *et al.,* 2006) and corn starch pellets (Lee *et al.,* 2000). For food powders such as toukir, bulk density, tapped density, friction characteristics, angle of repose, flow properties are affected by moisture content.

Similarly, the flowability is highly affected by the RH of the surroundings (Teunou and Fitzpatrick, 1999) and moisture content of the product.

Determination of moisture sorption isotherm of toukir is useful for predicting the form of water present in the food products, and the relationship that exists amongst the chemical constituents and water components. Also, water activity, together with temperature, plays a vital role in plasticization, which leads to the agglomeration of food powders. DSC thermogram, the adsorbed water induced no reactions such as crystallisation. Therefore, the increase in strength of the liquid bridges with increasing relative humidity is small and the flowability decreases only slightly in the range tested. At the high relative humidity of 76% the flour particles remained dispersible and were not agglomerated (Teunou and Fitzpatrick, 1999). Similarly, water absorptive index (WAI) gives an indication of ability of the starch to absorb the water molecules during their expansion.

Toukir is used in the preparation of khoa-jalebi as a binder and to improve the soaking ability of sugar syrup. The process of preparation of khoa-jalebi containing toukir was optimized by Pagote and Rao (2012). Similarly, Kumari *et al.* (2012) prepared khoa-jalebi containing toukir, and evaluated the samples for fat content, sugar syrup absorption, hardness and sensory parameters. Optimization by response surface methodology showed that 47 g of toukir per 100 g khoa with soaking time of 5.9 h gave desirability index of 0.79 and overall acceptability score of 7.70 out of 9.0 on hedonic scale. However, data on physico-thermal and microstructural properties of toukir are not available. Determination of these properties as a function of moisture content becomes important because toukir has a wider application in the preparation of many other indigenous dairy products. Particularly, it has the potential to replace maida in products such as gulabjamun, pantoa, etc.

Nowadays, ‘sweetmeats’ based on heat-desiccated (*khoa*) or heat-acid coagulated (*chhana*) milk solids are very popular. Gulabjamun is a nationally popular khoa based sweet. It is made with khoa, maida and baking powder. Shaped both round and cylindrical, gulabjamun is golden to dark brown in colour and has a soft to firm body and smooth texture. Various binders are used in the preparation of gulabjamun

but the most important and widely used material is maida, which is recommended at 12% of weight of khoa. The physico-chemical, textural, optical, thermal and dimensional properties of gulabjamun change during frying. These changes are the consequences of frying-induced thermal reactions such as gelatinization of starch, denaturation of proteins, hydrolysis, development of flavours, Maillard browning, caramelization and inactivation of enzymes. In this study, an attempt is made to incorporate toukir in the preparation of gulabjamun as a replacement to maida. The effect of toukir addition on the physiochemical, textural and sensorial properties of gulabjamun is studied.

Therefore, the study was taken up with the following objectives:

1. Determine the thermo-physical and engineering properties of toukir as a function of moisture content.

2. Analyze and model the moisture sorption and rheological behaviours of toukir.

3. Evaluate the sensorial, thermo-physical and textural qualities of toukir added gulabjamun.

In this chapter, the literature related to objectives of the current study is reviewed under the following heads:

- Structure and Properties of Toukir
- Physical and Engineering Properties of Powders
- Moisture Sorption Isotherm of Powders
- Rheology of Starch Flour Suspensions
- Application of Toukir in the Preparation of Dairy Products
- Preparation and Optimization of Gulabjamun
- Characterization of Gulabjamun and Other Fried Products

2.1. Structure and properties of toukir

Curcuma angustifolia Roxb (family Zingiberaceae), commonly called toukir, is a tuber commonly found in the hilly tracts of Central India, West Bengal and in some of the lower Himalayan ranges. It is also known as East Indian arrowroot. The plant mostly grows wild in the moist and cool areas though it is also cultivated to a smaller extent (Rani and Chawhaan, 2012). The rhizomes produced contain mostly starch. The rhizomes are processed to obtain the starch called as toukir. The starch is similar to arrow root, and is taken as a dietary aid in gastrointestinal disorders. It is also used as an ingredient in traditional local medicine. It is considered a cardiac tonic, diuretic and is good for peptic ulcers because of its soothing effect (Kumari *et al.,* 2012). The leaves of the plant also yield volatile oil, which possess antimicrobial properties (Rani and Chawhaan, 2012).

Rani and Chawhaan (2012) reported that the extraction of starch from 'tikhur' (toukir) using 0.03M ammonia solution yielded significant quantity of starch. They also studied the shape of the starch powder using scanning electron microscope and reported that the granules were small rounded, oval to elliptical, spherical, elongated and 3.32 to 32.55μ in length and 2.29 to 8.47μ in width.

For preparation of weaning food locally called shotti, the rhizomes of toukir plant were cleaned to remove soil and dirt, peeled, grated, and soaked in water. When the water turned milky white, it was strained to separate grated flakes of rhizomes and was kept for 12 h. Excess water was drained and again some water was added and left for 6 h. Finally the excess water was drained out, and the left over wet white dough was sun dried and crushed with hand to make fine powder (Sharma, 2012). Kumari *et al.* (2012) reported that the average moisture content of toukir was 1.7%, the starch content was 98% and fat and protein contents were negligible.

2.2. Physical and engineering properties of powders

The knowledge of physical and thermal properties and their dependence on moisture content is useful in the design and development of processing methods and equipment. For food powders such as toukir, bulk density, friction characters and angle of repose are affected by moisture content. Similarly, flowability is highly affected by the RH of the surroundings. Determination of these properties as a function of moisture content becomes important because toukir has a wider application in the preparation of many other indigenous dairy products. Particularly, it has the potential to replace maida in products such as gulabjamun, pantoa, etc.

Jouppila and Roos (1994) studied the glass transition temperatures of dehydrated milk products with various water contents and water activities. Also, the crystallization behaviour of milk powders stored at various relative humidities was studied. Skim milk powder with hydrolysed lactose had considerably lower glass transition temperature. Also it was reported that the glass transition temperature decreased as water content increased.

The protein, fat, ash and crude fibre contents of African breadfruit seed flour blends were determined by (Akubor *et al*., 2000). The flow showed significantly higher water absorption capacity, oil absorption capacity, fat content and emulsion activity than wheat flour. All the flour blends exhibited a least gelation concentration of 8% (W/V). The bulk density (g/cm^3) and wettability values of flour blends varied from 0.74 to 0.84 and 19 to 31, respectively.

Instant kheer mix was prepared using a pilot-scale spray drying system and analyzed for its physico-chemical properties. The freshly prepared powder had a good flowability (angle of repose of 40.09°) and fairly high loose and packed bulk densities (0.69 and 0.81 $g.cm^{-3}$, respectively) corresponding to a particle density of 1.25 $g.cm^{-3}$, occluded air content of 6.63 $cm^3.100\ g^{-1}$, interstitial air content of 45 $cm^3.100\ g^{-1}$ and porosity of 44.8%. It showed an insolubility index of 4.00 mL, wettability of 2.00 min, and dispersibility of 75.38% (Jha *et al*., 2002).

Goula *et al.* (2004) investigated the effect of spray drying conditions (feed rate, feed temperature, atomizer pressure, compressed air flow rate, flow rate of drying air and air inlet temperature) on moisture, solubility, density (bulk and packed), and hygroscopicity of tomato powder. The moisture content, solubility, bulk density, packed density and hygroscopicity were modelled using regression polynomial.

Nijdam and Langrish (2005) investigated the morphological changes that occur to milk particles during the spray drying. Differential scanning calorimetry was used to determine the glass transition and fat melting temperatures of the milk powders. Milk powders were examined with scanning electron microscope and the particle size distribution was measured using a laser diffraction instrument.

Quek *et al*. (2007) analyzed the spray-dried watermelon powders for moisture content, dissolution, water activity, colour, lycopene and β-carotene. Results demonstrated that as inlet air temperature increased, the moisture content and dissolution decreased. However, there were no significant changes in the water activities of the spray-dried powders for all the inlet temperatures investigated. Colorimetric analyses showed that the L^*, a^*, b^*, hue and chroma values changed with the inlet temperatures. The results were well correlated to the lycopene and β-carotene contents of the spray-dried powders.

Jinapong *et al.* (2008) reported that the spray-dried soymilk powders were very small in size (<25 μ) and very cohesive leading to their poor flowability. Agglomeration of the spray-dried soymilk powders with maltodextrin as an aqueous binder solution using a fluidized bed agglomerator improved the handling and

reconstitution properties of the powders. The optimum binder concentration was found to be 10% (w/v) maltodextrin which resulted in the largest particle size of the agglomerated powder (260 μm) having a good flowability and low cohesiveness. It was concluded that the wettability of this agglomerated powder (wetting time= 42 s) was good but its dispersibility (61%) could be improved.

Skim and whole milk powders manufactured by spray freeze drying (SFD) were examined using a scanning electron microscope. Samples were compared with equivalent spray-dried powders in tests of wettability and dissolution in water. The spray freeze-dried powders were found to be highly porous, with a uniform structure of pores throughout the entire particles. When tested in water, SFD skim milk powders wetted roughly three times as fast as industrially spray-dried agglomerated skim milk powders and were observed to dissolve rapidly by breaking down into smaller particles (Rogers *et al*., 2008).

The influence of particle size and shape on the rehydration properties of dairy powders were investigated on five different milk powders. The wettability, solubility and dispersibility for each powder were measured. By the use of the shape descriptors, prediction models for dispersibility and solubility were successfully developed and optimized (Gaiani *et al*., 2011).

The effects processing parameters on moisture content, water activity, drying yield, bulk density, solubility, glass transition temperature and microstructure of dried black mulberry juice powders were investigated. Bulk density of black mulberry powders varied from 0.35 to 0.55 g/mL. The blend of 2% maltodextrin 6 DE and 6% gum arabic showed the highest solubility of about 87%. The average particle size and glass transition temperature of powders ranged from 4 to 13μ and 40 to 75ºC, respectively (Fazaeli *et al.,* 2012).

Koç *et al.* (2012) measured the physical properties, moisture content, and reconstitution properties of spray-dried yoghurt powder. The bulk (bulk and tapped densities, porosity, flowability, hygroscopicity and degree of caking) and particle properties (particle size distribution, particle density and morphology) of yoghurt

powder were determined. The bulk, tapped and particle densities of yoghurt powder were 538, 746 and 1177 kg/m^3, respectively. The mean diameter and the span value of yoghurt powder were 3.053 and 2.487μ, respectively.

The physical-chemical properties of corn stalk powders with particle sizes of >300, 300-150, 150-74, 74-37 and <15μm were investigated. The particle size distributions of the powders were: d_{90} = 362, 147, 74, 40 and 12μm. The size of corn stalk powders was stated to be smaller while the surface area (1.188 to 2.432 m^2/g) and bulk density (0.103 to 0.1145 g/mL) were greater in value. Light microscopy and scanning electron microscopy observations were used to elucidate the shape and surface morphology of five types of corn stalk powders (Zhao *et al*., 2013).

2.3. Moisture sorption isotherms of powders

Determination of moisture sorption isotherm of toukir is useful for predicting the form of water present in the food products, and the relationship that exists amongst the chemical constituents and water components. Also, water activity, together with temperature, plays a vital role in plasticization, which leads to the agglomeration of food powders.

Water activity and equilibrium moisture content data of casein, lactose, skim milk and chhana powder at a fixed temperature of 50°C were obtained. BET, Caurie, 'stability' and 'local' isotherm models were used for analysing the data. The analysis showed that the range of water activities at which the major moisture related changes took place in the materials were: casein 0.08 to 0.56, lactose 0.20 to 0.73, skim milk 0.12 to 0.72 and chhana powder 0.06 to 0.60 (Bandyopadhyay *et al.,* 1987).

Sorption isotherm of gulabjamun mix powder at 15, 25, 35, and 45°C were determined using a gravimetric static method. GAB, modified Mizrahi, Caurie, Oswin, Halsey and Smith models were applied to the isotherm data. Net isosteric heats were estimated from equilibrium sorption data using the Clausius-Clapeyron equation. The sorption isotherms were best described by GAB equation (Govardhan and Kumar, 2006).

Water sorption isotherms were obtained for ready-to-use basundi mix over the temperature range of 5-45°C. GAB model gave excellent agreement between experimental and predicted values. Other properties of sorbed water viz., monolayer water, number of adsorbed monolayers, density and amount of bound water and surface area of adsorption were also obtained. The net isosteric heat of sorption had strong dependence on moisture content (Sharma *et al.,* 2009).

The adsorption and desorption isotherms of dried acid casein prepared from buffalo skim milk were determined at 25, 35 and 45°C over a water activity range of 0.11-0.97 (Sawhney *et al.,* 2011). Both adsorption and desorption isotherms exhibited sigmoid shape corresponding to type II of BDDT classification. The temperature effect on equilibrium moisture content was negative. Of the seven sorption models tested for fitting the sorption data, the GAB model gave the best fit at all the three temperatures. The calculated values of monolayer moisture content from BET isotherm equation have been found to be lower than the corresponding values found by using GAB equation. However, in both cases the monolayer moisture was higher in desorption than the adsorption and deceased with increase in temperature. The net isosteric heat of sorption decreased exponentially with increasing moisture content and approached a constant value of 0.331 kJ/mol at moisture content 28 g/100 g (d.b.). The moisture sorption hysteresis observed at 25, 35 and 45°C was statistically significant. The extent of hysteresis was negligible in monolayer moisture content region, occurred predominantly in the water activity range 0.35-0.60 and decreased at higher water activities. Temperature decreased the amount of hysteresis.

Pushpadass *et al*. (2013) determined the equilibrium moisture contents (EMC) of gulabjamun mix powder at 10, 25 and 40°C. They observed that the sorption isotherms of gulabjamun mix were of type II, with the sorption capacity decreasing with temperature. The Guggenheim-Anderson-de Boer best described the sorption data at all temperatures. The isosteric heat of sorption decreased with increasing moisture content, and it approached the latent heat of water at 15% moisture content. The spreading pressures increased with increasing water activity, but decreased with increasing temperature. The net integral enthalpy decreased with moisture content to a

minimum value of -0.50 $kJmol^{-1}$. The isokinetic temperature (T_β) and harmonic mean temperature (T_{hm}) values were determined as 339.5 and 297.5 K, respectively.

Thanuja and Ravindra (2014) determined the sorption data for cheese-puri mix at 25, 35 and 45°C by static gravimetric method. They attempted GAB, Caurie, Henderson, Oswin and Smith isotherm models to describe the experimental data and were found to describe the sorption behaviour of the product adequately. The solid surface area of the product was computed based on the GAB model monolayer moisture contents of the product and was found to increase with temperature.

Six connectionist models were proposed to predict sorption (adsorption and desorption) characteristics of dried acid casein from buffalo skim milk at three temperatures, i.e., 25, 35 and 45°C over a water activity range of 0.11-0.97 (Sharma and Sawhney, 2013). Also, several conventional empirical sorption models were used for fitting the sorption data. The error back propagation (EBP) learning algorithm with Bayesian Regularisation/Levenberg-Marquardt optimisation techniques as well as various combinations of connectionist network parameters was employed. The connectionist models predicted the adsorption characteristics with an accuracy ranging between 1.32 and 2.60 root mean square percent error (RMS%) as compared to the best (among six conventional empirical models used) GAB model, which attained RMS% between 1.92 and 5.77. While for desorption characteristics, the connectionist models attained RMS% between 1.56 and 4.08 vis-à-vis the best (among six conventional empirical models used) GAB model with RMS% ranging between 1.4 and 5.01. Hence, the results revealed that the connectionist models outperformed the conventional empirical models and, generally, well-described the experimental adsorption and desorption data of dried acid casein.

2.4. Rheology of starch flour suspensions

The shear-rate/shear-stress data of cooked debranned maize flour (2-10%) suspensions were obtained using a concentric cylinder viscometer in the shear rate range of 3-1326 s^{-1}. Attempts were made to fit the shear-rate/shear-stress data to power law (Ostwald De Waele), Bingham plastic, Casson, Costell-Duran, Herschel-Bulkley and Mizrahi-Berk rheological models (Bhattacharya and Bhattacharya, 1996).

The steamed wheat flour was used to make batters having 30, 33 and 36% solids suspended in water. The apparent viscosities of the batters increased from 9.6 to 19.2 Pa.s; the yield stress increased from 5.3 to 7.15 Pa; the consistency index increased from 27.86 to 78.31 $Pa.s^n$. The maximum values of all three parameters were observed in the batter which had a solids concentration of 36%, and which had been made with flour steamed for 30 min. But, the flow behaviour index decreased slightly with duration of steaming and with increasing solid concentrations in the batter (Prakash *et al*., 1998).

Dispersions of steamed rice flour at different solid (10-50%, dry basis) concentrations have been tested for their rheological behaviour employing a rheometer with a coaxial cylindrical attachment. Yield stress was determined by stress relaxation technique. Experimental values of yield stresses were 1.1-18.3 times higher than those calculated using Herschel- Bulkley model, Casson or Bingham plastic models. An increase in concentrations of solids from 10 to 50% increased consistency index and apparent viscosity by more than 20 and 10 times, respectively, but flow behaviour index decreased by about 30% (Latha *et al.,* 2002).

The controlled stress measurement of the rheology of black gram flour dispersions at different solid concentrations (5-30%) was conducted employing a coaxial cylinder attachment. The dispersions behaved like shear-thinning fluids with flow behaviour indices (0.91-0.44) decreasing with an increase in solid concentration. The experimental yield stresses were between 115 and 2375 mPa. An increase in solid concentration increased the yield stress, consistency index and apparent viscosity of these dispersions. Time-dependency was observed with these dispersions and showed thixotropic behaviour (Bhattacharya *et al.,* 2004).

The steady and dynamic rheological properties of Korean rice flour dispersions were evaluated at different concentrations (4, 5, 6, 7, and 8%). Rice flour dispersions at 25°C showed a high shear-thinning behaviour ($n = 0.23$-0.28) with low magnitudes of Casson yield stress ($\sigma = 4.1$-20.1 Pa). The magnitudes of yield stress, consistency index and apparent viscosity increased with increase in concentration. The apparent

viscosity over the temperature range of 25-70°C obeyed the Arrhenius temperature relationship, indicating that the magnitudes of activation energies (E_a) were in the range of 0.21-0.27 kJ/mol. Storage (G') and loss (G") moduli increased with increase in frequency (ω) while complex viscosity (η^*) decreased. Magnitudes of G' and G" moduli increased with increase in concentration (Chun and Yoo, 2004).

Physicochemical (solubility index, apparent density and dry matter content) and rheological properties of the hot salep, an indigenous Turkish beverage, were determined. The apparent viscosity of samples was measured in the temperature range of 10-50°C, with the rotational speed of 20-200 rpm. The empirical power law model was used for the determination of the flow behaviour and consistency indices of the samples. Dry matter content and apparent density of salep-milk beverage were significantly ($p<0.05$) higher than those of salep-water counterpart. Apparent viscosity, consistency and flow behaviour indices were also higher in the salep-milk samples (Dogan and Kayacier, 2004).

The effects of four dietary fibre sources (oat, wheat, apple and inulin) on the rheological and thermal properties of model sucrose–polysaccharides solutions and ice cream mixes were investigated. The use of oat and wheat fibre favoured viscosity development due to water-binding, whereas inulin caused a remarkable increase of glass transition temperature (T_g) in model solutions and ice cream mixes, indicating the reduction of water molecule mobility from the bulk aqueous phase to the ice crystals' surface. Apple fibre addition greatly increased viscosity and elevated the T_g values, particularly in the presence of proteins (Soukoulis *et al.,* 2009).

Indian varieties of sorghum (CSH-9, CSH-5, Dadar and Parbhani) were subjected for proximate analysis and characterization of extracted starch. Isolated starch was characterized for amylose and amylopectin content, gelatinization temperature, viscosity, swelling power, solubility and water absorption capacity. Maximum viscosity was reported for Parbhani and CSH-9 and minimum for CSH-5 and Dadar. Gelatinization temperature was varied from 64°C for CSH-9 to a maximum of 68°C for Dadar and Parbhani (Udachan *et al.,* 2012).

2.5. Application of toukir in the preparation of dairy products

Pagote and Rao (2012) characterised khoa-jalebi based on sensory, physico-chemical and textural characteristics. The khoa-jalebi sweets collected from Nagpur, Nasik, Indore, Raipur and Wardha cities were not found uniform. They also optimized the process of preparation of khoa-jalebi using toukir.

Toukir was analyzed for water absorption capacity and the khoa-jalebi batter was analysed for apparent viscosity and yield stress (Kumari *et al.,* 2012). The fried khoa-jalebi was evaluated for fat content, sugar syrup absorption, hardness and sensory parameters. Optimization by response surface methodology showed that 47 g of toukir per 100 g khoa and soaking time of 5.9 h gave desirability index of 0.79 and overall acceptability score of 7.70 on 9-point hedonic scale (Kumari *et al.,* 2012).

2.6. Preparation and optimization of gulabjamun

Rangi *et al.* (1985) standardized and optimized the procedure for manufacture of gulabjamun. They concluded that gulabjamun with excellent sensory quality could be prepared by adding 80 parts of khoa, 20 parts of flour and 5 parts of fat in the mix, followed by deep-fat frying at 130°C for 15 min and by soaking in sugar syrup of 50°Brix at 70°C for 4 h.

Joshi *et al.* (2009) optimized the formulation of gulabjamun by orthogonal matrix method. They concluded that 90:10 khoa:maida ratio, 0.8% baking powder, frying time of 11 min, and soaking in 50°Brix sugar syrup, at 60°C for 6 h gave best overall acceptability to gulabjamun.

2.7 Characterization of gulabjamun and other fried products

Deep fat frying is one of the oldest and most familiar unit operations of food preparation (Varela, 1988). The desirable characteristics of fried products such as soft and juicy interior with thick and crispy outer crust may be the reason for the large popularity. The fried foods have attracted the attention of researchers who tried to elucidate the physical and chemical mechanisms involved during frying and their effect on the quality attributes. During deep fat frying, heat transfer occurs uniformly

over the entire surface of the food with simultaneously mass transfer. Several phenomena take place simultaneously during frying include:

1. Cooking (thermal effects): Induce thermal reaction such as gelatinization of starch, denaturation of protein, hydrolysis, development of flavours, Maillard browning and caramelization etc. (Tangduangdee *et al.,* 2003). The crust formation results in increase in the consumer appeal of the product as a result of caramelization or non-enzymatic browning (Maillard reaction), resulting in golden brown colours that give a pleasant aspect to the product which improve its sensory quality. These same reactions also develop desirable flavours in fried products (Blumenthal, 1988; Parkash and Gertz, 2004).
2. Dehydration: Loss of moisture occurs, intentionally or unintentionally, during frying.
3. Fat uptake: Oil uptake by the food occurs during deep fat frying (Ufheil and Escher, 1996; Sioen *et al.,* 2006; Haak *et al.,* 2007).
4. Change in texture and microstructure: The most common and important effect is the formation of crust which give fried foods their unique texture and flavour (Wang, 2005).

The quality of the product during frying was found to be affected by the frying conditions. The quality related properties of the food can be grouped as structural properties (density, porosity), optical properties (colour, appearance), textural properties (hardness, cohesiveness, chewiness, gumminess, and springiness), mechanical properties (crystalline, rubbery), sensory properties (flavour) and nutritional properties (vitamin content, protein) (Krokida *et al.,* 2001b). A better understanding of changes in the quality attributes during deep fat frying is essential for the development of products with desirable quality.

Control of oil and moisture content becomes necessary in the industrial product frying quality aspects, since they are contributing to the overall acceptability of the food. Minimization of the chemical degradation, control on structural change and achievement of desired taste, texture and colour of the product are also essential to obtain a desired quality product. Frying conditions such as temperature and residence time of the product in the fryer and physicochemical changes occurring during frying

seems to affect the quality of the fried product (Alvis *et al.,* 2009). The knowledge of thermo-physical properties is essential to understand the heat and mass transfer phenomena during deep fat frying.

2.7.1 Colour

Colour of fried products critically influences the sensory acceptance. The colour of the material during frying changes not only due to evaporation of the surface water and oil uptake but also due to certain reactions like non-enzymatic browning and caramelization reaction (Kudra and Strumillio, 1998). Browning is a very important quality index as it differentiates the desirable and undesirable colour of food, and also points towards nutrient losses. These reactions are to be controlled and thus regulation of colour during frying should be done. The most common colour measurement units are RGB (Red, Green, Blue) and LAB (L: Lightness, a: Redness-Greenness, b: Yellowness-Blueness) (Krokida *et al.,* 2001a).

The kinetics of colour and texture changes in gulabjamun balls were investigated with regard to frying temperature (120, 130, 140°C). Crust colour was evaluated in terms of CIELAB parameters L^*, a^*, b^* and ΔE (total colour difference) and rheological properties in terms of hardness, stiffness and firmness (Kumar *et al.,* 2006).

Ateba and Mittal (1994) modelled the variation of lightness (L^*), redness (a^*), yellowness (b^*) and ΔE of beef meat ball crust using first order kinetics. They found that the L^*, a^*, b^* of crust decayed exponentially whereas ΔE increased with time. Paul and Mittal (1996) examined the degradation of the oil which affected the colour of the product during frying. They noticed a high correlation of the colour parameter with oil degradation. Ling *et al.* (1988) reported that the onion rings fried at 190°C had decreased lightness and yellowness and increased redness than onion rings fried at 170°C.

Bhat and Bhattacharya (2001) studied the colour changes of chickpea flour products during frying and found that there was a decrease in brightness of the product. Krokida *et al.* (2001a) noticed that the frying conditions significantly affected the

colour of fried potatoes. The lightness of potato strips increased with increase in frying temperature and frying time during early stages of frying and then remained almost constant afterwards. Chroma value also increased as the temperature of the frying increased for the same frying time which is undesirable as the final product becomes redder. The hue value showed a same trend to that of chroma value during frying of potato strips.

El-Dirani (2002) used CIELAB parameters to evaluate the colour changes in chicken nuggets during frying. The lightness and yellowness of chicken nuggets decreased with increase in frying temperature and frying time, whereas the redness followed increasing trend. The colour kinetics of tofu during deep fat frying and the effect of frying conditions on these colour parameters were investigated by Baik and Mittal (2003). They observed that the lightness decreased exponentially with frying time, while redness and total colour (ΔE) increased. Yellowness was found to be increased first and then decreased exponentially. All the colour parameters were found to follow first-order reaction kinetics.

Vélez-Ruiz and Sosa-Morales (2003) correlated the lightness and redness to the frying time during frying of donuts. They observed an increasing redness and ΔE and decreasing lightness as a function of process time and oil temperature. The activation energy for the process was calculated as 4.44 $kcal.mol^{-1}$ for the temperature range of 180-200°C. They stated that the non-enzymatic browning in the frying of donuts was a very fast transformation and not much energy was needed to promote the darkness at the crust.

Tan and Mittal (2006) studied the colour change of donut during vacuum frying. They reported that the total colour change increased progressively with increase in frying temperature. Sosa-Morales *et al.* (2006) observed that the change in pork meat colour increased with the advance of frying time and affected by the frying temperature when fried in sunflower oil. Taiwo *et al.* (2007) reported that the lightness value of sweet potato decreased with frying time, redness initially either decreased or was stable up to 120 s of frying and increased significantly thereafter. The yellowness increased initially and decreased afterwards up to the end of frying.

Emerald *et al.* (2009) studied the kinetics of colour change during frying of gulabjamun. They reported that the crust colour of gulabjamun changed with frying temperature and frying time and followed fractional conversion first order reaction kinetics.

2.7.2 Texture

Texture is one of the important parameters related to quality of product and consumer acceptability. It depends on raw materials and process conditions and the structural behaviour of the food (Ramana and Taylor, 1994; Krokida *et al.,* 2001b). Textural properties also depend on chemical and physical characteristics of the product (Mohsenin, 1986; Thiagu *et al.,* 1993).

The textural characteristics of gulabjamun was measured in terms gumminess, hardness etc. Amongst them, sponginess and juiciness were found to be the desirable attributes while crumbliness and gumminess were considered as less desirable (Patel *et al.,* 1992). The influence of use of pre-soaked suji (semolina) on the quality of gulabjamun was studied by Prajapati *et al.* (1992). They concluded that pre-soaked suji gave gulabjamun significantly improved flavour and body and texture scores as compared to the product obtained with dry suji.

Deshmukh *et al.* (1993) studied the effect of homogenization of milk on quality of gulabjamun. They concluded that there was no positive effect but it rather reduced the porosity of the product. Addition of trisodium citrate in the preparation of gulabjamun improved textural profile (softness, springiness) and sugar absorption (Thakar *et al.,* 1994).

Vélez-Ruiz and Sosa-Morales (2003) evaluated the rheological properties of donuts during frying and found that chewiness, cohesiveness, gumminess and springiness increased as frying time increased without a well defined trend. In contrast the hardness showed a slight diminution. Both compression and penetration forces were found to show an increasing trend with frying time and were not temperature dependent and fitted to a third order polynomial equation as a function of frying time. The texture properties of fried donuts were explained from the force-deformation

curve of puncture test. They indicated that the initial moisture content and fat to moisture ratio played an important role in the hardness of the product (Tan and Mittal, 2006).

The inter-relationship of chemical composition of potatoes to their textural quality was examined by Warren and Woodman (1974). The stress-strain curve obtained from compression tests was used to explain the textural properties of French fries. The maximum stress increased with the decrease of moisture content and increase of oil content during frying. Oil temperature also significantly affected the maximum stress. Indira *et al.* (1999) related the textural properties of samosa (fried composite product) to the moisture content of the casing, temperature of frying oil and time of frying using an empirical relationship.

The visco-elastic properties of tofu during frying followed zero-order reaction kinetics. The activation energies for the visco-elastic properties of tofu ranged between 100-149 $kJmol^{-1}$. The crust developed during the progress of frying, affected the texture characteristics (Baik and Mittal, 2006).

Kawas and Moreira (2001) observed that the tortilla chips became harder within 30 s of frying, and then became crunchy until the end of frying as moisture decreased. Krokida *et al.* (2001b) reported that as the oil temperature increased the maximum stress of the fried potatoes decreased, which denoted the higher firmness of the potatoes at lower temperature. Textural characteristics developed during the frying process of chicken nugget with respect to frying time and temperature conditions were studied using puncture tests by El-Dirani (2002). The maximum puncture load significantly increased with increase in frying temperature and frying time. Costa-Jimenez *et al.* (2005) reported that the crust of cheese kushiages became crisp and fragile textured, with increased hardness as the frying temperature increased. Sosa-Morales *et al.* (2006) studied the penetration force on fried pork meat crust and reported that the force increased with the frying time and the oil temperature. Kita *et al.* (2007) investigated the effects of oils and frying temperatures on fat content and texture of potato crisps and found that the crisp absorbed less fat and hardness was reduced with the increase in frying temperature.

The thermal properties of a food product are essential in heat transfer calculations and development of empirical models as it is a function of frying temperature. Higher the thermal diffusivity, the shorter the time required for the heat to propagate within the solid (Singh, 1982). However, whether an object with a higher thermal diffusivity will heat faster than a particle with a lower thermal diffusivity is actually a function of the surface convective heat transfer coefficient (Yildiz *et al.,* 2007).

2.7.3 Thermal properties

Several methods for measurement of effective thermal conductivity of foods have been reviewed by Mohsenin (1986). Many attempts have been reported to model the thermal conductivity of food materials which contained empirical factors and product-specific information (Murakami and Okos, 1989; Kopelman, 1996). Griffith (1985) determined the effective thermal conductivity of mass as a function of frying temperature, processing time and moisture content. Califano and Calvelo (1991) determined the thermal conductivity of potato between 50 and 100°C using an iterative least squares procedure by fitting the experimental core temperature data to the numerical solution of heat transfer equation for an infinite cylinder. The thermal conductivity of potato was found to increase with increase in frying temperature and modelled to a second order polynomial equation.

A first order exponential model was used to relate thermal conductivity with moisture content (% d.b.) by Moreira *et al.* (1992) for tortilla chips. The specific heat of tortilla chips was modelled in terms of moisture content and product temperature. Moreira *et al.* (1995) reported that thermal conductivity of tortilla chips decreased from 0.23-0.09 W/m°C and specific heat from 3.36-2.31 kJ/kg°C during the frying. Kopelman's equation was used to predict the thermal conductivity of fried tortilla chips measured at 25°C. Specific heat of tortilla chips decreased with decrease of moisture content and increase of oil content.

The thermal diffusivity of samosa during frying was found to decrease with increase in frying temperature, indicating that the crust of low thermal conductivity

was formed at higher temperature of frying (Indira *et al.,* 1999). Vélez-Ruiz *et al.* (2002) noticed that the thermal diffusivity value showed an increasing trend upto a certain time period depending on the frying temperature and smoothly decreased for the rest of the frying period during the deep fat frying of chicken strips. Similarly, Vélez-Ruiz and Sosa-Morales (2003) reported that the thermal conductivity was constant for donuts (0.097-0.098 W/m°C) at different temperature during the whole frying process, indicating structural transformations did not affect this property. They reported that the specific heat value increased slightly as the oil temperature increased. Farinu (2006) found that the specific heat, thermal conductivity and thermal diffusivity of sweet potato were increased with the increase in temperature and moisture content.

This chapter describes the experimental techniques employed to fulfil the various objectives involved for this study. It includes physico-thermal properties of toukir such as bulk density, tapped density, true density, colour, angle of repose (flowability), particle size distribution, wettability, water solubility index, water absorption index, dispersibility, microstructure, powder flow properties, glass transition temperature, thermal properties, moisture sorption isotherms of toukir at different temperatures, rheological behaviour of toukir suspensions at different concentrations and proximate composition of the powder. In addition, the methodologies for preparation and standardization of gulabjamun containing toukir at different levels and measurement of quality parameters like colour, texture, expansion ratio, thermal properties, etc are discussed.

3.1 Bulk and tapped densities of toukir

The toukir powder was gently loaded into a tarred graduated cylinder to 500 mL mark and weighed. The volume, read directly from the cylinder, was then used to calculate the bulk density (mass/volume). For the tapped density, the cylinder was tapped 1000 times using a tapped density tester (model Thermonik, Campbell Electronics, Mumbai, India). The volume of sample was then read and used to calculate the tapped density.

3.2 True/ particle density of toukir

Exactly 3 g of powder was transferred onto a 25 mL centrifuge tube with an air-tight stopper. Then 15 mL of petroleum ether was added and the tube was shaken well for 1 min until all the powder particles were suspended. Subsequently, all powder particles on the wall of the tube were rinsed down with additional 3 mL of petroleum ether (18 mL in total). The tube was then vigorously agitated on a vortex mixer for 5 min. The total volume of petroleum ether along with suspended powder was read. The particle density was calculated as follows:

$$Particle\,density = \frac{Weight\,of\ sample\,(g)}{Total\,volume\,of\ \ petroleum\ \ ether\,with\,suspended\ \ powder\,(mL) - 18} \qquad (3.1)$$

3.3 Colour of toukir

A Minolta colour spectrophotometer (model: CM5, Konica Minolta Sensing, Inc, Osaka, Japan) was used to determine the colour of toukir powder in terms of CIELAB parameters. The sample was loaded in the sample holder and L^*, a^* and b^* values were obtained using the software provided along by the instrument manufacturer.

Fig. 3.1. Minolta CM5 Colour Spectrophotometer

3.4 Flowability (Angle of repose)

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 the inter-particulate friction related to the particles density, size, surface area, shape and coefficient of friction (Littlefield *et al*., 2011). A new optical method of measuring the static angle of repose was used. A free-standing pile was formed by allowing the powder to pass through a fixed funnel. The powder was allowed to flow through a funnel of 15 cm top dia and 2.5 cm bottom opening. The images of the pile of toukir at moisture contents of 3, 6, 9 and 12% were taken by a digital camera and the angle of repose was measured using Image J software (ver. 1.45). The "Drop snake" tool from the Image J plugin was used to measure the angle of repose from the images after converting them to grey-scale.

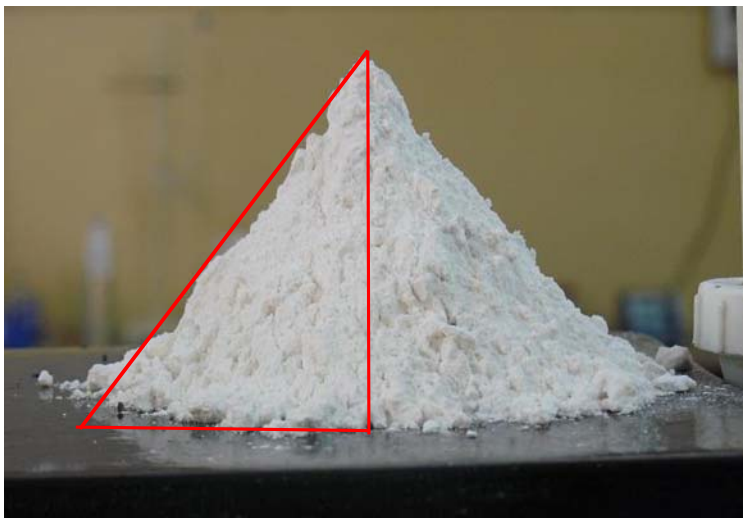


Fig. 3.2. Measurement of angle of repose

3.5 Particle size analysis

The particle size distribution of toukir in the dry method was estimated by laser diffraction technique (model Mastersizer Scirocco 2000, Malvern Instruments Ltd., UK) (Fig. 3.3). In this method, air was used as the dispersion agent for the powder from the inlet to sample cell. Approximately 30 g of toukir was loaded into a feeding tray. The dispersion air pressure was adjusted from 40-120 kPa in order to determine if particle attrition had occurred. At least three repeat measurements were obtained for each sample and the mean values of d0.1, d0.5, d0.9 diameters were determined.

Fig. 3.3. Particle size distribution measurement in Mastersizer Scirocco 2000

3.6 Wettability of toukir

Wettability of the toukir was determined according to the procedure outlined by A/S Niro Atomizer (1978a). About 100 mL of distilled water at ambient temperature was poured onto a 250 mL beaker. A glass funnel held on a ring stand was set over the beaker, with the height between the bottom of the funnel and the water surface as 10 cm. A test tube was placed inside the funnel to block the lower opening of the funnel. Exactly 0.1g of sample was placed around the test tube and then the test tube was lifted. The time taken for the toukir powder to become completely wetted (visually assessed as when all the toukir powder penetrated the surface of the water) was recorded.

3.7 Water absorption index (WAI) and water solubility index (WSI) of toukir

The WAI and WSI were determined as described by Anderson *et al.* (1969) with slight modifications. To determine WAI, 1 g of sample was suspended in 10 mL of distilled water (at ambient temperature) taken in a tarred centrifuge tube. The suspension was stirred in a vortex mixer for 5 min, and then centrifuged at 3500×g rpm for 15 min. The liquid supernatant was poured onto a tarred evaporating dish and dried at 110°C to constant weight. The weight of remaining gel was taken as WAI, and expressed in g/g. The amount of dried solids, recovered by evaporating the supernatant from the WAI analysis and expressed in dry solids, was taken as WSI.

$$WAI = \frac{W_g}{W} \tag{3.2}$$

$$WSI = \frac{W_s}{W} \tag{3.3}$$

where 'W' was the weight of dry solids in the original sample (g), 'W_g' was the weight of sediment (g) and 'W_s' was the weight of dissolved solids in supernatant (g).

3.8 Dispersibility of toukir

Dispersibility of toukir powder was measured according to the procedure outlined by A/S Niro Atomizer (1978b) with some modifications. Distilled water (10 mL), at 25±1ºC, was taken in a 50 mL beaker. Exactly 1 g of toukir was added into the beaker. The contents were stirred vigorously with a spoon for 15 s, making 25

complete movements back and forth. The reconstituted toukir was poured through a 212 μ sieve. The sieved and reconstituted sample was transferred to a pre-weighed petri dish and dried for 6 h in a hot air oven at 103±1ºC. The dispersibility of the powder was calculated as follows:

$$Dispersibility\ (\%) = \frac{(10+a)\times \%TS}{a\times\left(\frac{100-b}{100}\right)} \qquad (3.4)$$

where 'a' was the amount of toukir powder (g) being used, 'b' was the moisture content of the sample, and % TS was the dry matter in the reconstituted sample after it has been passed through the sieve.

3.9 Microstructure of toukir

The microstructure of toukir was examined using a scanning electron microscope (SEM) (model JSM-6390LA, JEOL, Japan) (Fig. 3.4). The sample was loaded into a sample holder and it was sputter-coated with gold to make it conductive before examination. After coating, the samples were scanned through scanning electron microscope under vacuum to get the microstructural images. Images were acquired at 500X and 1000X magnifications and at 1280 x 960 pixels resolution.

Fig. 3.4. JEOL JSM-6390LA Scanning Electron Microscope

3.10 Glass transition temperature of toukir powder

The temperatures which characterize the viscous behaviour of food powders are T_s (sticking point), T_c (collapse temperature) and T_g (glass transition temperature) (Mathlouthi and Rogé, 2003). The T_g decreases when moisture content is increased. The glass transition (T_g) of toukir powder was determined using a differential scanning calorimeter (model DSC822, Mettler Toledo, Greifensee, Switzerland) (Fig. 3.5). Samples weighing 6-8 mg were heated under nitrogen atmosphere from 30 to 80ºC, at a heating rate of 3ºC/min. The DSC was calibrated using indium as the standard and measurements were taken against an empty aluminium pan as the reference. Scans were done in duplicate on each sample. The onset of T_g was calculated using the Star SW 8.10 software supplied by the equipment manufacturer. The enthalpies associated with gelatinization of starch also were determined.

Fig. 3.5. Mettler Toledo DSC 822^e Differential Scanning Calorimeter

3.11 Thermal properties of toukir

The thermal properties of toukir powder such as thermal conductivity, thermal diffusivity, thermal resistivity and volumetric specific heat were determined using a thermal properties analyser (Model: KD2 Pro, Decagon Devices Inc., Pullman,

Washington, USA) with a dual-needle SH1 probe (Fig. 3.6). The device is based on the line heat source probe theory of transient heat transfer analysis. One needle contains a line heat source and the other is a thermocouple. When electric current is passed through the heater, the probe gets heated at a constant rate and the temperature of the probe inserted at the centre of the food sample was monitored over time. The thermal properties are calculated by monitoring the dissipation of heat from a line heat source given a known voltage. The length and diameter of the needle are 30 and 1.3 mm, respectively with the spacing of 6 mm. The operating temperature range of the probe was from -50 to 150°C.

The properties were measured after loading the sample into 50 mL beakers at the respective bulk densities (depending on the moisture content) at ambient temperature. The probe was inserted into the geometric centre of the beaker with sample. The measurement ranges were: thermal conductivity: 0.02-2 $Wm^{-1}K^{-1}$, thermal diffusivity: 0.1-1 mm^2s^{-1} and volumetric specific heat: 0.5-4 $MJm^{-3}K^{-1}$ with an accuracy of ≤10%. The SH-1 is compatible with most solid and granular materials. Measurement time for each sample was about 3-4 min. Before performing the actual experiment, the probe was calibrated using 99.5% pure glycerol. All thermal measurements were replicated at least twelve times.

Fig. 3.6. KD2 Pro Thermal Properties Analyzer

3.12 Moisture sorption isotherms of toukir

The static gravimetric technique based on isopiestic transfer of water vapour was adopted to obtain the moisture sorption characteristic of toukir powder. Saturated salt solutions of lithium chloride, potassium acetate, magnesium chloride, potassium carbonate, magnesium nitrate, sodium chloride, ammonium sulphate, potassium chloride, barium chloride and potassium sulphate were used to generate controlled humidity environment in a closed chamber giving a range of water activity (a_w) values of 0.113, 0.234, 0.335, 0.431, 0.574, 0.757, 0.821, 0.868, 0.930 and 0.982 respectively at three temperatures. Toukir samples (triplicate) were weight in the respective moisture beakers and then placed in desiccators. Each desiccator had respective saturated salt solutions used to obtain constant relative environment. The desiccators were placed in a temperature controlled cabinet at 10, 25 and 40±1ºC in subsequent runs. Toukir samples were equilibrated for approximately 45 days. BET, GAB, Kuhn, Caurie, Halsey and modified Mizrahi isotherm models were used to fit the moisture sorption data.

3.13 Powder flow properties

The dynamic testing of powders using a powder rheometer employs a specially shaped blade to establish a particular flow pattern in a precise volume of powder and evaluates the ability of the sample to resist the motion of the blade. The Freemans FT-4 powder rheometer (Freeman Technologies, Tewkesbury, UK) was used for this purpose. The powder measurements consisted of the determination of dynamic, bulk and shear properties. All tests were carried out with a 48 mm blade and 50 mm dia. vessels. The flow pattern is downward anti-clockwise motion generating a compressive, relatively high stress flow mode in the powder. The basic flowability energy (BFE), specific energy (SE), stability index, conditioned bulk density (CBD), aeration properties, compressibility, permeability and wall friction were measured.

The BFE was calculated from the work done in moving the blade through the powder from the top of the vessel to the bottom, i.e. during the downward traverse. In the same test, the SE was also derived during the upward movement of the blade through the powder. The SE was more dependent on the cohesive and mechanical interlocking forces between the particles and less influenced by other factors, such as

compressibility. The aeration energy measured the energy required to pass a blade through a specific volume of powder whilst passing a continuous stream of air through the base of the test vessel. In order to measure conditioned bulk density, the bulk density of 160 mL of conditioned powder was tested. The CBD was calculated automatically using the inbuilt balance of the FT-4. The conditioning process utilised the standard FT-4 blade and moved the powder in a gentle reproducible way in order to establish a homogenised stress in the powder. Compressibility indicates the percentage by which the bulk density has increased with an applied normal stress to the sample.

Permeability refers to the porosity of the powder bed at a normal stress and at a specified air velocity. This test measured the air pressure required to maintain a constant air flow through the powder bed whilst being consolidated at increasing normal stresses. Generally, a higher normal stress results in a higher pressure drop as the permeability is reduced due to particles becoming more closely packed. The wall friction angle (WFA) is the shear angle required to initiate steady-state flow for a powder sample relative to a given material. Its magnitude depends on the properties of both the powder and the surface finish and material of construction of the test. A larger WFA indicates a higher resistance to flow of the specific powder across the test surface. These properties of toukir were tested and compared at 3 and 12% moisture content.

3.14 Rheological properties of toukir suspensions

The apparent viscosities of toukir suspensions at different temperatures and concentrations were determined using a rotational viscometer (Model RVDV-II+Pro or LVDV-II Pro, Brookfield Engineering Laboratory, Stoughton, MA) (Fig. 3.7). In case of RVDV-II, the measurements were taken at spindle speed range of 10-100 rpm (in steps of 10 rpm) in a continuous run mode. The viscosity measurements were carried out at 20-80°C, at 10°C interval. The viscosity measurements were done using an appropriate spindle based on the consistency. The spindles were selected such that the measurement range of torque in the viscometer was maintained within the range of 10 to 95%. The disc spindle was inserted into the sample at a depth indicated by the notch on the spindle, and the depth was kept constant throughout the study. As

mentioned before, the samples for viscosity measurement were taken in 600 mL beakers having a diameter of 90 mm.

In the case of LVDV-II, the cup and cylinder geometry was used. Both viscometers were operated in an external mode using a computer loaded with Rheocalc v. 3.1.1 software supplied by Brookfield Engineering Laboratory. At each rpm, shearing of the sample was done for 30 s before the speed was ramped up to the next level. The torque and apparent viscosity data were collected at 10 s interval for each rpm. The data were acquired using the same software.

3.14.1 Conversion of viscometric data and time-independent flow modeling

The RVDV viscometric data were converted into shear stress-shear rate form by Mitschka method (Briggs and Steffe, 1997). The flow behaviour index 'n' was determined as the slope of the $\log_{10}$ of shear stress vs. $\log_{10}$ of rpm plot as shown in the equation below:

$$n = \frac{d(\log_{10} \sigma)}{d(\log_{10} N)}$$

The shear stress, σ, was given by the equation:

$\sigma = k_{\alpha\tau}$.(C x dial reading)

where 'n' was the flow behaviour index (dimensionless), '$k_{\alpha\tau}$' was shear stress conversion factor (Pa), 'N' was the rotational speed in rpm and 'C' was the spring constant (C=1 for the RV model). The parameter '$k_{\alpha\tau}$' was a function of spindle number. The dial reading represented the percent torque displayed on the Brookfield viscometer.

The average shear rate, $\dot{\gamma}_a$, was computed using the equation:

$$\dot{\gamma} = K_{NY} \times N$$

where 'K_{NY}' was the shear rate conversion factor. Values of 'K_{NY}' as a function of the spindle number and flow behaviour index were obtained from Briggs and Steffe (1997). In case of LVDV-II, the shear stress – shear rate data were directly measured

using the instrument. The Ostwald De Waele (Power law) model was fitted to the shear stress-shear rate data.

$$\sigma = K.\dot{\gamma}^n$$ (Ostwald De Waele model)

where 'σ' was the shear stress (Pa), '$\dot{\gamma}$' was the shear rate (s^{-1}). The constant 'n' is a measure of the extent of departure from Newtonian behaviour. These models relate the shear stress to the shear rate, thus enabling the apparent viscosity to be calculated. The Ostwald De Waele model was fitted by plotting *ln* σ against *ln* $\dot{\gamma}$. The slope of this straight line relationship yielded the flow behaviour index 'n'.

Fig. 3.7. Brookfield RVDV II+ Pro Rotational Viscometer

3.15 Proximate analysis of toukir powder

The toukir powder was analysed for moisture, fat, protein, ash and carbohydrate contents.

3.15.1 Protein content

The protein content of toukir powder was estimated by using Micro-Kjeldhal method as prescribed for cereals with slight modifications (AOAC, 2005). About 0.2 g of the sample was taken in a 300 mL digestion tube followed by the addition of 5 g of digestion mixture and 15-20 mL of concentrated sulphuric acid (H_2SO_4). The samples were digested at temperature of 100-300ºC until a clear filtrate was obtained. Then the

contents were cooled to room temperature. About 25-30 mL of 50% (w/w) sodium hydroxide (NaOH) was added to make the solution alkaline. The contents were distilled and the liberated ammonia was collected in 25 mL of saturated boric acid containing 3-5 drops of mixed indicator (10 mL of 0.1% bromocresol green + 2 mL of 0.1% methyl red indicator in 95% ethyl alcohol). Distillation was continued until about 65 mL of distillate was collected and was titrated against N/10 HCl till the end point. The same procedure was adopted for blank also. The percentage protein in the sample was calculated as follows:

$$\%\ Nitrogen\ = \frac{1.4008\ \times\ (S - B)\ \times\ Normality\ of\ H_2SO_4}{Weight\ of\ sample\ (mg)} \times 100 \qquad (3.5)$$

$$\%Protein\ =\ 6.38\ \times\ \%\ Nitrogen \qquad (3.6)$$

where 'S' was the volume of HCl used for sample titration and 'B' was the volume of HCl used for blank titration.

3.15.2 Fat content

Fat content of the toukir powder was estimated using Mojonnier method (AOAC, 2005). About 2 g of sample was taken in a 50 mL beaker, added 2 mL of alcohol and stirred. The sample was digested using 10 mL concentrated HCl at 70-80 ºC in water bath for about 1 h and 10 mL alcohol was added and cooled. The content was transferred to the Mojonnier fat extraction apparatus. About 25 mL diethyl ether was added to the above content. The flask was closed with the cork (or stopper). Then the content was shaken vigorously for one minute. Exactly 25 mL petroleum ether was added to the content and was shaken vigorously for one minute. The flask was allowed to stand till for 30 min the ethereal layer was clear and completely separated from the aqueous layer. The supernatant layer was carefully decanted into 250 mL conical flask which was previously weighed and kept. The extraction was repeated two times using 15 mL of each diethyl ether and petroleum ether. The solution collected in conical flask from Mojonnier flask was evaporated slowly on steam bath to remove the

solvent. The residual fat was dried in the oven at 100 ± 2ºC to constant weight (usually 90 min.) the fat content in the sample was calculated as:

$$Fat\ content\ (\%w.b.) = \frac{(W_d - W_i)}{W_s} \times 100 \qquad (3.7)$$

where 'W_s' was the weight of sample (g), 'W_i' was the initial weight of conical flask (g) and 'W_d' was the final weight of conical flask after drying (g).

3.15.3 Ash content

The ash content in the sample was estimated using direct method for powder (AOAC, 2005). About 3-5 g sample was taken into shallow, clean, dry and predetermined weight of silica crucible dish. The ashing was carried out in a muffle furnace maintained at 550ºC until light gray ash results, or to constant weight (usually 5 h). After ashing of the sample, it was cooled in a desiccator and the weight of crucible dish was taken.

$$Total\ ash\ (\%\ w.b.) = \frac{(W_d - W)}{W_s} \times 100 \qquad (3.8)$$

where, 'W_s' was the initial weight (g), 'W' was the weight of empty crucible dish (g) and 'W_d' was the weight of crucible dish with the sample after drying (g).

3.15.4 Carbohydrate content

The carbohydrate of toukir powder was determined by standard difference method (% w.b.).

$$Total\ carbohydrate\ (\%\ w.b.) = 100 - (moisture\ \% + fat\ \% + protein\ \% + ash\ \%) \qquad (3.9)$$

3.16 Incorporation of toukir in gulabjamun

3.16.1 Preparation of gulabjamun

Gulabjamun was prepared as outlined in the flow chart below (Fig. 3.8). The detailed methodology is given in the succeeding paragraphs.

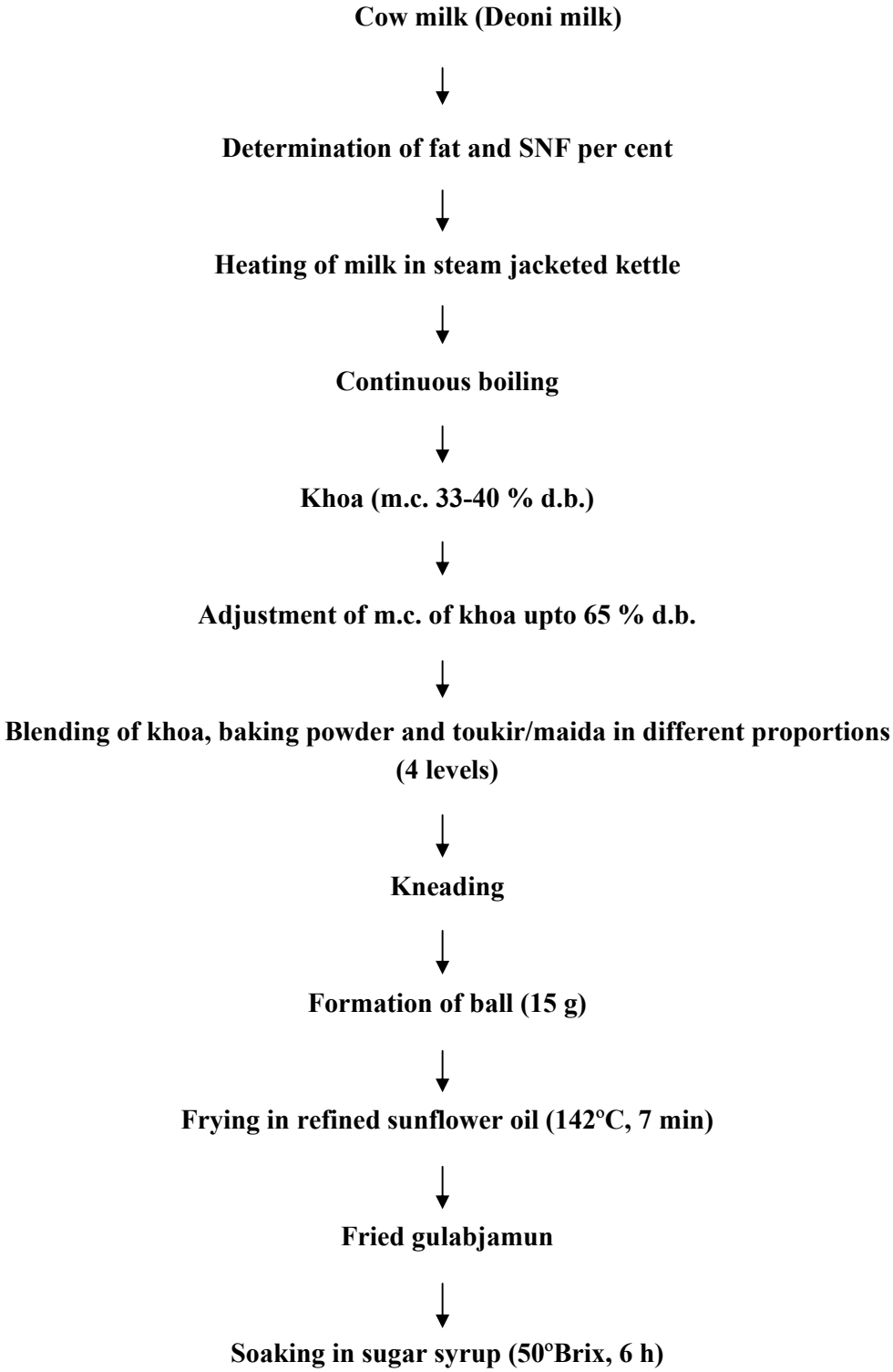


Fig. 3.8. Process flow chart for the preparation of fried gulabjamun

3.16.1.1 Raw material

Fresh cow milk (Deoni milk) was collected from the cattle farm of National Dairy Research Institute (NDRI). The fat and solid not fat (SNF) content of milk were determined using Gerber method and lactometer formula method respectively. The other ingredients such as refined wheat powder (maida), baking powder, sugar and sunflower oil were procured from market.

3.16.1.2 Preparation of khoa

For the manufacture of khoa, the milk was transferred to a steam jacketed kettle where the steam pressure was maintained at 2 kg/cm^2. The milk was then allowed to boil vigorously with continuous stirring cum scraping. It was concentrated to a semisolid consistency till the moisture content reached 33 to 40 % on dry basis (d.b.).

3.16.1.3 Preparation of dough

Dough was prepared by blending khoa, maida (or toukir), baking powder in required proportion. The maida was added to the blend at the rate of 12% on w/w basis of dough. The toukir was added at three different rates of 6, 12 and 18% on w/w basis of dough. Baking powder was added at the rate of 3% on w/w basis of dough. Again, all the ingredients were kneaded in a dough blender. The moisture content of the dough was adjusted in such a way that the final dough should contain 65% moisture (d.b.).

3.16.1.4 Frying equipment

Frying was carried out on batch basis in mini-master electric fryer (model CMF-6/I/E, Continental Equipment India Pvt. Ltd., Bangalore). The capacity of the fryer was 6 L with dimensions of 190×435×310 mm and used 2 kW of electric power for heating. The temperature of the frying oil was measured using a thermocouple probe connected to a digital temperature indicator (Sigma Automation, Bangalore, India). The heating range of the fryer could be varied from 30 to 300°C using the thermostatic temperature controller.

3.17 Determination of moisture content of fried and unsoaked gulabjamun

The whole gulabjamun was grounded using pestle and mortar. From the grounded mass, about 3 g of the sample was taken and weighed accurately. Moisture content was determined by gravimetric method as discussed before.

3.18 Determination of dimensional changes

The weight and dimensional changes of gulabjamun during frying were measured using weighing balance (model CP323S, Sartorius Mechatronics India Pvt. Ltd.) and digital caliper (model CD-6"CSX, Mitutoyo Corporation, Kawasaki, Japan), respectively. The dimensions of fried gulabjamun were measured as 'a', 'b' and 'c' in 'x', 'y' and 'z' directions of the geometry, respectively. From the 'a', 'b' and 'c' values obtained sphericity, apparent density and expansion ratio were calculated.

3.18.1 Sphericity (ϕ)

Sphericity of gulabjamun was calculated using Mohsenin (1986).

$$\phi = \frac{Geometric\ mean\ diameter}{a} \tag{3.10}$$

$$Geometric\ mean\ diameter = (a.b.c)^{\frac{1}{3}} \tag{3.11}$$

where 'a', 'b' and 'c' were the dimensions of gulabjamun.

3.18.2 Expansion ratio (ε)

The expansion ratio of a product can be defined as the ratio of final cross sectional area to initial cross sectional area. It was determined using Eqn (3.12).

$$\varepsilon = \frac{A_f}{A_i} \tag{3.12}$$

where 'A_f' was the final cross sectional area of gulabjamun and 'A_i' was the initial cross sectional area of gulabjamun.

3.18.3 Apparent density (ρ_{app})

The apparent density of the fried gulabjamun was calculated from given formula

$$\rho_{app} = \frac{weight\ of\ gulabjamun}{volume\ of\ gulabjamun} = \frac{w}{\frac{4}{3}\pi r^3} \quad (3.13)$$

where 'w' was the weight of gulabjamun ball and 'r' was the radius of gulabjamun ball.

3.18.4 Cell to total area ratio (Porosity)

Images of gulabjamun added with different concentrations of toukir ball were acquired at 300 dpi resolution by scanning it on a flatbed scanner (model HP Scanjet 3970, Hewlett Packard India, Mumbai) connected to a PC (Datta *et al.,* 2007). The brightness and contrast parameters of the scanner software program were kept in the default mode (zero) for all samples to avoid any interference. The images were cropped and converted to grayscale (16 bit) using Image J 1.34s software (National Institutes of Health, Bethesda, Maryland, USA), and a field of view of 852×98 pixels was selected at the center of the slice. Pre-processing (change to gray-level), segmentation (Otsu Thresholding) (Matos and Rosell, 2012) and crumb grain measurements (extraction of parameters) were done using the same program.

Otsu thresholding is a simple and effective method that produces binary images with a high degree of uniformity, and it generates consistent binary image in terms of threshold performance for measuring bread crumb evolution and features (Gonzales-Barron and Butler, 2006). The method utilizes only the zeroth- and the first-order cumulative moments of the gray-level histogram. In this work, a constant threshold value between 168 and 175 was selected for all images by the discriminant criterion so as to maximize the separability of the air vacuoles in gray-level images. For each baking time interval, this method was then used to convert the gray-level image to binary images, and the drawing of air vacuoles was extracted from them using the "Analyze Particles" routine. In the "Analyze Particles" dialog, the particle areas to be considered were set as "2 to infinity" pixel units, and the option of "Exclude on Edges" was deselected. Similar approach has been used by Igathinathane *et al.* (2009) and others for particle size analysis. Cell to total area ratio corresponds to the proportion of the crumb area computed as cells as follows:

$$Cell\ to\ total\ area\ ratio\ = \frac{\sum_{i=1}^{N} A_i}{Total\ area\ surveyed} \qquad \text{(Sapirstein } et\ al.\text{, 1994)} \quad (3.14)$$

3.19 Measurement of crust colour

The crust colour of gulabjamun after frying was measured using a computer based image analysis technique. The samples were placed on a flatbed scanner (HP Scanjet 3970) and scanned at 300 dpi resolution. The images were then imported into Adobe Photoshop software and the 'L', 'a' and 'b' values were obtained. These values were converted into CIELAB L^*, a^* and b^* values using the following formulae (Yam and Papadakis, 2004).

$$L^* = \left[\frac{L}{255}\right] \times 100 \quad (3.15)$$

$$a^* = \left[\frac{240a}{255}\right] - 120 \quad (3.16)$$

$$b^* = \left[\frac{240b}{255}\right] - 120 \quad (3.17)$$

3.20 Measurement of thermal properties of fried and unsoaked gulabjamun

The thermal properties of gulabjamun such as thermal conductivity, thermal diffusivity, thermal resistivity and volumetric specific heat were measured and recorded using KD2 Pro thermal properties analyzer (Decagon Devices, Pullman, USA) with SH-1, dual needle type probes (30 mm). The properties were measured after cooling the samples to ambient temperature. The probe was inserted into the geometric centre of the product and kept undisturbed when the measurement was taken.

3.21 Determination of textural properties

Textural profile analysis (TPA) was performed using TA.XT Plus Texture Analyzer (Stable Micro Systems, Texture Technologies Crop., Godalming, UK) equipped with 50 kg load cell (Fig 3.9). TPA was done to characterize the hardness, springiness, cohesiveness, chewiness and gumminess. Fried and soaked gulabjamun was compressed twice in a reciprocating motion to give a two-bite texture profile

curve. The compression depth of 15 mm was achieved using P/75 compression platen (75 mm diameter) at a cross-head speed of 0.5 mm/s, pre-test speed of 1 mm/s and post-test speed of 10 mm/s with 60 s of time interval between the two bites. The data obtained were analysed using Texture Exponent software supplied by the equipment manufacturer.

Fig. 3.9. Stable Micro Systems TA XT Plus texture analyzer

From the force deformation curve (Fig. 3.10), the texture profile parameters were calculated. Hardness is defined as the maximum peak force during the first compression cycle (first bite) while springiness is the relation between the height that the food recovers during the time that elapses between the end of the first bite and the start of the second bite.

$$Springiness = \frac{Time\,difference\,4:5}{Time\,difference\,1:2} \qquad (3.18)$$

Cohesiveness is defined as the ratio of the positive force area during the second compression to that during the first compression.

$$\text{Cohesiveness} = \frac{\text{Area 4:6}}{\text{Area 1:3}} \tag{3.19}$$

$$\text{Gumminess} = \text{Hardness} \times \text{Cohesiveness, N} \tag{3.20}$$

$$\text{Chewiness} = \text{Gumminess} \times \text{Springiness, N} \tag{3.21}$$

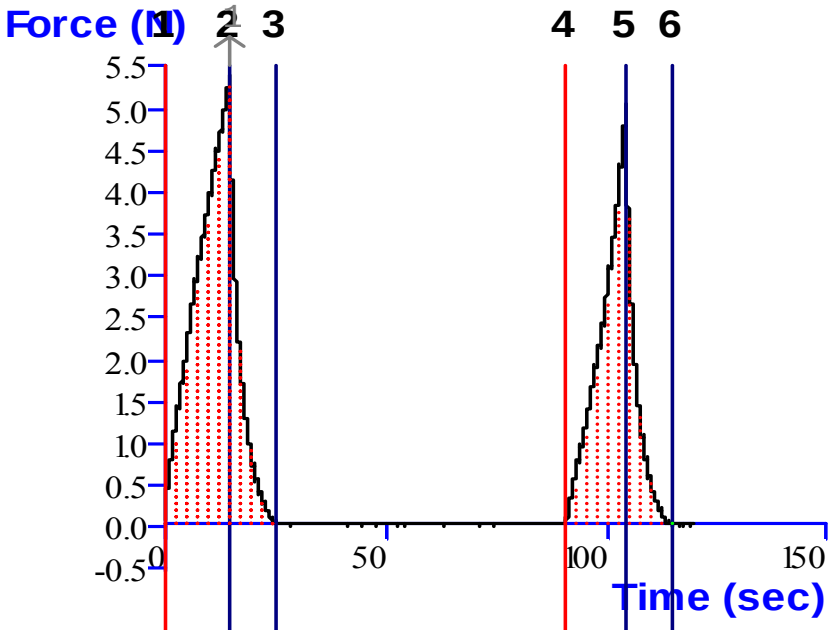


Fig. 3.10. Typical texture profile curve of fried gulabjamun

3.22 Sensory evaluation of fried and soaked gulabjamun using fuzzy-logic approach

Forty three judges were selected for the study. Judges were trained about the characteristics of the product, sensory evaluation procedure, score card and method of scoring. The responses were taken on a five-point linguistic scale: “Poor”, “Fair”, “Good”, “Very Good” and “Excellent” (Table 3.1). The major steps involved in the fuzzy modeling were: (1) calculation of overall sensory scores of gulabjamun in the

form of triplets; (2) estimation of membership function on standard fuzzy scale; (3) computation of overall membership function on standard fuzzy scale; (4) estimation of similarity values and ranking of the product and (5) quality attribute ranking in general (Das, 2005).

Table 3.1. Score card for sensory evaluation of gulabjamun using fuzzy-logic

Sensory attribute	Sample	Poor	Fair	Good	Very good	Excellent
Colour & appearance						
	sample 1					
	sample 2					
	sample 3					
	sample 4					
Body & texture						
	sample 1					
	sample 2					
	sample 3					
	sample 4					
Flavour						
	sample 1					
	sample 2					
	sample 3					
	sample 4					
Mouthfeel						
	sample 1					
	sample 2					
	sample 3					
	sample 4					
Sweetness						
	sample 1					
	sample 2					
	sample 3					
	sample 4					

This method utilizes linguistic data obtained by subjective evaluation, and also accurate and precise data obtained using objective evaluation. Ranking of the product was done using triangular fuzzy membership distribution function, which has been explained in detail by Das (2005). The score card was converted to triplets and was used for estimation of similarity values used for ranking of samples. The triplet for sensory scores for a particular quality attribute of every sample was obtained from the

sum of sensory scores, triplets associated with sensory scale and number of judges. For example, when total number of judges is ($n_1 + n_2 + n_3 + n_4 + n_5$) and n_1 judges give "Poor" score, n_2 judges give "Fair" score, n_3 judges give "Good" score, n_4 judges give the score as "Very Good" and n_5 judges give "Excellent," the triplets for the sensory scores for that attribute was calculated as follows:

$$Attribute = \frac{n_1(0\ \ 0\ \ 25) + n_2(25\ \ 25\ \ 25) + n_3(50\ \ 25\ \ 25) + n_4(75\ \ 25\ \ 25) + n_5(100\ \ 25\ \ 0)}{n_1 + n_2 + n_3 + n_4 + n_5} \quad (3.22)$$

Similar triplet values were obtained for each of the quality attributes of all the samples, and the triplet for the sensory score of quality attributes were calculated from the general weightage given by the judges to the quality attributes of gulabjamun in general.

3.23. Statistical analyses

The data on various properties of toukir and gulabjamun were analyzed using One-Way Analysis of Variance (ANOVA) procedure in SAS 9.1. The level of significance was 0.05.

This chapter deals with the presentation and discussion of results related to the various experiments conducted for fulfilling the objectives of the current study. It includes physico-thermal properties of toukir powder at different moisture contents, moisture sorption isotherm of toukir powder at different temperature, chemical composition of toukir powder, rheology of toukir suspensions at different concentrations and application of toukir in the preparation of gulabjamun and characterization of its attributes.

4.1 Proximate analysis of toukir

The chemical composition of toukir samples were analyzed by standard procedure. It was found that toukir was rich in starch (98.436%), followed by fat, ash and protein contents of 0.584, 0.143 and 0.837%, respectively. The moisture content of toukir on dry basis was 6.870%.

4.2 Bulk and tapped densities of toukir

The bulk and tapped densities decreased from 630 to 530 kg/m^3 and from 930 to 767 kg/m^3, respectively with increase in moisture content from 3 to 12% (Figs. 4.1 and 4.2). The bulk density of toukir was on par with the bulk densities of millet grains as reported by Subramanian and Viswanathan (2007). One way ANOVA (Appendix Tables A1-2) showed that bulk and tapped densities were significantly dependent on moisture content ($p<0.05$). The densities decreased with increasing moisture content due to bridging up of toukir particulates. Keogh *et al.* (2003) observed that decrease in moisture content from 3.7 to 3.0% in standardized milk powder decreased the particle and bulk densities from 1226 to 1185 kg/m^3 and from 600 to 560 kg/m^3, respectively.

4.3 True/ particle density of toukir

The true or particle density of toukir was found to be 2424 kg/m^3. It was also observed that change in moisture content did not affect the particle density within the range of moisture content studied.

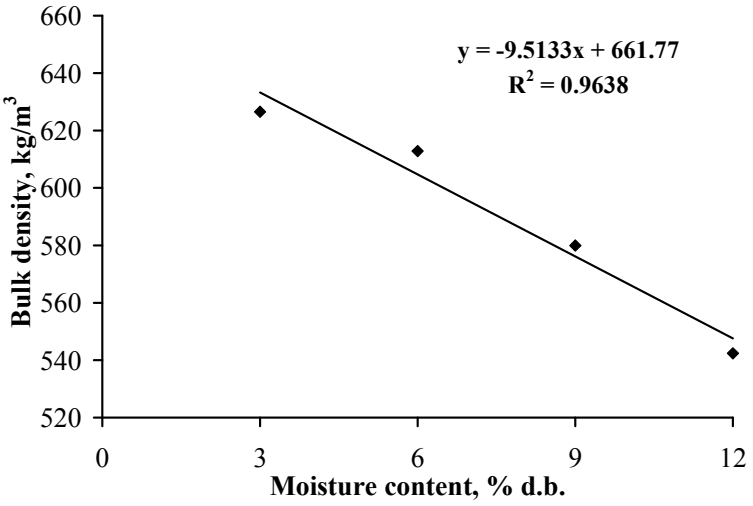


Fig. 4.1. Influence of moisture content on bulk density of toukir

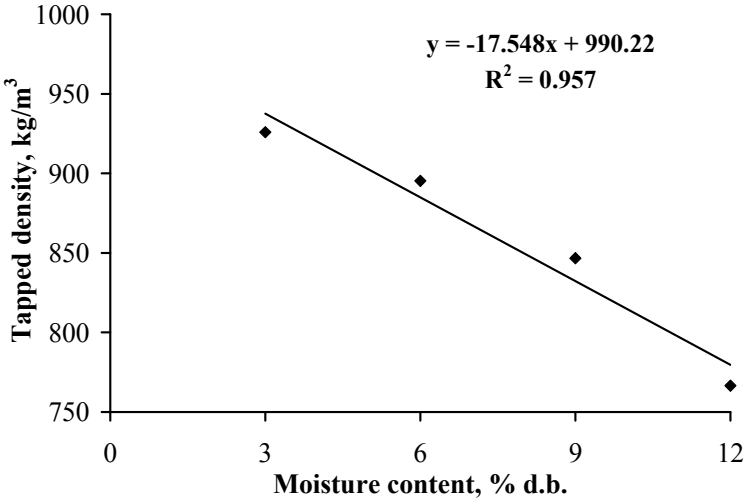


Fig. 4.2. Influence of moisture content on tapped density of toukir

4.4 Colour of toukir

The colour of starch has an impact on its quality. Any pigmentation in the starch is carried over to the final product, which may influence the acceptability of the product. A high value of lightness (L^* value) and a low value of chroma (b^* value) are desired for toukir starch to meet the consumer preference. Colour of toukir, in terms of L^*, a^* and b^* values, were 95.74, -0.01 and 3.30, respectively. From these values, it

could be concluded that toukir had a high value of whiteness and a low value of chroma. It was observed that moisture content did not affect the colour of toukir within the range studied.

4.5 Flowability (angle of repose)

The flowability of toukir decreased continuously (angle of repose increased) with increasing moisture content (Table 4.1). This was because toukir was moisture sensitive and moisture played a vital role in its cohesiveness. One way ANOVA (Appendix Table A3) also showed that angle of repose was significantly dependent on moisture content ($p<0.05$). The angle of repose at 3, 6, 9 and 12% moisture contents were 50.02, 54.49, 55.55 and 56.14º, respectively. As the RH of the surrounding air increased, the powder tend to adsorb molecules of water, which formed liquid bridges between powder particles, resulting in increased cohesion and reduced flowability. The increase in the strength of the liquid bridges with increasing relative humidity was considerable, and therefore, the flowability decreased in the range of moisture content tested. Also, increased moisture content could make the particle surfaces stickier, resulting in greater adhesion between the particles and a wall surface. Walker (1967) showed that the flowability of a powder first decreased with moisture content until a critical water content, above which it increased, but the rate of decrease and the critical water content were dependent on the powder and its behaviour in the presence of water.

Table 4.1 Angle of repose of toukir at different moisture contents

S.No.	Moisture content, % (d.b)	Angle of repose (deg)
1	3	50.02
2	6	54.49
3	9	55.55
4	12	56.14

4.6 Particle size analysis

Particle size is considered as one of the most important physical properties which affect the flowability of toukir. The particle size distribution graph of toukir is

presented in Fig. 4.3a, and the cumulative volume percentage under different particle size is presented in Fig. 4.3b. The gentle shift of both curves to the right without much change in the volume percentage of the fractions suggested that all the particles increased in size. The particle size parameters such as d(0.1), d(0.5), and d(0.9) increased from 9.510 to 9.709µ, 15.568 to 16.792µ, and 178.631 to 224.360µ, respectively as the moisture content increased 3 to 12% (Table 4.2). This was due to the swelling of particulates (starch) as they imbibed water. A positive relationship could be described between particle size and angle of repose. As the particle size increased due to swelling, the particle surface smoothness increased, which in turn increased the particle-particle interaction by Van der Waals forces and by mechanical linkages. This was because smooth surface particles provide a high contact area that enabled them interact easily with each other (Landillon *et al*., 2008).

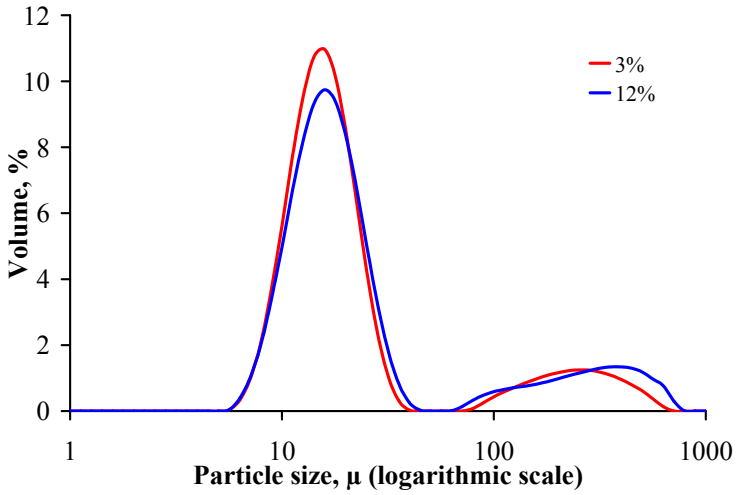


Fig. 4.3a. Particle size distribution of toukir at 3 and 12% moisture contents

Table 4.2 Particle size diameter of toukir at different moisture contents

Moisture content of toukir	Particle diameter		
	d(0.1)	d(0.5)	d(0.9)
3%	9.51µ	15.568µ	178.631µ
12%	9.636µ	16.684µ	244.818µ

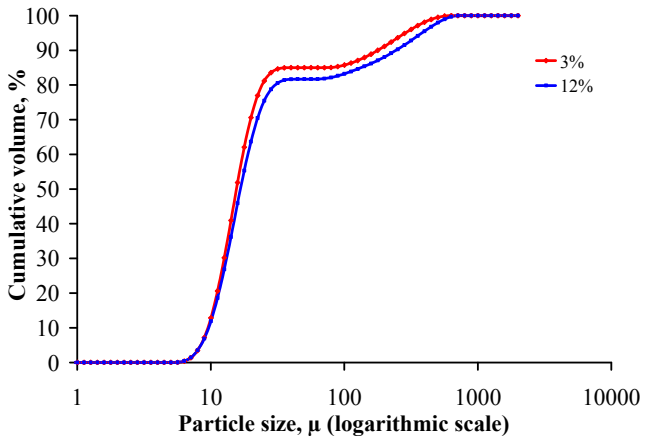


Fig. 4.3b. Cumulative particle size distribution of toukir at 3 and 12% moisture contents

4.7 Water absorption index and dispersibility

WAI measures the volume occupied by the starch after swelling in excess water, which corresponds to the integrity of starch in aqueous solutions and the volume of the gel formed. WAI depends on the availability of hydrophilic groups and on the capacity of gel formation of the macromolecule (Silva *et al.,* 2009). The WAI for toukir ranged between 2.01 and 2.06 $g.g^{-1}$. The wettability of toukir powder was found to be very poor. The dispersibility of toukir was determined as 81%.

4.8 Water solubility index

WSI is related to the amount of soluble solids. Experimental WSI values for toukir powder ranged between 0.028 and 0.031 $g.g^{-1}$. The swelling power and solubility pattern are indicative of the associative binding force within the starch granules. Toukir could be described to have a high swelling power as the solubility exceeds 30% (Ikegwu *et al*., 2010). Therefore, these granules well enormously and the internal bonds become fragile toward shear when it is cooked in water. However, the initial moisture content of toukir did not have any effect on the WSI of the product.

4.9 Microstructure of toukir

Scanning electron microscopic analysis of toukir showed the powder particulates were tetrahedral in shape, and were similar in structure to cassava starch

(Figs. 4.4a & b). It was observed that toukir was loose and porous with a fine surface texture. Rani and Chawhaan (2012) observed that toukir powder was granular, with rounded or oval to elliptical shape. The particle size was reported to range from 3.32 to 32.55µ in length and 2.29 to 8.47µ in width. The loose particle nature of the product seemed to improve the flowability and reduce binding with each other. However, if fineness increases its buoyance, it will lead to lump formation, which will reduce the flowability of the product. The SEM micrographs at different moisture contents also revealed the increase in particle size of toukir powder with increasing moisture content. The mean particle size increased from 17.33 to 19.19µ as moisture in toukir increased from 3 to 12%. The wet and swollen surfaces of the granules are evident in Fig 4.4b.

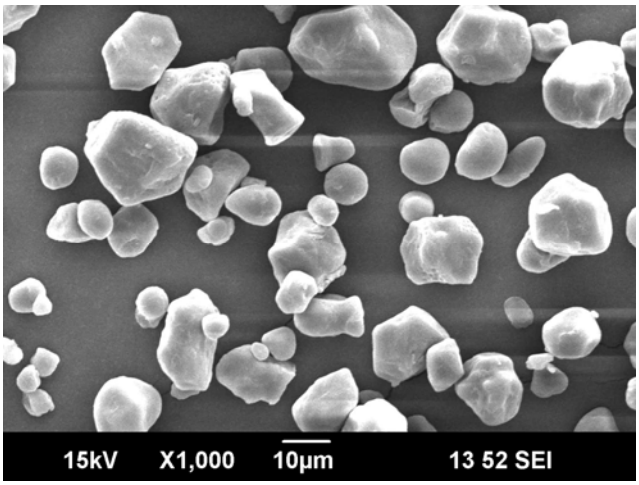


Fig. 4.4a. SEM micrograph of toukir at 3% moisture content

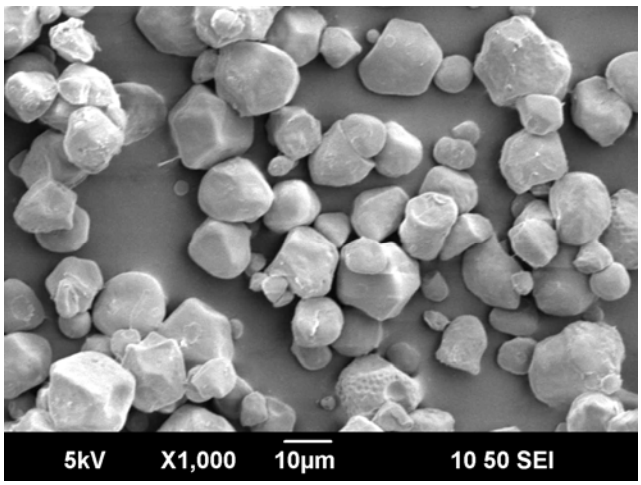


Fig. 4.4b. SEM micrograph of toukir at 12% moisture content

4.10 Glass transition temperature

The differential scanning calorimeter simultaneously scans and measures the heat input to the sample compares it to that of the reference. Any heat-induced physicochemical changes in the sample are thus recorded as a peak on the thermogram. The DSC thermograms of toukir starch exhibited glass transition typical of a semi-crystalline polymeric system (Fig. 4.5). The glass transition temperatures of toukir at different moisture contents are presented in Fig 4.6.

The T_g decreased linearly from 70.15°C at 3% moisture content to 64.65°C at 12% moisture content (R^2=0.985). One way ANOVA (Appendix Table A4) showed that T_g of toukir was significantly dependent on moisture content ($p<0.05$). The results of toukir were in confirmation with the values of 67-78°C reported by Stevens and Elton (1971) for maize starches. The lowering of T_g with increasing concentrations of plasticizers also affirmed the classical theory of plasticization. Within starch, the amorphous regions are more water-accessible than crystalline regions, where the intermolecular interactions between chains are too strong to allow solvent penetration. Thus, water influenced the structure of toukir by acting as plasticizer of the amorphous regions.

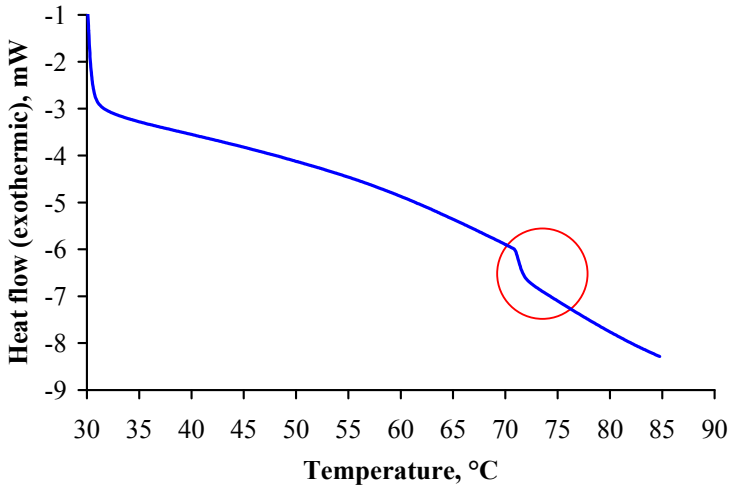


Fig. 4.5. DSC thermogram showing glass transition in toukir

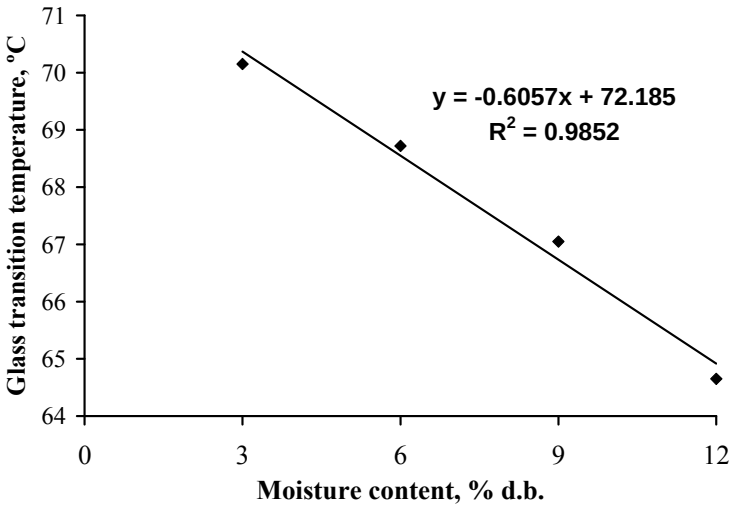


Fig. 4.6. Influence of moisture content on glass transition temperature of toukir

4.11 Thermal properties of toukir

Significant changes in thermal properties of toukir flour were observed with moisture content (Appendix Tables A5-8). The volumetric specific heat, thermal conductivity, and thermal diffusivity increased from 1.526 to 1.582 kJ/m^3.K, 0.141 to 0.158 W/m.K and 0.089 to 0.097×10^{-6} m^2/s, respectively as the moisture content increased from 3 to 12% (Table 4.3). The increase in thermal conductivity, thermal diffusivity and specific heat was expected as moisture was a good conductor of heat amongst food constituents. Similar results were reported by Subramanian and Viswanathan (2003) for different millet flours. Consequent to the increase in thermal diffusivity, the thermal resistivity decreased from 7.104 to 6.539 °cm/W with increasing moisture content.

Table 4.3. Thermal properties of toukir at different moisture contents

Moisture content (%)	Thermal conductivity, W/m.K	Volumetric specific heat, kJ/m^3.K	Thermal diffusivity, m^2/s	Thermal resistivity, °cm/W
3	0.141	1.526	0.089×10^{-6}	7.104
6	0.145	1.534	0.095×10^{-6}	6.891
9	0.151	1.564	0.097×10^{-6}	6.612
12	0.153	1.582	0.097×10^{-6}	6.539

4.12 Moisture sorption isotherms at different temperatures

The isotherms at all three temperatures were sigmoidal in shape, belonging to type II of Brunauer-Deming-Deming-Teller (BDDT) classification. Two bends were noted in the isotherms, one at about a_w of 0.09 and the other at a_w of 0.83 (Fig. 4.7). The moisture uptake was slow and steady till 0.80 a_w, followed by an accelerated rise in region III of the isotherm. This type of isotherm is characteristic of multilayer sorption in which water molecules are adsorbed in layers whose thickness increased with increasing a_w. The crystalline regions of starch (in refined wheat flour) exhibit resistance to penetration of water molecules until the a_w was high enough to cause swelling (Al-Muhtaseb *et al.*, 2004a). Furthermore, at low a_w, the plasticizing effect of water would be small and the mobility of the amorphous regions of starch would be restricted.

Sorption temperature affects the mobility of water molecules and the dynamic equilibrium between vapour and adsorbed phase (Al-Muhtaseb *et al.,* 2004b). Figure 4.5 shows the effect of temperature on moisture sorption behaviour of toukir. The sorption isotherms showed a decrease in the amount of sorbed water with increase in temperature at constant a_w. Similar decrease in EMC with temperature was reported in foods containing starch (Pushpadass *et al.*, 2013). The EMC decreased due to the increased tendency of water molecules to break away from the binding sites. Also, the shift in water activity caused by temperature changes was reasoned to the change in water binding, the dissociation of water or the increase in solubility of a solute in water (Rahman, 1995). Crossing over of the isotherms was observed at a_w above 0.90. This was because the temperature effect was negated by the increased solubilities of low molecular compounds at high a_w. Such isotherm crossover behavior with temperature has been widely observed in carbohydrate-rich foods such as sugar beet root, sultana raisins, barley malt, (Brett *et al.*, 2009). The a_w of toukir at 10, 25 and 40ºC, corresponding to the initial moisture content of 6.87%, were 0.31, 0.42 and 0.54, respectively. This indicated that the product would certainly gain moisture when stored above 54% RH at ambient temperature.

The GAB monolayer moisture contents of toukir, as determined from the GAB model, were 6.10, 5.23 and 3.73% d.b. at 10, 25 and 40°C (Table 4.4). The monolayer

value gives the total number of polar groups binding water and the level of hydration at which the mobility of small molecules become apparent. The monolayer moisture content decreased with increasing temperature due to the reduction in the number of active sites. The BET monolayer values (4.91, 4.59 and 3.69% d.b.) were closely matched with those of the GAB model. The BET monolayer was indicative of the optimum moisture content of toukir for assured shelf-life stability.

Table 4.4. Parameters of the fitted GAB model

Temperature, ºC	Monolayer, M_g	Multilayer constant, K_g	C_g
10	6.10	0.766	12.10
25	5.227	0.768	6.976
40	3.728	0.877	6.363

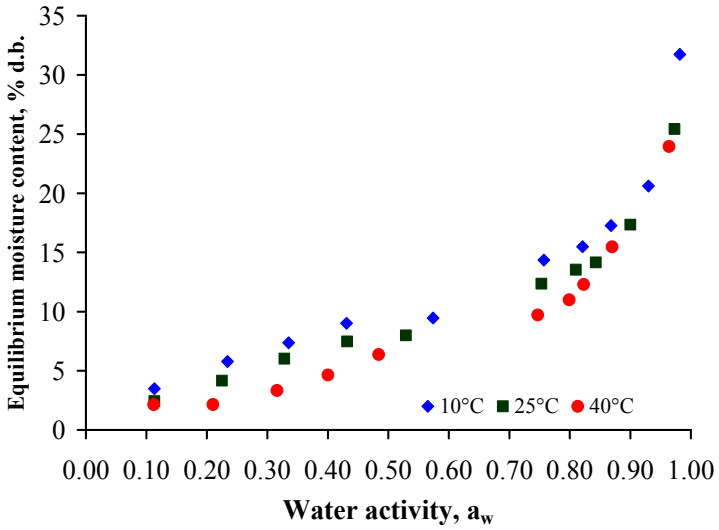


Fig. 4.7. Moisture sorption isotherms of toukir at different temperatures

4.12.1 Fitting of sorption isotherm models

The BET, GAB, Caurie, Kuhn, Modified Mizrahi and Halsey models were fitted to the experimental data, and the results of the statistical analyses are presented in Table 4.5. Mean percent relative deviation (P%) and root mean squared error (RMSE) were used to evaluate the goodness of fit of the sorption models. The

Modified Mizrahi model gave the best fit of the data at 10 and 25ºC (%P=2.99-13.76) while the GAB model gave a better fit at 40ºC (%P=6.28-9.30). The GAB model has been reported to fit the sorption data of many foods (Pushpadass *et al.,* 2013). The standardized residuals obtained from the Modified Mizrahi and GAB models were plotted against predicted values, to check the normality and homogeneity of variance of the data. The residual plots showed no obvious systematic patterns (graph not shown). Thus, it could be concluded that the Modified Mizrahi model was adequate to describe the sorption behaviour of toukir, with the GAB model closer to it. Modified Mizrahi is a semi-empirical model while the GAB model is based on thermodynamics of moisture sorption. Therefore, the GAB model parameters have physical meaning, and are related to the temperature and physical properties of the food.

Table 4.5. Precision of fit of various sorption models

Model	Temperature, ºC	Adj. R^2	RMSE	%P
BET	10	0.401	10.832	345.134
	25	0.453	11.365	431.367
	40	0.543	7.651	230.980
GAB	**10**	**0.756**	**2.096**	**6.518**
	25	**0.600**	**1.446**	**6.281**
	40	**0.620**	**0.536**	**9.303**
Caurie	10	0.973	1.391	7.839
	25	0.956	1.772	10.885
	40	0.970	1.456	10.892
Kuhn	10	0.752	3.716	40.346
	25	0.724	3.236	47.266
	40	0.794	2.810	52.641
Modified Mizrahi	**10**	**0.468**	**0.432**	**2.992**
	25	**0.222**	**0.760**	**3.160**
	40	**0.023**	**3.497**	**13.755**
Halsey	10	0.918	2.481	14.250
	25	0.888	2.779	18.049
	40	0.939	2.806	16.54

The GAB model parameters provide valuable information on the thermodynamics of moisture sorption in toukir. If the GAB parameter 'C_g' is greater than 2, the model should yield a sigmoidal shape curve. In this study, the value of 'C_g' was greater than 6 at all temperatures, and the above prediction was proved. The

values of GAB constants, 'M_g' and 'C_g', decreased gradually with increasing temperature, while 'K_g' increased slightly, consistent with the thermodynamics of sorption.

The term 'C_g 'represents the difference in chemical potential between water molecules that have been adsorbed in the first and subsequent layers (Martinez-Monteagudo and Salais-Fierro, 2012). Similarly, 'K_g' represents the difference in chemical potential between bulk liquid water molecules and molecules adsorbed in the multilayer. It was observed that the value of 'K_g' parameter in the GAB model was about at all temperatures. The values of 'C_g' (6.36-12.10) and 'K_g' (0.728-0.877) proved that moisture sorption in toukir was a strongly-multilayered phenomenon. If K_g=1, it was suggestive of the fact that multilayers had properties of liquid water.

4.13 Rheological behaviour of toukir solutions

Toukir solutions at all concentrations below 60ºC exhibited majorly Newtonian behaviour, exhibiting a slight shear thickening (increase in viscosity) with increasing rpm or shear rate. Also, no significant differences in viscosities were observed with increasing concentration of toukir. The viscosity vs. shear rate (rpm) relationships of toukir solutions at all concentrations and at 60ºC temperature are presented in Fig. 4.8. These results indicated that the no gelatinization occurred in toukir at less than 60ºC, regardless of the concentration of toukir. If the starch underwent gelatinization, the viscosity was expected to increase drastically. Therefore, non-Newtonian model (power law) was not fitted to the data to describe the rheological behaviour of toukir at less 60ºC.

At 70 and 80ºC, the initial viscosity of the toukir solutions increased steeply, regardless of the concentration. This suggested that the starch had undergone gelatinization and swelling. However, the viscosities of the solutions at all concentrations except 4% decreased with increasing shear rate as the toukir paste exhibited shear-thinning behaviour. The 4% toukir solution displayed only Newtonian behaviour at all temperatures. Therefore, the shear stress vs. shear rate data of 8 to 20% concentration solutions were fitted to the power law model. The flow behaviour

index (n) of the power law model ranged from 0.1 to 0.7. A sample power law plot for 12% toukir solution at 70ºC temperature is shown in Fig. 4.9.

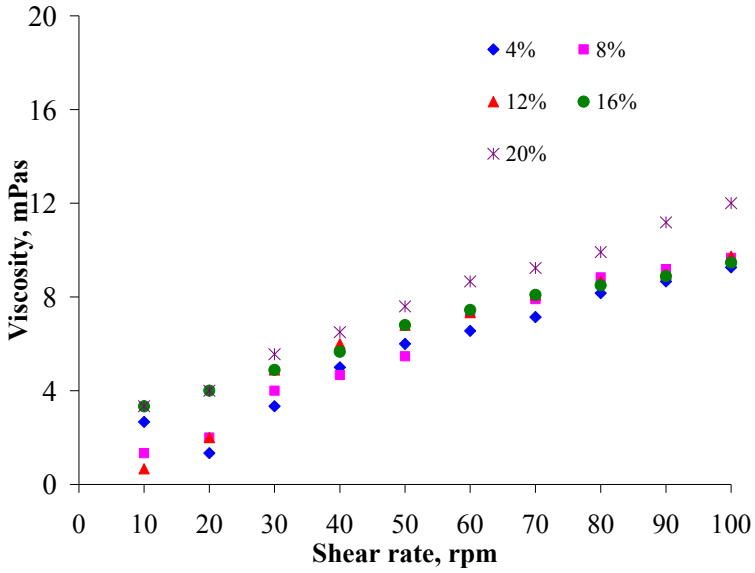


Fig. 4.8. Viscosity vs. shear rate (rpm) of toukir solutions at 60ºC

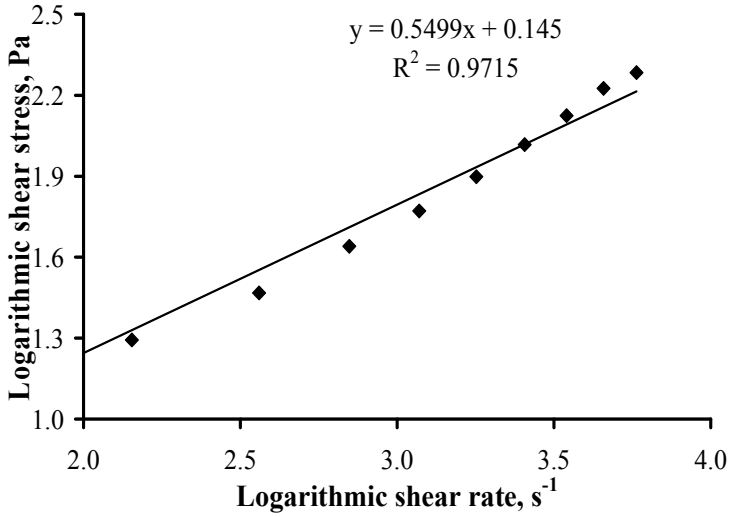


Fig. 4.9. Power law plot for 12% toukir solution at 70ºC

In general, the flow behaviour index was dependent on the concentration of the toukir solution as well as temperature. The huge variation in the flow behaviour index was suggestive of the gelatinization and swelling behaviour of starch at different concentrations and temperature. The gelatinized toukir solutions may have yield stress before flow as evidenced from the power law plot (Fig. 4.9).

4.14 Powder flow properties

The BFE for repeated trials as well as various tip speeds of toukir at 3 and 12% moisture contents are presented in Figs. 4.10 and 4.11. The BFE value for toukir at 3% moisture content was lower compared to 12% moisture, indicating that toukir powder at the lower moisture content would be easier to move as compared to the powder with 12% moisture in this forced flow regime. The SE values for 3 and 12% moisture content indicated that both samples were moderately cohesive ($5<SE<10$) in this mode of flow. The SE value at 3% moisture was lower as compared to 12% moisture, indicating that it was the least cohesive sample in an unconfined flow regime (this was consistent with the relatively low BFE value). With SI value close to unity, toukir at 12% moisture was the most stable sample compared to toukir at 3% moisture (SI value 1.3). Generally a stable sample has SI value within $0.9<SI<1.1$. From the BFE and SE values, it could be concluded that toukir at 12% moisture had lower flowability and higher cohesivity. The CBD values of both samples were distinctly different. The higher CBD value of toukir at 3% moisture indicated it had efficient packing compared to toukir at 12% moisture.

Aeration tests indicated that both samples were sensitive to low levels of aeration. Toukir at 3% moisture was slightly more sensitive to low levels of aeration as compared to toukir at 12% (Fig. 4.12). However, toukir at 3% moisture had the lowest aeration energy and higher aeration ratio values as compared to toukir at 12%. This suggested that the toukir at 3% moisture would have an overall lower cohesivity in an aerated environment.

Compressibility tests suggested that both samples were moderately compressible (Fig. 4.13). Toukir at 3% moisture was less compressible as compared to 12%, which was another indicator of lower cohesivity and better packing in the lower

moisture content sample. This interpretation was also in agreement with the stability and CBD test.

Table 4.6. Primary flow characteristics and dynamic measurements of toukir

Measured parameter	Value at 12% moisture	Value at 3% moisture
Basic flowability energy, (mJ)	618 (±1.8%)	493 (±2.0%)
Stability index,	0.9 (±2.9%)	1.3 (±3.2%)
Specific energy (mJ/g)	7.8 (±0.9%)	6.0 (±1.1%)
Conditioned bulk density, (g/mL)	0.480 (±0.2%)	0.666 (±0.1%)
Aerated energy (mJ)	134 (±5.6%)	30.1 (±0.8%)
Aeration ratio	4.4 (±3.6%)	12.2 (±3.4%)
Pressure drop (mbar)	10.8 (±1.9%)	40.5 (±0.5%)
Permeability x 10^9 (cm^2)	9.8 (±2.5%)	2.8 (±0.3%)
Compressibility, (%)	23.1 (±2.8%)	15.4 (±1.2%)
Cohesion, kPa	1.6	0.6
Wall friction angle, (º)	27.0	23.9

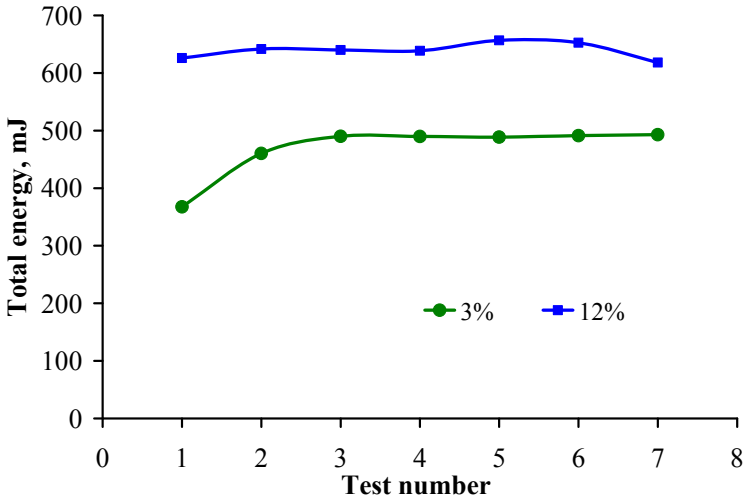


Fig. 4.10. Influence of repeatability on total energy (basic flowability energy)

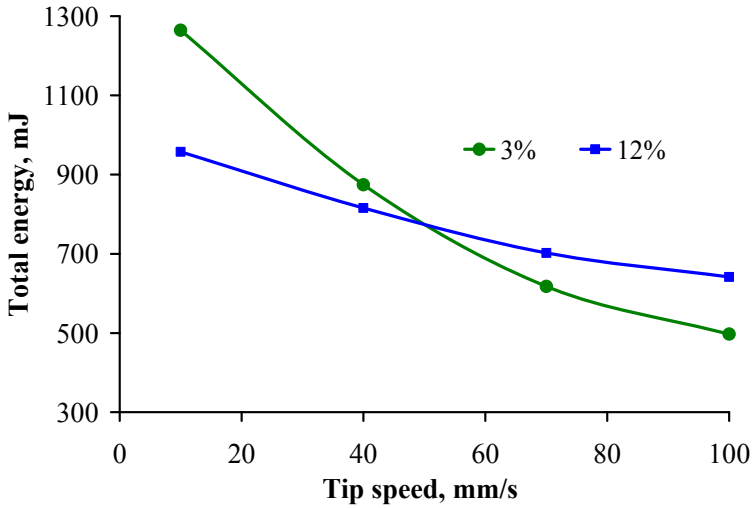


Fig. 4.11. Influence of tip speed on total energy (basic flowability energy)

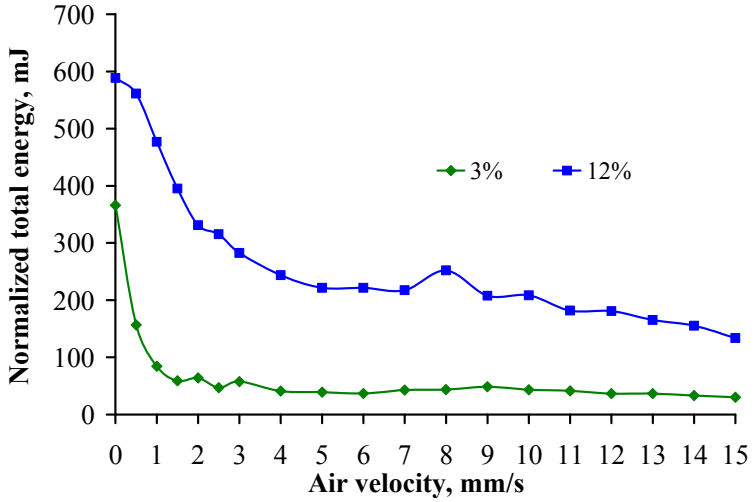


Fig. 4.12. Influence of air velocity on normalized energy consumption (aeration test)

Toukir at 12% moisture had a considerably lower pressure drop (higher permeability) than at 3% moisture content (Fig. 4.14). This again indicated that toukir at 3% moisture had efficient packing as compared to 12% moisture under compressed test regime as well. Lower WFA values were observed for toukir with 3% moisture content, indicating that it was more free-flowing against the steel surface (1.2μ roughness) as compared to 12% moisture (Fig. 4.15). These results were consistent with those of the shear test.

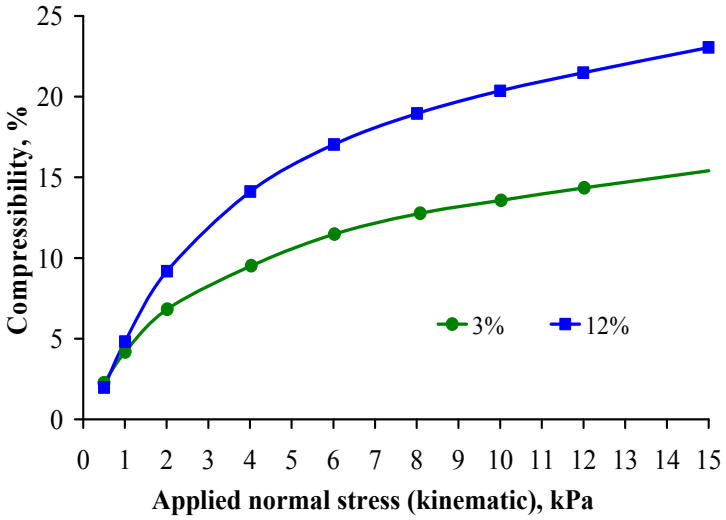


Fig. 4.13. Influence of applied normal stress on compressibility

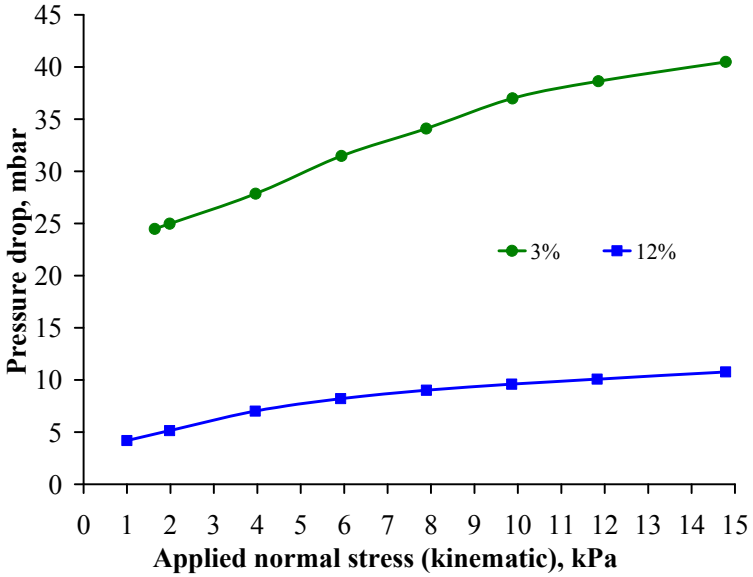


Fig. 4.14. Influence of applied normal stress on pressure drop (permeability test)

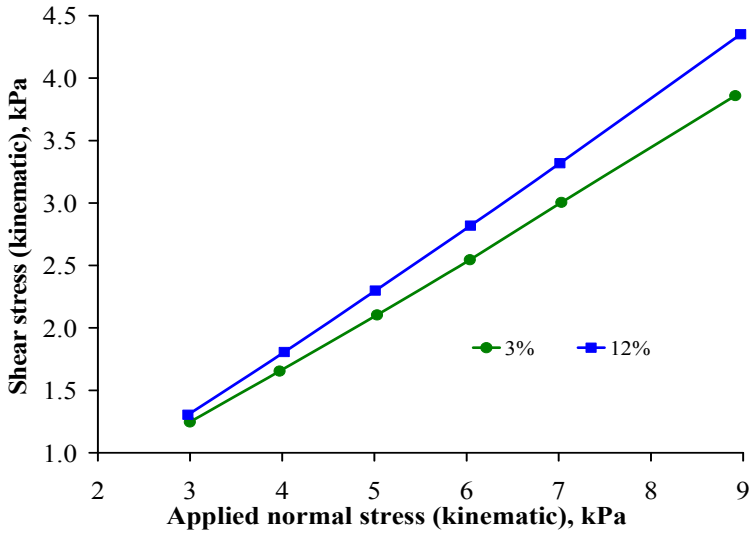


Fig. 4.15. Influence of applied normal stress on shear stress (wall friction angle)

4.15 Preparation and proximate analysis of fried and unsoaked gulabjamun

Gulabjamun was prepared using 0, 6, 12 and 18% toukir in the dough as per the process flow chart described in Fig. 3.8. The 0% toukir dough had 12% maida, which served as control. The balls were fried at 140ºC for 7 min, and were tested for various physicochemical, textural and sensory qualities.

4.15.1 Moisture content

The moisture content of fried gulabjamun containing different levels of toukir is presented in Table 4.7. It ranged from 20.84 to 22.07% (w.b.) as compared to 21.45% in control (contains 0% toukir but 12% maida in the dough). The moisture content was influenced by the concentration of toukir used in the dough (Appendix Table A9). As the toukir content of the dough increased, there was a significant increase in the moisture content of fried gulabjamun. This was because of higher level of starch, which facilitated the retention of more moisture inside the dough during frying. At same levels, it could be stated from the moisture content data that toukir had higher ability to withhold water in the fried product as compared to maida (control).

4.15.2 Protein

Significant level of protein was observed in all gulabjamun samples including control. The protein content of gulabjamun prepared with different levels of toukir was compared (Table 4.7) (Appendix Table A10). Gulabjamun prepared from 6, 12 and 18% toukir was recorded as 14.12, 12.86 and 11.67%, respectively as compared to 12.71% in control. It could be stated that the protein content of gulabjamun containing same level of toukir was marginally higher than that of control. This was because toukir contained higher amount of protein as compared to maida. However, as toukir content increased in the dough to 18%, the protein content of fried gulabjamun decreased. This was because of the replacement of khoa, containing (20-22%) of milk protein, with starch from toukir.

4.15.3 Ash

The mean ash content of gulabjamun added with toukir ranged from 3.0 to 3.81%, which was comparable to the value of 3.23% obtained for control. The ash content in gulabjamun decreased marginally but not significantly ($p>0.05$) (Appendix Table A11) with increase in toukir content (Table 4.7). Thus, addition of toukir did not change the total mineral content and insoluble components of the prepared product.

4.15.4 Fat

The fat content of gulabjamun containing toukir ranged from 26.88-29.63%, as compared to 29.28% in control (Table 4.7). At 12% concentration, it could be stated that there was no significant difference between the fat contents of gulabjamun containing toukir and maida. Therefore, it could be evidenced that, during frying, the fat uptake of gulabjamun containing toukir and maida was similar. However, increased addition of toukir in the dough led to a noticeable reduction (Appendix Table A12) in total fat content of fried gulabjamun (26.88%). This was because the oil uptake during frying was relatively same in all samples, but the contribution of fat from khoa decreased when it was replaced with toukir. Thus, it could be stated that milk fat from khoa was the highest contributor for total fat in the fried product. These results were in accordance with the observations of Kumari *et al.* (2012) during the preparation of khoa-jalebi.

4.15.5 Starch/Carbohydrate

The carbohydrate/starch content in gulabjamun prepared from 6, 12 and 18% toukir was observed as 31.60, 33.26 and 36.38%, respectively as compared to 33.33% in control (Table 4.7). The carbohydrate content of gulabjamun containing 12% maida and toukir are statistically same ($P>0.05$) but there was significant difference between other samples (Appendix Table A13). As expected, the carbohydrate content increased with increasing addition of toukir in the dough.

Table 4.7 Proximate composition of fried and unsoaked gulabjamun

Toukir content, %	Parameter (% w.b.)				
	Carbohydrate	Moisture	Fat	Protein	Ash
0 (12% maida)	33.33	21.45	29.28	12.71	3.23
6	31.60	20.84	29.63	14.12	3.81
12	33.26	21.40	29.34	12.86	3.14
18	36.38	22.07	26.88	11.67	3.00

4.16 Sphericity, apparent density, expansion ratio and percent volume change

The geometric mean diameter of gulabjamun added with 0, 6, 12 and 18% toukir ranged between 28.411 to 29.260 mm (Table 4.8). The sphericity ranged between 0.97 and 0.985, which was closer to 1. Therefore, for all practical and design purposes, gulabjamun could be assumed as a sphere. The dough expanded after frying, and the expansion ratio ranged between 1.255 to 1.221, depending on the toukir content in the dough and the pore development. The porosity of the product, as determined through image analysis, ranged between 18.21 and 34.34%.

The percent volume change in 0, 6, 12 and 18% toukir added gulabjamun after soaking was calculated as 25.11, 17.68, 24.6 and 21.9%, respectively (Fig. 4.16). The highest percent change in volume was observed in control followed by gulabjamun added with 12% toukir. One way ANOVA (Appendix Table A14) showed that the percent volume change in soaked gulabjamun was significantly dependent on the

levels of toukir added to the dough. At 6% toukir content, the dough after frying partially collapsed because the matrix could not hold together in the absence of sufficient binder, consequently decreasing the expansion and percent volume change. The percent volume change in gulabjamun decreased again at 18% toukir addition because moisture evaporation decreased, thereby decreasing the diameters of the air cells/ vacuoles formed in the product (Figs. 4.17 and 4.18).

Table 4.8. Dimensional changes, sphericity, expansion ratio and porosity of gulabjamun

Toukir content, %	Dimensions			Geometric mean dia. (mm)	Sphericity	Expansion ratio (unsoaked)	Porosity (air cell to total area ratio)
	a (mm)	b (mm)	c (mm)				
0 (12% maida)	29.840	29.760	27.660	29.069	0.970	1.255	30.68%
6	30.015	28.901	28.954	29.260	0.976	1.312	34.34%
12	30.020	29.040	27.680	28.897	0.980	1.277	29.84%
18	29.100	29.060	27.120	28.411	0.985	1.221	18.21%

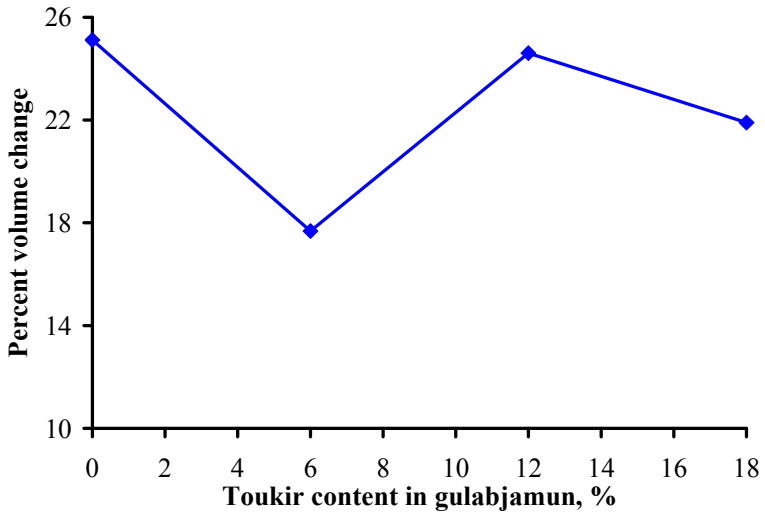
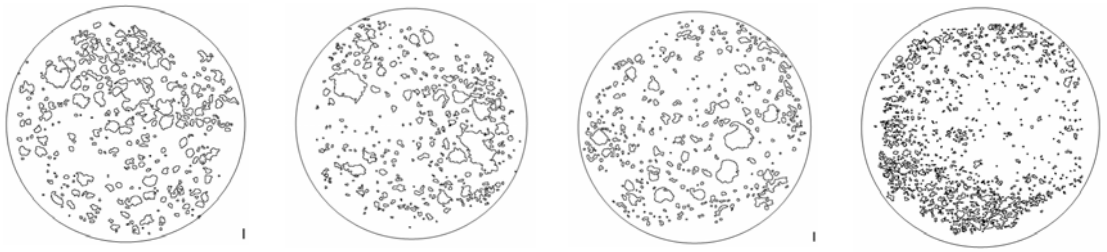


Fig. 4.16. Percent volume change in gulabjamun at different levels of toukir

0% toukir (control) 6% toukir 12% toukir 18% toukir

Fig. 4.17. Pore development in fried gulabjamun at different levels of toukir



0% toukir (control) 6% toukir 12% toukir 18% toukir

Fig. 4.18. Porosity (air vacuoles) in fried gulabjamun at different levels of toukir

4.17 Colour of fried gulabjamun

The lightness (L^* value) of gulabjamun prepared using different concentrations of toukir is presented in Table 4.9 and compared (Appendix Table A15). The mean L^* value of 6, 12 and 18% toukir added gulabjamun was measured as 26.22, 28.09 and 29.01, respectively as compared to 30.78 for control. It is evident that the samples prepared using toukir were darker in colour as compared to that prepared using maida (control) (Fig. 4.19). Gulabjamun made with 6% toukir was the darkest in terms of colour. As the toukir content and binder in the dough was less, moisture evaporated from this sample quite rapidly during frying. As moisture content of the crust decreased, the crust became darker in colour.

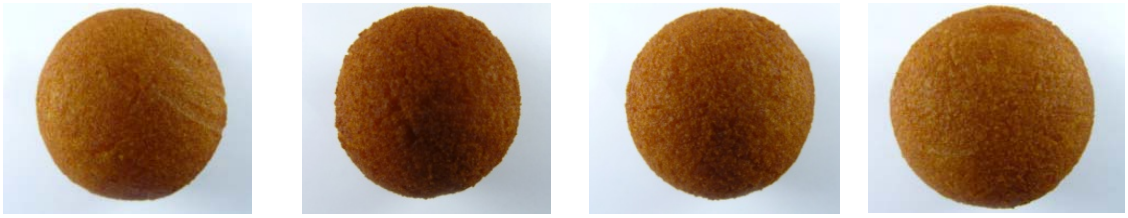
The redness (a^* value) in fried products is a useful parameter to evaluate the extent of frying, so that excess frying of the product is avoided. In the current study, a noticeable variation in a^* value between the treatments was observed. As the toukir content in the original dough increased, the redness of the final product increased. The mean a^* value of 6, 12 and 18% toukir added gulabjamun was found to be 29.51, 31.56 and 34.48, as compared to 34.10 for control. No significant difference ($p<0.05$)

(Appendix Table A16) between the 12% toukir sample and control was thus observed. A higher a^* value indicates that the product could withstand higher frying temperature and does not get affected easily. Therefore, it could be argued that addition of maida might be better in terms of redness in fried gulabjamun.

Table 4.9. Crust colour of fried and unsoaked gulabjamun

Toukir content, %	CIELAB parameters		
	L*	a*	b*
0 (control)	30.78±5.10[b]	34.09±5.28[a]	23.37±2.71[a]
12	26.09±3.66[a]	31.56±2.86[a]	24.04±1.44[a]
18	29.01±3.75[ab]	32.47±4.36[a]	23.24±1.48[a]
6	26.21±4.24[ab]	29.50±5.23[a]	23.76±1.25[a]

The b^* value is indicative of the yellowness in the product. No significant influence of toukir on the yellowness of the fried product was observed (Appendix Table A17). The mean b^* value of 6, 12 and 18% toukir added gulabjamun was observed to be 23.27, 24.04 and 23.25 as compared to 23.28 in control.



0% toukir (control) 6% toukir 12% toukir 18% toukir

Fig. 4.19. Colour of fried gulabjamun at different levels of toukir

4.18 Thermal properties of fried and unsoaked gulabjamun

The thermal conductivity of 0, 6, 12 and 18% toukir added gulabjamun was recorded as 0.256, 0.245, 0.260 and 0.265, respectively. It is evident that the thermal conductivity increased as the toukir content in the dough increased (Table 4.10). One way ANOVA (Appendix Table A18) also showed that thermal conductivity of fried and gulabjamun was significantly dependent on the toukir content. The highest value

was observed in 18% toukir added gulabjamun and the lowest value for 6% toukir added sample. The differences in thermal conductivities were due to differences in porosities and moisture contents. Gulabjamun prepared with 18% toukir had the highest retention of moisture and lowest porosity after frying, which translated into higher thermal conductivity.

Similar to thermal conductivity, the volumetric specific heat of gulabjamun also was significantly dependent on toukir content ($p<0.05$) (Appendix Table A19). The specific heat of 0, 6, 12 and 18% toukir added gulabjamun was recorded as 2.101, 1.769, 2.049 and 2.192 MJ/m^3K, respectively. The higher amount of moisture in gulabjamun prepared from 18% toukir resulted in the highest specific heat. This was expected as water has the highest specific heat among food constituents.

Thermal diffusivity is suggestive of the rate of propagation of heat in the sample. The thermal diffusivity of gulabjamun increased with increasing toukir content. The thermal diffusivity of 0, 6, 12 and 18% toukir added gulabjamun was measured as 0.120, 0.125, 0.128 and 0.152 mm^2/s, respectively. As toukir content increased, the thermal diffusivity also significantly increased (Appendix Table A20) because of higher moisture in the product. Moreover, the decreased porosity in the product at higher toukir content also facilitated the diffusion of heat. Consequent to the increase in thermal conductivity, the thermal resistivity significantly decreased with increasing toukir content (Appendix Table A21). The thermal resistivity of 0, 6, 12 and 18% toukir added gulabjamun was found to be 3.927, 3.817, 3.869 and 4.097°cm/W, respectively.

Table 4.10. Thermal properties of fried gulabjamun containing different levels of toukir

Toukir content (%)	Thermal conductivity, W/m.K	Volumetric specific heat, $kJ/m^3.K$	Thermal diffusivity, m^2/s	Thermal resistivity, °cm/W
0	0.256 ± 0.033^a	2.101 ± 0.219^b	0.120 ± 0.017^a	3.927 ± 0.478^a
6	0.245 ± 0.022^a	1.769 ± 0.243^a	0.125 ± 0.018^a	4.097 ± 0.303^a
12	0.260 ± 0.018^a	2.049 ± 0.120^b	0.128 ± 0.018^a	3.869 ± 0.518^a
18	0.265 ± 0.039^a	2.192 ± 0.213^b	0.152 ± 0.027^b	3.817 ± 0.323^a

4.19 Texture profile analysis of fried and soaked gulabjamun

The textural changes in fried and soaked gulabjamun containing different levels of toukir were evaluated in terms of TPA parameters such as hardness, adhesiveness, resilience, cohesiveness, springiness, gumminess and chewiness (Table 4.11). The hardness of soaked gulabjamun prepared from dough containing 6, 12 and 18% toukir was found to be 7.41, 8.12 and 12.36 N as compared to 7.72 N in control. One way ANOVA (Appendix Table A22) showed that hardness of fried and soaked gulabjamun was significantly influenced by the toukir content. The hardness of gulabjamun containing 6% toukir was lowest since there was insufficient binder (starch) to hold the ingredients of the dough together.

The hardness increased in samples containing 12% maida (control) or ≥ 12% toukir because the starch in those samples acted as a good binder upon gelatinization, and held the protein matrix of khoa together. As water was bound to the matrix, very small air cells/ vacuoles were formed during frying, decreasing the porosity of the product and thereby decreasing the soaking ability of fried gulabjamun. As diffusion of water/sugar syrup decreased at higher levels of toukir due to reduced porosity, the hardness of the product increased. It was also found that the hardness of gulabjamun containing 12% toukir was marginally higher than that of control (8.12 vs. 7.72 N). Therefore, it could be stated that toukir had higher binding capacity than maida at the tested concentration of 12%.

The adhesiveness of gulabjamun containing 0 (control), 6, 12 and 18% toukir was found to be -0.35, -1.93, -2.07 and -4.94 N.s. One way ANOVA (Appendix Table A23) showed that adhesiveness of gulabjamun was significantly dependent on the levels of toukir added. At 12% concentration, the higher values of adhesiveness in gulabjamun added with toukir testified that toukir was a better binder than maida. However, it is anticipated that very high levels of toukir might not increase the adhesiveness as it reduced the porosity of the product and increased the hardness.

One way ANOVA (Appendix Table A24) analysis showed that resilience of soaked gulabjamun was significantly dependent on levels of toukir ($p<0.05$). The resilience of 0, 6, 12 and 18% toukir containing gulabjamun were found to be 18.69,

17.15, 18.77 and 19.40%, respectively. The resilience increased as the toukir content increased. However, the resilience of gulabjamun added with 12% maida and toukir are statistically same.

The cohesiveness of 0, 6, 12 and 18% toukir added gulabjamun was determined as 0.51, 0.47, 0.48 and 0.49, respectively. One way ANOVA (Appendix Table A25) analysis showed that cohesiveness of fried and soaked gulabjamun was not significantly dependent on toukir content. The springiness of 0, 6, 12 and 18% toukir added gulabjamun was found to be 74.22, 78.39, 81.38 and 80.70%, respectively. One way ANOVA (Appendix Table A26) analysis showed that springiness values of fried and soaked gulabjamun significantly were not dependent on the level of toukir addition. Similar to springiness, gumminess and chewiness of gulabjamun were not dependent on toukir content (Appendix Tables A27-28). Gumminess of 0, 6, 12 and 18% toukir containing gulabjamun was found to be 4.12, 3.67, 4.97 and 4.54 N, respectively. The corresponding values of chewiness were 3.33, 2.96, 4.12 and 3.80 N.

Table 4.11. Texture profile analysis of fried and soaked gulabjamun

TPA parameter	Toukir content			
	0% (control)	6%	12%	18%
Hardness, (N)	7.72±5.48^{a}	7.41±3.08^{a}	8.12±4.84^{ab}	12.36±5.96^{b}
Adhesiveness, (N.s)	-0.35±0.45^{b}	-1.93±2.35^{ab}	-2.07±3.18^{ab}	-4.94±6.73^{a}
Resilience, (%)	18.69±5.63^{a}	17.15±4.66^{a}	18.77±4.54^{a}	19.40±6.26^{a}
Cohesiveness	0.51±0.13^{a}	0.47±0.14^{a}	0.48±0.15^{a}	0.49±0.14^{a}
Springiness, (%)	74.22±10.24^{a}	78.39±7.78^{a}	81.38±6.16^{a}	80.70±12.21^{a}
Gumminess, N	4.12±3.23^{a}	3.67±2.27^{a}	4.97±2.57^{a}	4.54±2.41^{a}
Chewiness, N	3.33±2.92^{a}	2.96±2.01^{a}	4.12±2.32^{a}	3.80±2.17^{a}

4.20. Sensory evaluation of gulabjamun by fuzzy-logic approach

The similarity values for all the four samples under different scale factors are presented in Table 4.12. For control and 18% toukir added gulabjamun, the highest similarity value was obtained under the category very good. For samples 2 and 4 (6% and 18% toukir addition), the highest similarity values were obtained under the category good and satisfactory, respectively. Thus, it could be concluded that both

control and gulabjamun prepared using 12% toukir were adjudged as very good, followed by that prepared using 6% toukir (good) and 18% toukir (satisfactory) by the panelists.

Table 4.12. Similarity values of gulabjamun samples and their ranking

Scale factors	Control	6% toukir	12% toukir	18% toukir
Not satisfactory, F1	0.000	0.033	0.000	0.045
Fair, F2	0.075	0.300	0.078	0.343
Satisfactory, F3	0.343	0.680	0.352	**0.718**
Good, F4	0.655	**0.695**	0.666	0.664
Very Good, F5	**0.678**	0.292	**0.670**	0.238
Excellent, F6	0.246	0.026	0.233	0.015
Ranking	I	III	II	IV

So the ranking was done as control ≈ sample 3 (12%toukir) > sample 2 > sample 4. Thus, sample 4 has the least acceptability. The addition of toukir has a significant influence on the sensory qualities of the product.

5. Summary And Conclusions

Toukir powder is used in preparation of specific Indian based sweets (khoa-jalebi) as a binder and to improve the soaking ability of sugar syrup. However, the data on physicochemical, thermal, engineering, microstructural and rheological properties of toukir are not available, but are very much required for development of commercial products. In particular, it has the potential to replace maida in fried products such as gulabjamun, pantoa, etc.

The study was taken up with the following objectives:

- Determine the thermo-physical and engineering properties of toukir as a function of moisture content.
- Analyze and model the moisture sorption and rheological behaviors of toukir.
- Evaluate the sensorial, thermo-physical and textural qualities of toukir added gulabjamun.

The engineering properties of toukir powder namely, bulk and tapped density, true/particle density, angle of repose, flowability, particle size, wettability, glass transition temperature and thermal properties such as thermal conductivity, thermal diffusivity, thermal resistivity and volumetric specific heat were determined at moisture content of 3, 6, 9 and 12%, (d.b.). Moisture sorption isotherm of toukir was analyzed at three different temperatures and the data was observed for best fit to different sorption models (BET, GAB, Caurie, Halsey and modified Mizrahi). Powder flow properties was determined using powder rheometer and rheological property at different temperatures (20-80°C) and concentration (4-20%) was determined using rotational viscometer. The proximate composition of toukir powder was analyzed for ash, protein, fat and total carbohydrate contents.

Gulabjamun was prepared by blending khoa (m.c. 33-40%, d.b.) adjusted to 65% moisture, baking powder (1-2%) and toukir/maida in different proportions (4 levels - 0,

6, 12 and 18%) to a smooth homogenous dough. The dough was portioned to 15 g balls and fried in sunflower oil at suitable frying temperature (140°C) until the desired product colour was achieved (7 min). The product characteristics such as crust colour, porosity, moisture content and fat were analysed before soaking in sugar solution (50° Brix). The textural properties and dimensional changes after soaking were also determined. The expansion ratio of fresh dough (balls), fried & unsoaked and fried & soaked samples were measured. The sensory evaluation of toukir added gulabjamun was conducted using fuzzy logic technique and the results were compared with control. The major findings of the present study are summarized as:

1. Proximate compositional analysis of toukir showed that it was rich in starch (98.436%), followed by fat, ash and protein contents of 0.584, 0.143 and 0.837%, respectively.

2. The bulk and tapped densities decreased from 630 to 530 kg/m^3 and from 930 to 767 kg/m^3, respectively with increase in moisture content from 3 to 12%. True density (2424 kg/m^3) was not affected by change in moisture content. The angle of repose increased with increase in moisture content, suggestive of the cohesive property of the product. The angle of repose values at moisture contents of 3, 6, 9 and 12% were determined as 50.02, 54.49, 55.55 and 56.16°, respectively.

3. L*, a* and b* values of toukir powder were found to be 95.74, -0.01 and 3.30, respectively, with a negligible effect of moisture content over change in colour values.

4. Increase in particle size was observed with increase in moisture content from 3 to 12%. The d(0.1), d(0.5) and d(0.9) diameters increased from 9.511 to 9.709µ, 15.568 to 16.792µ and 178.631 to 226.360µ, respectively.

5. Water absorption index of toukir ranged from 2.01 to 2.069 $g.g^{-1}$ with poor wettability. However, 81 % of dispersibility was recorded with toukir powder.

Water solubility index test showed a high swelling capacity of toukir, which lied between 0.028 and 0.031g.g^{-1}.

6. Microstructural analysis revealed that toukir was tetrahedral in shape. The increase in moisture content has increased the particle size from 17.33 to 19.99µ as moisture in toukir increased from 3 to 12 %. Glass transition temperature decreased linearly form 70.15°C at 3% to 64.65°C at 12% moisture content (R^2=0.985).

7. Analysis of thermal properties of toukir powder showed that the volumetric specific heat, thermal conductivity, thermal diffusivity increased from 1.526 to 1.582 KJ/m^3.K, 0.141 to 0.158 W/m.K. and 0.089 to 0.097×10^{-6} m^2/s, respectively as the moisture content increased from 3 to 12%.

8. Moisture sorption isotherms of toukir presented a sigmoid shape at all three temperatures (10, 25 and 45°C), belong to type II of BDDT classification. The GAB monolayer moisture content of toukir was 6.10, 5.23 and 3.73% at 10, 25 and 40°C temperature, respectively. Similarly, BET monolayer values were 4.91, 4.59 and 3.69% (w.b.) on par with values of GAB model. The sorption data were in good agreement with modified Mizrahi and GAB sorption models.

9. Powder flowability tests showed that the basic flowability energy values increased with increase in moisture content of toukir powder. The specific energy values for 3 and 12% moisture content (5<SE<10) showed that samples were cohesive in nature. The stability index values were in between 0.9 to 1.1. The conditioned bulk density value of toukir was higher at 3% moisture content as compared to 12%.

10. The moisture content of toukir added gulabjamun was found to be in range of 20.84 to 20.07% (w.b.) as compared to 21.45% in control. Protein content of gulabjamun prepared from 6, 12 and 18% toukir was recorded as 14.12, 12.86 and 11.67%, respectively as compared to 12.71% in control.

11. The mean ash and fat contents were in range of 3.0 to 3.81% and 26.88 to 29.63% respectively, which were on par with control. Carbohydrate of gulabjamun prepared from 6, 12 to 18% toukir was observed as 31.60, 33.26 and 36.38%, respectively.

12. The geometric mean diameter of gulabjamun added with 0 (control), 6, 12 and 18% toukir ranged between 28.41 to 29.26 mm with the sphericity value between 0.97 to 0.985. The dough expansion was observed to be in range of 1.255 to 1.221 while the porosity was between 18.21 to 34.34%. The percentage volume change of 0, 6, 12 and 18% toukir added gulabjamun samples were 25.11, 17.68, 24.60 and 21.91%, respectively.

13. Colour analysis of toukir based gulabjamun was showed that L* value as 26.22, 28.09 and 29.01 and a* values as 29.51, 31.56 and 34.48 and b* values as 29.51, 31.56 and 34.48 for moisture contents 6, 12 and 18%, respectively.

14. Thermal properties of fried and unsoaked gulabjamun showed noticeable change in thermal conductivity (0.256, 0.245, 0.260 and 0.265 W/m.K), volumetric specific heat (2.101, 1.769, 2.049 and 2.192 $kJ/m^3.K$), thermal diffusivity (0.120, 0.125, 0.128 and $0.152 m^2/s$) and thermal resistivity (3.927. 4.097, 3.869 and 3.817 K.m/W) at 0, 6, 12 and 18% moisture content.

15. Textural analysis of fried and soaked gulabjamun in terms of hardness (7.41, 8.12 and 12.36 N) was increased with increase in toukir percentage (6, 12 and 18%) as compared to 7.72 for control. The adhesiveness of gulabjamun containing 0, 6, 12 and 18% toukir was found to be -0.35, -1.93, -2.07 and -4.94, respectively. Similarly, cohesiveness for above treatments was recorded as 0.51, 0.47, 0.48 and 0.49. The springiness and gumminess of 0, 6, 12 and 18% toukir added gulabjamun was found to be 74.22, 78.39, 81.38, 80.70% and 4.12, 3.67, 4.97, 4.54%, respectively. The corresponding values of chewiness were 3.33, 2.96, 4.12 and 3.80.

16. The rheological study of toukir solutions below 60ºC exhibited near Newtonian behaviour with slight shear thickening as shear rate increased with increase in viscosity. At 70 and 80ºC, initial viscosity of toukir solutions increased steeply due to swelling and gelatinization of starch. The 4% toukir solution displayed Newtonian behaviour at all temperatures while the solutions of 8 to 20% concentration displayed non-Newtonian behaviour and were fitted to power law model. The flow behaviour index 'n' ranged from 0.1 to 0.7.

17. Sensory evaluation through fuzzy logic technique showed that, both control and gulabjamun prepared using 12% toukir were adjudged as very good followed by the product with 6% (good) and 18% toukir (satisfactory). Final ranking was done as Control ≈ Sample 3 (12%toukir) > Sample 2 > Sample 4.

The current study helped in exploitation of physicochemical properties data of toukir for production and development of different sweet products like gulabjamun, pantoa, etc. Also, the compositional data could be useful to replace maida through toukir in the preparation of many dietary food products. Thermal properties and sorption data would be helpful in storage and blending of toukir with other food ingredients. The powder flow properties would be useful in the design of hoppers, silos, storage bins and packaging. The study also would create awareness among farmers to grow toukir as a crop for nutritional and health benefits.

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Table A1. ANOVA of bulk density of toukir

Bulk density	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	50707.480	3	16902.493	244.106	0.000
Within Groups	3046.667	44	69.242		
Total	53754.147	47			

Table A2. ANOVA of tapped density of toukir

Tapped density	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	173765.335	3	57921.778	488.629	0.000
Within Groups	5215.737	44	118.539		
Total	178981.072	47			

Table A3. ANOVA of angle of repose of toukir

Angle of repose	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	184.688	3	61.563	174.540	0.000
Within Groups	9.876	28	0.353		
Total	194.563	31			

Table A4. ANOVA of glass transition temperature of toukir

GTT	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	31.528	3	10.509	3.254	0.142
Within Groups	12.921	4	3.230		
Total	44.449	7			

Table A5. ANOVA of thermal conductivity of toukir

Thermal conductivity	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	0.001	3	0.000	11.165	0.000
Within Groups	0.002	44	0.000		
Total	0.003	47			

Table A6. ANOVA of volumetric specific heat of toukir

Volumetric specific heat	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	0.024	3	.008	1.272	0.296
Within Groups	0.280	44	.006		
Total	0.304	47			

Table A7. ANOVA of thermal diffusivity of toukir

Thermal diffusivity	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	0.000	3	.000	23.581	0.000
Within Groups	0.000	44	.000		
Total	0.001	47			

Table A8. ANOVA of thermal resistivity of toukir

Thermal resistivity	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	2.436	3	0.812	11.001	0.000
Within Groups	3.248	44	0.074		
Total	5.684	47			

Table A9. ANOVA of moisture content in fried and unsoaked gulabjamun

Moisture	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.497	3	0.166	1.869	0.276
Within Groups	0.354	4	0.089		
Total	0.851	7			

Table A10. ANOVA of protein content in fried and unsoaked gulabjamun

Protein	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6.029	3	2.010	225.908	0.000
Within Groups	0.036	4	0.009		
Total	6.064	7			

Table A11. ANOVA of ash content in fried and unsoaked gulabjamun

Ash	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.689	3	0.230	298.706	0.000
Within Groups	0.003	4	0.001		
Total	0.692	7			

Table A12. ANOVA of fat content in fried and unsoaked gulabjamun

Fat	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9.870	3	3.290	20.038	0.007
Within Groups	0.657	4	0.164		
Total	10.526	7			

Table A13. ANOVA of carbohydrate content in fried and unsoaked gulabjamun

Carbohydrate	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	39.613	3	13.204	51.049	0.001
Within Groups	1.035	4	0.259		
Total	40.647	7			

Table A14. ANOVA of percentage volume change in gulabjamun

% volume change	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	973.483	3	324.494	3.618	0.019
Within Groups	4663.926	52	89.691		
Total	5637.409	55			

Table A15. ANOVA of crust colour (L*) of fried and unsoaked gulabjamun

CIELAB (L*)	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	175.609	3	58.536	3.269	0.030
Within Groups	787.888	44	17.907		
Total	963.497	47			

Table A16. ANOVA of crust colour (a*) of fried and unsoaked gulabjamun

CIELAB (a*)	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.756	3	1.585	0.479	0.699
Within Groups	145.676	44	3.311		
Total	150.432	47			

Table A17. ANOVA of crust colour (b*) of fried and unsoaked gulabjamun

CIELAB (b*)	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	131.971	3	43.990	2.128	0.110
Within Groups	909.715	44	20.675		
Total	1041.687	47			

Table A18. ANOVA of thermal conductivity of fried and unsoaked gulabjamun

Thermal conductivity	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.004	3	0.001	1.377	0.259
Within Groups	0.053	60	0.001		
Total	0.056	63			

Table A19. ANOVA of volumetric specific heat of fried and unsoaked gulabjamun

Volumetric specific heat	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.374	3	0.458	10.925	0.000
Within Groups	2.516	60	0.042		
Total	3.890	63			

Table A20. ANOVA of thermal diffusivity of fried and unsoaked gulabjamun

Thermal diffusivity	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.010	3	.003	7.865	0.000
Within Groups	0.026	60	.000		
Total	0.036	63			

Table A21. ANOVA of thermal resistivity of fried and unsoaked gulabjamun

Thermal resistivity	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.710	3	0.237	1.362	0.263
Within Groups	10.421	60	0.174		
Total	11.131	63			

Table A22. ANOVA of hardness of fried and soaked gulabjamun

Hardness	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	325.418	3	108.473	4.399	0.007
Within Groups	1775.503	72	24.660		
Total	2100.921	75			

Table A23. ANOVA of adhesiveness of fried and soaked gulabjamun

Adhesiveness	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	208.761	3	69.587	4.546	0.006
Within Groups	1102.124	72	15.307		
Total	1310.884	75			

Table A24. ANOVA of resilience of fried and soaked gulabjamun

Resilience	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	51.878	3	17.293	0.610	0.611
Within Groups	2041.471	72	28.354		
Total	2093.348	75			

Table A25. ANOVA of cohesiveness of fried and soaked gulabjamun

Cohesion	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.153	3	0.051	2.424	0.073
Within Groups	1.517	72	0.021		
Total	1.670	75			

Table A26. ANOVA of springiness of fried and soaked gulabjamun

Springiness	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	596.572	3	198.857	2.255	0.089
Within Groups	6349.795	72	88.192		
Total	6946.367	75			

Table A27. ANOVA of gumminess of fried and soaked gulabjamun

Gumminess	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	17.958	3	5.986	0.852	0.470
Within Groups	505.973	72	7.027		
Total	523.932	75			

Table A28. ANOVA of chewiness of fried and soaked gulabjamun

Chewiness	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	14.977	3	4.992	0.878	0.457
Within Groups	409.426	72	5.686		
Total	424.404	75			