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Effect of moisture level on the rheological properties of khoa jalebi batter and its modelling

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Abstract

Khoa jalebi is popular traditional confectionary sweet of central India. The rheological characteristics of jalebi batter were determined using a computer-controlled Brookfield RVDV II Pro rotational viscometer. The effect of moisture level on flow characteristics including yield stress, flow behaviour index, consistency index and the apparent viscosity were investigated. Shear-thinning characteristics with yield stress were observed for all samples. The moisture content of batter has significant effect on the rheological parameters. Yield stress, consistency index and apparent viscosity increased markedly with decrease in moisture content of batter but the flow behaviour index decreased. The experimental yield stress varied between 83.96 to 654.34 Pa. The rheological behaviour of jalebi batter was adequately described by the Herschel-Bulkley and Casson models with a high coefficient of determination (R^2) and root mean square error (RMSE). The optimum level of moisture in jalebi batter, in terms of rheological characteristics, was 45%. The rheological properties of jalebi batters were also measured by Textural Analyzer (TA-XT). The firmness of jalebi batter was 32.24N, 19.01N and 6.5N for 40%, 45% and 50% moisture, respectively. There was a wide variation in consistency of batter from 62N.sec to 316.34N.sec for variation in moisture from 50% to 40%. Also, the stickiness was observed to be decreased with increase in moisture of batter.

Introduction

Jalebi is a traditional sweet product and a popular street food in the Indian subcontinent due to its unique shape, crisp texture and juicy mouthfeel (Chakkaravarthi *et al.*, 2009a). Though it is popular in many countries, its consumption figures are not available. Jalebi, also known as Zulbia, is popular in countries of South Asia, the West Asia, North Africa, East Africa . Jalebi is similar to variants like jahangiri, imarti and chhena jalebi. It is also known as Jilbi, Jilipi, Jilapi, Zelapi, Jilapir Pak, Jilebi (India), Jilawii, Zoolbia (Middle East), Jeri (Nepal), Z'labia (Tunisia) Mushabakh (Ethiopia) (Anonymous, 2016).

The jalebi is prepared from a thick batter made of, mainly, maida (refined wheat flour). The batter is fermented and thoroughly 'beaten' to get the desirable smooth texture and flowability. The batter is extruded through a thick cloth into hot refined oil or hydrogenated oil in the form of coils. The coils are fried to brown colour and then dipped in hot sugar syrup for absorption. The coils absorb sugar syrup and sugar diffuses into the jalebi coils to impart sweet taste and crisp, juicy texture to the jalebi. For obtaining a good quality jalebi, the rheological quality of batter is extremely important. It was stated that moisture content of 57-61% was required in batter for its extrusion for making jalebi coil. Khoa jalebi is a one of the popular khoa (semi solid desiccated milk) based sweets in some parts of Maharashtra. It is made by frying the khoa based batter extruded from a cloth hole into hot hydrogenated vegetable oil and soaking the fried coils in sugar syrup for sugar syrup absorption (Pagote and Rao, 2012).

Recently, jalebi preparation using khoa as the base material has been reported (Pagote and Jayaraj Rao, 2011). In maida jalebi, maida is used as the base ingredient whereas khoa forms the base material for khoa jalebi. Khoa jalebi is tastier than maida jalebi and most liked and enjoyable product. Like in maida jalebi preparation, even in khoa jalebi preparation also, proper battering is extremely important to get desirable characteristics in the final product. The moisture content of the batter is very important as it directly affects its rheology and subsequently the final product quality.

The batter rheology can be studied by recording its behaviour in terms of shear rate and shear stress which is also important for the quantitative assessment of characteristics like spreadability and flowability. It is also necessary to know the magnitude of yield stress as it directly affects the initiation of flow

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from a container or extrusion. Further, the integrity of the batter is highly crucial for the formation of jalebi coils/ strands during subsequent frying and for maintaining the quality of finished product. Thus, rheology of batter is important not only from the point of view of acceptability of finished product in terms of texture but also in relation to process development, process control, quality assurance and equipment design (Chakkaravarthi *et al*., 2009b). The recent trend towards the mechanization of traditional dairy products is mainly to produce uniform and high quality product. Khoa jalebi has great opportunity to enter into the organized dairy sector as well as food sector. The method of manufacture of khoa jalebi has been standardized very recently (Pagote, 2010). In this study, batter was selected on the basis of its extrusion performance through the hole of cloth especially to retain its shape during frying. Accordingly three levels with narrow ranges of moisture were studied and finally only one range i.e. 45-50% was considered as optimum level of moisture in the jalebi batter. But no work has been conducted so far on rheological properties of batter and its relationship with the final product quality. For designing extrusion unit and for process mechanization, thorough information on the rheological behaviour of jalebi batter is very important.

In khoa jalebi making, proper battering is extremely important to get desirable characteristics in the final product. The moisture content of the batter is very important as it directly affects its rheology and subsequently the final product quality. The batter rheology can be studied by recording its behaviour in terms of shear rate and shear stress. Further, the integrity of the batter is highly crucial for the formation of jalebi coils/ strands during subsequent frying and for maintaining the quality of finished product. Chakkaravarthi *et al.* (2013) discussed importance of flowability and pourability of batter on the quality of maida jalebi. Rheology of batter is important not only from the point of view of acceptability of finished product's texture, but also in relation to process development, process control, quality assurance and equipment design (Chakkaravarthi *et al*., 2009). The method of manufacture of khoa jalebi has been standardized recently (Pagote and Rao, 2012; Pagote and Nawale, 2013). For designing extrusion unit and for process mechanization, thorough information on the rheological behaviour of jalebi batter is very important. The objective of this work was to determine the effect of moisture level in khoa jalebi batter on its rheological behaviour and properties.

Materials and Methods

Raw material

The khoa was prepared by desiccating cow milk (3.5% fat and 8.5% SNF) in an open steam jacketed kettle at Experimental Dairy of Institute (De, 1980). The average composition of khoa was as follows: 25.6% moisture, 25.8% fat, 19.4% total protein, 25.5% lactose and 3.8% ash. Arrowroot powder was obtained from the local market. High quality crystalline sugar obtained from the local market was used for sugar syrup preparation. Hydrogenated vegetable oil purchased from local market was used as the frying medium and toukir powder (starch of tubers of *Curcuma angustifolia*) (Pagote and Rao, 2014) was procured from suppliers in Nagpur city.

Preparation of jalebi batter

Khoa, arrowroot powder and toukir were mixed in the ratio of 100:25:5 respectively. Khoa jalebi batter with different moisture levels was prepared by keeping the quantities of khoa, arrowroot powder and toukir constant and varying the water level (3 levels). The amount of water required to make the jalebi batter was calculated using the following equation:

$$x = ((MQ-m))/((1-M))$$

Where,

M= required moisture content in the jalebi batter, %

Q= Total quantity of dry mixture of jalebi batter, gm

x = Amount of water to be added to get the required moisture content in final jalebi batter, ml

m = Moisture content in khoa, %

Measurement of rheological properties of khoa jalebi batter

Before starting the test, the Texture Analyser probe was calibrated to a distance of 50 mm. Sample was transferred into a cylindrical plastic container (200 ml capacity) and tempered to 30ºC. The plastic container containing the sample was placed below the TA probe and TA probe was brought close to the product surface. On prompting, TA probe travelled to a distance of 30 mm into the product and returned to its original position, generating a force-time curve.

With the help of anchors, the areas of the positive and negative curves were determined and expressed as consistency (N.sec) and index of viscosity (N.sec) respectively. The highest positive and negative peak forces were taken as firmness and stickiness, respectively of the product and expressed in terms of

Newton (N).

Determination of apparent viscosity of khoa jalebi batter

The apparent viscosities of khoa jalebi batter samples were determined using a rotational viscometer (Model RVDV-II Pro, Brookfield Engineering laboratory, Stoughton, MA) at different spindle speeds, at 10 rpm increments and in a continuous run mode. The viscosity measurements were done at ambient temperature, about 30°C. The range of torque measurement was kept between 10% and 100% by selection of appropriate spindle as per the nature of the khoa jalebi batter samples. The batter samples were taken in 125 ml beakers and the spindle depth into the batter samples was kept constant in all the measurements. The measurements were started at spindle rpm of 10 and the end speed was 100 rpm. At each rpm, the sample was sheared for 30 sec before the speed was increased to the next level. The torque and apparent viscosity data were collected at 10 sec interval at each rpm (three readings were recorded at each spindle speed). The data were collected using the Rheocalc V 3.1.1 software supplied by Brookfield Engineering Laboratory.

Mathematical modeling of khoa jalebi batter

The viscosity vs. torque data at various spindle speeds were converted into shear stress and shear rate by Mitschka method (Briggs and Steffe, 1997; Haminiuk *et al.*, 2009). The slope of the logarithm of shear stress versus logarithm of rotational speed was computed as the flow behavior index 'n':

$$n = (d(\log \sigma))/(d(\log \xi))$$

Shear stress, σ, was given by the following equation:

$$\sigma = k_{\alpha\tau}\ (C^{*}\ \text{Dial reading})$$

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

The average shear rate, γ_a, was determined by the following equation:

$$\gamma_a = K_{NY}{}^{*}N$$

where K_{NY} is the shear rate conversion factor.

The apparent viscosity *(η, Pa.s)* is given by the following equation:

$$\eta = \sigma/\gamma$$

The Ostwald De Waele (Power law), Casson and Herschel-Bulkley models were fitted to the shear stress and shear rate data.

$\sigma = K.\gamma^{n}$ (Ostwald De Waele or Power law model)
$\sigma = \sigma_o + K.\gamma^{n}$ (Hershel-Bulkley model)
$\sigma^{½} = \sigma_o ½ + \eta_a.\gamma^{½}$ (Casson's model)

where 'σ' is the shear stress (Pa), 'σ_0' is the yield stress (Pa), η_a is the apparent viscosity (Pa.s) (Casson viscosity), 'γ' is the shear rate (s^{-1}), 'K' is the consistency coefficient ($Pa.s^n$) and 'n' is the flow behaviour index (dimensionless). While value of 'n' reflects the extent of departure from Newtonian behaviour of the batter, 'K' is a measure of viscosity or consistency.

The Ostwald De Waele model was fitted by plotting 'ln σ' against 'ln γ '. The slope of this straight line relationship was determined as the flow behaviour index 'n' while the intercept was taken as the consistency coefficient 'K'. Casson's model was fitted by σ vs. γ relationship which resulted in a straight line whose intercept indicating σ_0. It means, yield stress of the batter can be determined. The yield stress obtained was used in the Herschel-Bulkley model, and the parameter 'ln σ-σ_0' was plotted against 'ln γ' to determine the flow behaviour index and the consistency coefficient. Finally, the yield stress, consistency coefficient and flow behaviour index were used to characterize the flow properties of the khoa jalebi batter samples while the apparent viscosity at 10 rpm (initial viscosity) was used for comparison of the samples.

Root mean square error (RMSE) value was determined by the equation:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}}$$

where X_{obs} is observed values and X_{model} is modelled values at time/place i.

Statistical analysis

Data obtained from various experiments during preparation of batter with different moisture levels was statistically analyzed by analysis of variance as described by Snedecor and Cochran (1994), and employing appropriate computer package SPSS 15.0.

Table 1. Change in the rheological properties of jalebi batter at different moisture levels and effect on textural properties of khoa jalebi

Moisture Level in batter, %	Properties of batter					Properties of khoa jalebi	
	Firmness, N	Consistency, N.sec	Index of Viscosity, N.sec	Stickiness, N	Apparent Viscosity, Pa.sec †	Hardness, N	Consistency, N.s
40	32.24±0.7	316.34±4.4	48.3±2.02	14.43±0.4	405.78±6.0	8.23±0.6	46.55±2.0
45	19.01±0.6	179.7±3.3	37.67±1.9	9.52±0.3	220.84±7	6.91±0.5	44.5±2.6
50	6.5±0.5	62±3.5	15.73±0.55	6.45±0.3	76.53±6	5.63±0.3	38.74±2.2

† determined by Brookfield viscometer

Results and Discussion

Initial study was undertaken to select a range of moisture in batter to be suitable for the formation of jalebi coils. The extrusion behaviour of batter was recorded on the basis of visual observations. Jalebi cloth with suitably sized hole (4 - 5 mm dia) was used for the purpose. The recorded observations indicated that jalebi batter with 55 and 60% moisture content was not suitable for making jalebi, hence these levels were discontinued for further studies; and remaining three levels viz. 40%, 45% and 50% were taken for extensive study.

The rheological properties of batter at different moisture levels were measured using Textural Analyser. Data in Table 1 indicates a marked decrease in the hardness of batter from 32.24N to 6.5N for the increase in moisture level of batter from 40% to 50%. Batter with 40% moisture offers more resistence to the probe during penetration than the batter with 50% moisture. Decrease in consistency indicates the non-Newtonian shear-thinning characteristics of jalebi batters. Decrease in consistency was because of the change in the ratio of total solids (TS) to water. The TS-water ratio decreased with increase in water content of batter giving lower values of consistency.

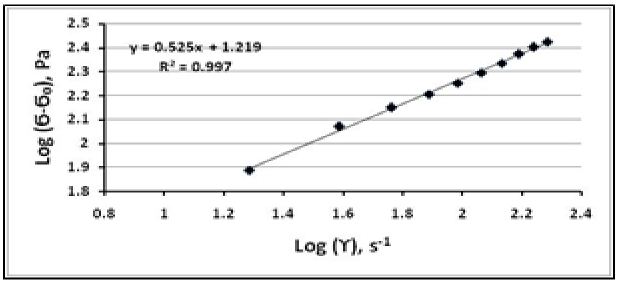
For batters with 40%, 45% and 50% moisture levels, the index of viscosity values were 48.3N.sec, 37.67N.sec and 15.73N.sec, respectively (Table 1). The trend shows decrease in index of viscosity with increase in moisture content. The viscosity of batter actually depends on the adhesive forces present between the solid particles. For batter with 40% moisture, the adhesive forces between solid particles were strong due to presence of less water giving more viscosity. For batter with 50% moisture, amount of water present was higher resulting in low viscosity of batter. The stickiness values for batters with 40%, 45% and 50% moistures were 14.43N, 9.52N and 6.45 N, respectively (Table 1). It was observed that there was gradual decrease in the stickiness values from 14.43N to 6.45N with increase in moisture from 40% to 50% in batter. There was decrease in stickiness of batter with increase in moisture levels due to the decrease in the existing adhesive forces between solid particles. It was observed that with increase in moisture level from 40 to 45 and 45 to 50%, the viscosity of batter decreased from 405.78 to 220.84 and 220.84 to 76.53 Pa.s, respectively (Table 1). There was a drastic decrease in viscosity of batter as moisture level increased.

For batter with 40% moisture, the viscosity value was very high i.e. 405.78 Pa.s due to the higher solid content. It had a semi-solid consistency and not pourable. High torque was required for shearing of the batter sample. In case of batter with 50% moisture level, the viscosity was very low i.e. 76.53 Pa.s due to less solid content. It has smooth consistency and homogeneous body. It was pourable in nature. Low torque is required for shearing of the batter sample.

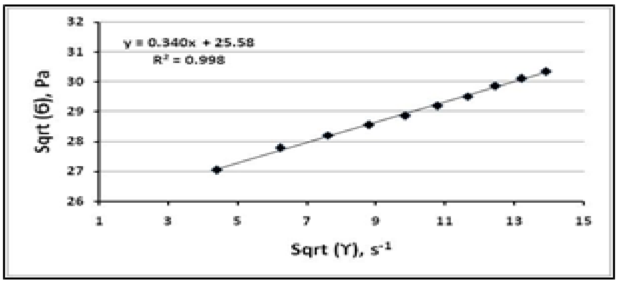
The apparent viscosity of jalebi batter for selected moisture levels was studied by using a computer-controlled Brookfield RVDV II Pro rotational viscometer along with the mathematical modeling of jalebi batter. The viscometric data were converted into basic shear stress vs. shear rate form using Mitschka method (Briggs and Steffe, 1997). From the shear rate-shear stress data, the flow nature of jalebi batter was evaluated. The apparent viscosities of jalebi batter decreased with increasing shear rate, indicating pseudoplastic behaviour (Table 2). For example, at 10 spindle rpm, the viscosity was 405.78Pa.s for 40% moisture batter which decreased to 76.53Pa.s in 50% moisture batter. Higher average torque indicated lower viscosity. The rheological behaviour of jalebi batter was adequately described by the Herschel-Bulkley and Casson models with a high coefficient of determination (R^2) and root mean square error (RMSE) (Figures 1a and b and Table 3). Though Casson's was the best model for jalebi batter, the Herschel-Bulkley model was recommended because it yields three useful parameters namely, yield stress, consistency coefficient and the flow

Table 2. Brookfield viscometer data for batter with different moisture levels

Spindle speed, rpm	Average Torque, %			Average Viscosity, Pa.s		
	40% M	45% M	50% M	40% M	45% M	50% M
10	87.11	55.21	19.12	405.78	220.84	76.53
20	91.89	58.87	19.54	207.21	117.73	39.05
30	94.71	64.08	21.31	151.90	85.44	28.41
40	97.03	67.5	23.99	119.58	67.5	23.99
50	99.20	70.75	27.11	100.94	56.60	21.69
60	101.44	72.6	29.84	88.66	48.40	19.89
70	103.67	74.93	32.29	81.14	42.82	18.45
80	106.06	78.16	34.63	75.67	39.08	17.32
90	107.91	82.28	36.75	72.6	36.57	16.83
100	109.58	86.46	38.36	69.11	34.58	15.34



(a)



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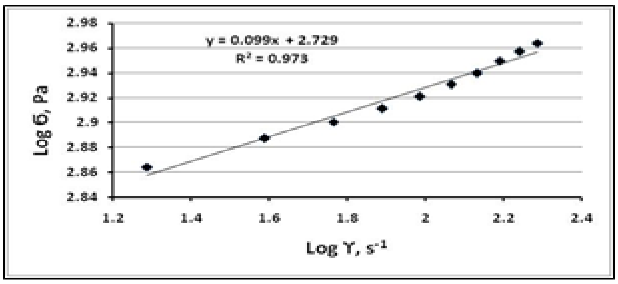


(c)

Figure 1. (a) Herschel- Bulkley plot (b) Casson's plot and (c) Ostwald De Waele plot of jalebi batter containing 40% moisture

behaviour index as compared to the two-parameter Casson's model. The Ostwald De Waele model did not fit very well because of the yield stress in jalebi batter (Figure 1c).

Among the time-independent rheological models tested in this study, it could be concluded from the R^2 data that the Casson's model was the best one for jalebi batter with 50% moisture while Herschel-Bulkley model was the best one for jalebi batters with 40 and 45% moisture contents. However, the Herschel-Bulkley model very closely matched with the Casson model in most cases, and gave a slightly superior fit for some samples (Table 3). The Ostwald De Waele model did not fit very well because of the yield stress in jalebi batter. The Herschel-Bulkley yield stress (σ_0), consistency coefficient (K) and the flow behaviour index (n) were determined from shear stress vs. shear rate data. The flow behaviour index varied from 0.523 to 0.560 for all samples while the consistency coefficient ranged from 16.56Pa.s^n to 28.73Pa.s^n. The yield stress of jalebi batter was found to lie between 83.78Pa to 655.24Pa.

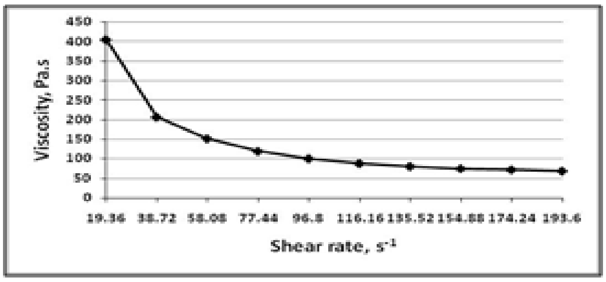
The apparent viscosity against the shear rate also demonstrates shear thinning behaviour of the batter. The apparent viscosity as a function of shear rate at different moisture levels in jalebi batter is shown in sample Figure 2a to c. During shearing, the apparent viscosity decreased to more or less a constant value, which was true for all samples. Thus, all the apparent viscosity vs. shear rate curves showed a strong shear-thinning behaviour (pseudoplastic). The reduction in viscosity of the batter with increasing shear rate was related to the possible realignment and streamlining of the batter due to the rotational movement.

The effect of moisture on the apparent viscosity, yield stress, consistency coefficient and flow behaviour index were found to be significant ($P<0.05$). Thus, wide ranges of apparent viscosities, yield

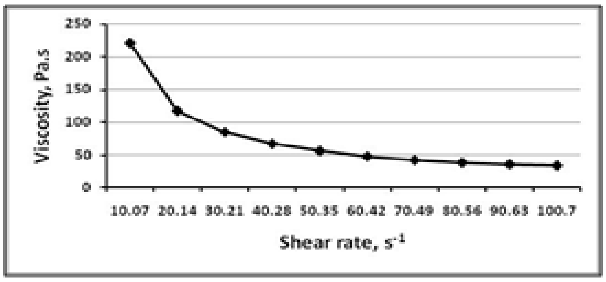
Table 3. Rheological model coefficients of jalebi batter at different moisture levels

M, %	Ostwald De Waele				Herschel-Bulkley					Casson			
	K	n	R^2	RMSE	σ_0	K	n	R^2	RMSE	σ_0	Ƞa	R^2	RMSE
40	535.80	0.099	0.973	0.32	654.34	16.56	0.525	0.997	0.14	654.34	0.340	0.998	0.17
40	533.22	0.11	0.975	0.31	653.23	16.58	0.527	0.996	0.13	653.54	0.342	0.997	0.16
40	534.54	0.097	0.968	0.33	655.24	16.57	0.523	0.997	0.16	655.24	0.338	0.998	0.18
40	535.37	0.099	0.971	0.32	654.12	16.54	0.524	0.998	0.15	654.25	0.339	0.998	0.16
45	285.10	0.190	0.957	0.49	358.72	28.71	0.537	0.988	0.04	358.72	0.762	0.988	0.05
45	283.41	0.189	0.961	0.50	358.14	28.69	0.533	0.989	0.05	358.14	0.767	0.989	0.05
45	286.73	0.192	0.958	0.47	359.27	28.73	0.536	0.985	0.04	359.27	0.771	0.986	0.06
45	284.36	0.190	0.955	0.49	358.87	28.70	0.534	0.992	0.04	358.87	0.758	0.991	0.05
50	74.64	0.338	0.902	0.20	83.96	21.04	0.557	0.922	0.01	83.96	1.046	0.964	0.01
50	73.11	0.336	0.901	0.19	84.22	21.07	0.560	0.925	0.008	84.12	1.051	0.966	0.009
50	75.24	0.339	0.903	0.22	83.78	21.03	0.556	0.919	0.009	83.68	1.048	0.962	0.01
50	74.51	0.337	0.902	0.21	84.08	21.05	0.555	0.923	0.01	84.08	1.044	0.965	0.01

Note: M% = Moisture% in batter; σ_0 = Yield stress, Pa; Ÿ = Shear rate, 1/sec; k = Consistency index, Pa.s^n; n = Flow behavior index; R^2 = Regression coefficient; RMSE= Root mean square error; Ƞa = Apparent viscosity



(a)



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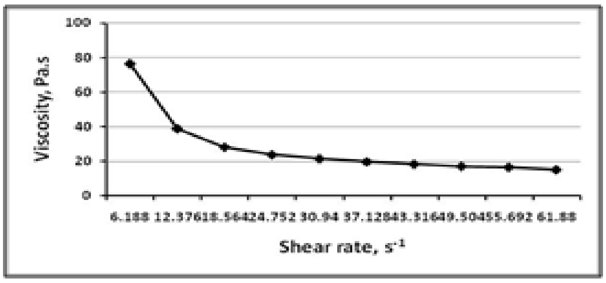

(c)

Figure 2. Apparent Viscosity vs. Shear Rate curve of jalebi batter with (a) 40% (b) 45% and (c) 50% moisture

stress, consistency coefficients and flow behaviour indices were observed by varying the moisture level in jalebi batter. From the rheological data, it could be concluded that the optimum moisture content in jalebi batter was 45% for the production of desired khoa jalebi.

Effect on textural properties of khoa jalebi

The moisture content of batter had a remarkable effect on the textural property of khoa jalebi produced from the batter. The hardness of the jalebi decreased from 8.23 N to 5.63 N with increase in moisture of batter from 40 to 50% (Table 2). The maximum hardness value was obtained for jalebi made from 40% moisture batter due to less absorption of sugar syrup. The minimum hardness value was obtained for jalebi made from 50% moisture batter indicating more absorption of sugar syrup during soaking. This was also reflected in consistency values of the jalebi made from 50% moisture batter. Consistency of khoa jalebi depends on the size and distribution of pores, absorption of sugar syrup and homogeneity of jalebi coils. There was not much decrease in consistency values of khoa jalebi with increased moisture content of batter from 40 to 45% (Table 2). But, there was considerable decrease in consistency values from 44.5 to 38.74 N.s for increased moisture level from 45 to 50%. For khoa jalebi prepared from 40% moisture batter, the pore size was small and therefore, less absorption of sugar syrup. This gave higher consistency value. For 45% moisture batter, the pore size was medium and resulted in more absorption of sugar syrup. This reduced resistance to the test probe. In case of khoa jalebi prepared from batter with 50% moisture, the pore size was large as well as distribution of pores was non-uniform. So sugar syrup absorption was more but retention of sugar syrup was unsatisfactory. Larger pore size gave loose body and texture of khoa jalebi. Therefore, the consistency value was less i.e. 37.74 N.s.

Conclusion

Khoa jalebi batters are composed of khoa, arrowroot powder and toukir. The jalebi batters showed very high yield stress up to 654.34 Pa. Jalebi batters also exhibited shear-thinning behaviour with flow behaviour index between 0.52 – 0.56 meaning moderate non-Newtonian characteristics. The analysis of variance indicated significant effect of moisture. The rheological behaviour of jalebi batter changed phenomenally when moisture level was increased by 5% to get the batter of 45% and 50% moisture. Thus, rheological parameters of jalebi batter can be adequately controlled by adjusting the moisture content of the batter system.

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