Jilebi 2: Flowability, pourability and pH of batter as affected by fermentation

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Abstract Fermentation of batter is an integral part of the preparation of *jilebi*, a traditional ready-to-eat sweet product of Indian sub-continent. The flowability and pourability of batter are crucial for forming *jilebi* strands during frying. Flowability and pourability have been determined from simulation studies based on the movement of batter on an inclined surface and the exit from an orifice, respectively; simple gadgets have been designed to determine these two characteristics along with providing the definitions. Response surface experimental design consisting of moisture content (50–65%), amount of added curd (0–10%) and time of fermentation (0–24 h) has been employed. The response functions are pH, flowability and pourability. Strong interaction effects of added curd and time of fermentation on the response functions have been observed. An increase in added curd and time of fermentation decreases pH in a curvilinear manner as both linear and quadratic effects are significant ($p \leq 0.01$). Moisture content has a non-significant effect on pH but markedly affects the flowability and pourability of batter. Flowability and pourability decreases when there is an increase in consistency index or apparent viscosity.

Keywords *Jilebi* batter · Pourability · Flowability · Definition · Fermentation

Introduction

The traditional sweet *jilebi* is popular throughout the Indian subcontinent because of its crisp texture, attractive taste and

juicy mouth feel (Chitale 2000; Berry 1992). The process of *jilebi* making includes the preparation of a thick batter using refined wheat flour (*maida*), addition of a small quantity of curd and allowing for fermentation, pouring of the batter in a skilled manner into the hot oil for frying of *jilebi* strand-embedded structure followed by soaking in sugar syrup (Chakkaravarthi et al. 2009a). In our earlier communication, Chakkaravarthi et al. (2009b) have reported the effect of batter preparation conditions on the rheological behaviour of the batter. Shear-thinning characteristics with yield stress have been observed for all the *jilebi* batter samples. Moisture content of batter possesses the most dominating effect on rheological parameters like yield stress, flow behaviour index, consistency index and apparent viscosity.

It is obvious that the characteristics of batter are affected by several factors. These are type, composition and concentration of major raw materials used particularly the moisture content of batter and the protocol of fermentation employed. These factors in turn affect the rheological characteristics of batter, and consequently, formation of the *jilebi* strands. Initial trials on strand formation through gravity flow have indicated that too thin batter offers strands that easily disintegrate in frying oil while too thick batter yields non-continuous strands which are undesirable. The preferred batter status is easy flow and possibly by gravity flow only in a continuous manner that offers circular cross-sectional strands of 5–8 mm in diameter that do not disintegrate during frying as well as soaking in sugar syrup. The batter flow should be continuous to obtain continuous strands. This helps in shaping into the typical shape of *jilebi* having two or three concentric rings that are also tied by a perpendicular strand. Hence, there exists a need to understand the flowability and pourability of *jilebi* batter but such data are not available nor do such methods exist.

Therefore, the objectives of the present paper are to (a) develop appropriate methods for determining the pourability

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and flowability of *jilebi* batter, (b) determine pH, flowability and pourability of batter as affected by moisture content, amount of added curd and time of fermentation, (c) obtain inter-relation among the response functions, and (d) optimise (minimisation and maximisation) the fermentation conditions for *jilebi* batter.

Materials and methods

Materials Refined wheat flour (*maida*) was procured from a local supermarket of Mysore, India while curd was procured from a local dairy. *Jilebi* batter was prepared as mentioned by Chakkaravarthi et al. (2009b). *Maida* particles, less than 130 μm , were used to make a smooth paste without possessing any lump.

Experimental design A central composite rotatable design (CCRD) was employed with variables like moisture content, amount of added curd and the time of fermentation on selected response functions (pH, flowability and pourability). The variables were expressed in coded levels of -1.682 , -1 , 0 , 1 , and 1.682 . The actual (decoded) levels of independent variables (Table 1) were 50.0, 53.1, 57.5, 62.0 and 65.0% for moisture content, 0.0, 2.0, 5.0, 8.0 and

10.0% for curd added, and 0.0, 5.0, 12.0, 19.1 and 24.0 h for fermentation time. The analysis of variance (ANOVA) was employed to know the effect of individual variables on the response functions. The details of the experimental design and consequent analysis of results was done (Khuri and Cornell 1989; Myers 1971) as mentioned earlier by Chakkaravarthi et al. (2009b). A second order polynomial was fitted and F values were considered for comparison of the effects of individual variables.

Development of gadgets for determining flowability and pourability An instrument, as shown in Fig. 1, was developed for the measurement of flowability of the *jilebi* batter on a slanted surface and by employing Eq. 1. The pourability of the batter was determined as per the set up shown in Fig. 2 along with Eq. 2. Both instruments worked on the principle of gravity induced flow which simulated the movement of *jilebi* batter and pouring into hot oil for frying. The angle of inclination of the gadget used to measure flowability was 45° . The gadget was made of perplex or acrylic (poly methyl methacrylate) sheets of thickness 3 mm. A fixed volume of batter (70 ml) was poured manually to measure flowability by using a beaker of diameter 37 mm after touching the top part of the slanted surface. The overall dimensions (height, length and

Table 1 Design of experiments for *jilebi* batter in coded and actual level of variables

Experiment No	Variables (coded level)			Variables (actual level)		
	Moisture content, x_1 (-)	Added curd, x_2 (-)	Time of fermentation, x_3 (-)	Moisture content, X_1 (%)	Added curd, X_2 (%)	Time of fermentation, X_3 (h)
1	1	1	1	61.95	7.97	19.13
2	1	-1	-1	61.95	2.03	4.87
3	0	0	-1.682	57.5	5	0.01
4	-1	-1	-1	53.05	2.03	4.87
5	0	0	0	57.5	5	12
6	-1.682	0	0	50.02	5	12
7	1	-1	1	61.95	2.03	19.13
8	0	0	0	57.5	5	12
9	-1	1	1	53.05	7.97	19.13
10	0	0	0	57.5	5	12
11	0	0	1.682	57.5	5	23.99
12	0	0	0	57.5	5	12
13	0	0	0	57.5	5	12
14	0	0	0	57.5	5	12
15	1.682	0	0	64.98	5	12
16	-1	-1	1	53.05	2.03	19.13
17	1	1	-1	61.95	7.97	4.87
18	0	-1.682	0	57.5	0.01	12
19	0	1.682	0	57.5	10.0	12
20	-1	1	-1	53.05	7.97	4.87

Fig. 1 Developed gadget for determining the flowability of batter on slanted surface

breadth) of the v-shaped slanted surface were: width 60 mm, length 365 mm and height 260 mm. The diameter of the container used for measuring pourability was 80 mm; the orifice through which the batter was allowed to come out was 7 mm in diameter. In the bottom tapered portion of

Fig. 2 Developed gadget for determining the pourability of batter through an orifice

setup, the diameter decreases from 80 to 7 mm in a height of 80 mm. The temperature of measurement was 25 ± 1 °C.

Methods The moisture content of batter was determined by following the air oven method (AOAC 1980). Five g of *jilebi* batter was mixed with 50 g of distilled water and the pH of the mixed system was measured by using a portable electronic pH meter (Model EZDO PL-600, HTA Instrumentation, Bangalore, India); these values were reported as the pH of the batter.

The time required for the batter to move 30 cm was noted for flowability measurement. Flowability is defined as per Eq (1).

$$\text{Flowability} = \frac{1}{\text{Time required to flow on 30 cm of inclined surface}} \quad (1)$$

The unit for flowability is s^{-1} , and Eq (1) indicates that an easily flowable material will take a small time to flow and thus flowability of the same sample will be very high.

The pourability of batter was determined by allowing the batter to fall freely under gravity through a port opening of 7.0 mm diameter (Fig. 2). A specific volume of batter was allowed to pass between the graduated marks of the developed instrument and the corresponding time was noted. In the similar manner like that of flowability, pourability is defined by Eq (2).

$$\text{Pourability} = \frac{\text{Distance of the graduated marks}}{\text{Time required to flow between two graduated marks}} \quad (2)$$

The unit for pourability is mms^{-1} . It indicates that the easily pourable material will take a small time such that the magnitude of pourability becomes high. All measurements were conducted on triplicate samples and the average values are reported. During the measurement of flowability and pourability, we observed that a few thick samples took several hours to complete the measurement, and hence, the actual values are not reported here. The chance of obtaining erroneous results was possible for these thick samples because drying of batter could happen during such a long time of measurement.

Measured quantities of water and curd were added to refined wheat flour and were thoroughly mixed (Chakkaravarthi et al. 2009b). These samples were allowed to stand for different times as per the experimental design before subjecting to rheological studies. A controlled stress rheometer (Model # RT10, Haake GmbH, Karlsruhe, Germany) was used to determine the rheological properties of batter. All rheological measurements were conducted at 25 ± 0.1 °C on triplicate samples by employing a circulatory water bath. The yield stress of the samples was determined from the

Table 2 Response functions (pH, flowability and pourability) for *jilebi* batter as a function of experimental variables^a

Experiment No.	Response functions			
	pH	Apparent viscosity (Pas)	Flowability (s ⁻¹)	Pourability (mm s ⁻¹)
1	3.70	3.64	0.0425	0.1191
2	5.32	4.62	0.0186	0.0448
3	5.29	7.68	0.006122	0.0138
4	4.84	26.02	NM	NM
5	3.87	11.23	0.006977	0.0230
6	3.85	44.10	NM	NM
7	3.53	4.24	0.0638	0.2202
8	4.01	10.33	0.009464	0.0248
9	3.82	23.65	NM	NM
10	3.68	11.26	0.006122	0.0264
11	3.60	7.99	0.0159	0.0067
12	3.84	6.65	NM	0.0214
13	3.90	6.64	0.0071	0.0208
14	3.93	7.01	0.00682	0.0235
15	3.62	2.24	0.0938	0.274
16	3.89	26.09	NM	NM
17	4.26	3.50	0.0422	0.1280
18	4.76	9.86	0.002679	0.0090
19	3.64	9.27	0.005535	0.0208
20	4.13	24.02	NM	NM

^a According to Table 1

NM indicates not measured

shear-stress/time data employing the method of relaxation of sample. In brief, the sample was initially sheared at a shear-rate of 5 s⁻¹ for 30 s followed by allowing the sample to relax for 60 s. The lowest shear-stress at the end of relaxation was considered as the yield stress. The flow curves of batter were generated by progressive increase of shear-rate upto 100 s⁻¹ to obtain 25 shear-stress/shear-rate data sets. A cone-plate attachment was employed when the diameters of the plate or cone were 35 mm while the cone had an angle of 1°. Apparent viscosity was taken as the ratio of shear-stress and shear-rate while the latter was taken as 50 s⁻¹. Shear-stress and shear-rate data were subjected to fitting to a common rheological model like the Herschel-Bulkley (HB) equation; the experimental yield stresses were used to obtain the flow parameters. The closeness of fitting to the model was judged by finding the correlation coefficient (r), and checking their statistical significance at $p=0.01$. The flow behaviour index and consistency index were estimated by employing the technique of non-linear analysis by using the software supplied by the rheometer manufacturer.

Jilebi batters, prepared according to the experimental design, were categorised into extremely difficult, very difficult, difficult, easy and very easy to flow/pour by assigning numbers from 1 to 5, respectively. A sensory panel consisting of three members assessed the batter samples.

Statistics Multiple correlation coefficients (R) were calculated for the fitted second order polynomials linking the individual variables with the response functions, and the significance of R values were tested at a probability (p) of

Table 3 Condensed analysis of variance (ANOVA) for response functions in coded level of variables (x₁: Moisture content, x₂: Amount of curd and x₃: Time of fermentation)

Source of variation	pH		Flowability		Pourability	
	Coefficient of polynomial	F- value	Coefficient of polynomial	F- value	Coefficient of polynomial	F- value
Constant	3.8694		0.00725		0.02332	
Moisture	-0.0192	0.257 ^{NS}	0.00916	21.139***	0.05844	256.705***
Curd	-0.2604	47.336***	0.00085	3.128 ^{NS}	0.00351	15.933**
Time	-0.4722	155.643***	0.00291	36.668***	-0.00211	5.768*
Moisture ²	-0.0392	1.130 ^{NS}	0.02515	303.446***	0.05387	415.379***
Curd ²	0.1261	11.712***	-0.00111	11.345**	-0.00298	24.318***
Time ²	0.2127	33.326***	0.00133	16.299***	-0.00462	58.610***
Moisture x Curd	-0.0149	0.090 ^{NS}	-0.00027	0.135 ^{NS}	-0.00798	34.174***
Moisture x Time	-0.1366	7.632**	0.00847	128.9***	0.04374	1025.806***
Curd x Time	0.2341	22.410***	-0.01123	386.590***	-0.04608	1943.312***
R	0.983***	0.979***	0.989***			

*Significant at $p \leq 0.10$ **Significant at $p \leq 0.05$ ***Significant at $p \leq 0.01$ NS Non-significant at $p \geq 0.10$

0.01. The F-values, obtained in ANOVA tables were tested for their significance at probabilities of 0.1, 0.05 and 0.01. Inter-relations among the response functions were reported in terms of correlation coefficient (r) and the latter was tested at probabilities of 0.05, 0.01 and 0.001.

Results and discussion

Effect of fermentation of batter The effects of the three independent variables (moisture content, amount of added curd and time of fermentation) on the response functions

(pH, flowability and pourability) were determined. These response functions are shown in Table 2, and the condensed ANOVA table (Table 3) are presented along with generated response surface (Figs. 3, 4 and 5) for easy visualization of the effect of individual variables on response functions. High multiple correlation coefficients (R) between 0.983 and 0.989 (significant at $p \leq 0.01$) indicated the suitability of the second order polynomials linking the individual variables with the response functions.

The pH of the batter varied between 3.53 and 5.29 (Table 2) indicating moderately acidic batter due to addition of curd and the consequent fermentation. The linear effect of time of fermentation (significant at $p \leq 0.01$) and amount of added curd dominated over its quadratic and interaction effects. An increase in added curd and time of fermentation decreased pH (Fig. 3) in a curvilinear manner as the quadratic effects were also significant at $p \leq 0.01$. The

Fig. 3 Experimental pH of batter as a function of variables (in coded levels)

Fig. 4 Experimental flowability of batter as a function of variables (in coded levels)

Fig. 5 Experimental pourability of batter as a function of variables (in coded levels)

interaction effect of added curd and time of fermentation was also significant ($p \leq 0.01$) meaning that the effect of curd on pH depended on the duration of fermentation. It is interesting to mention that moisture content did not significantly affect the pH of the fermented batter.

The flowability of *jilebi* batters was between 0.0027 and 0.0638 s⁻¹ (Table 2). Some samples of this planned experiment even took several hours to flow which was particularly true for samples containing low moisture content (less than 57.5%), and hence, these results were removed during analysis of results (discussed earlier in **Materials and methods**). The linear, quadratic and interaction effects on flowability were all significant. Among the individual variables, moisture content imparted a dominating effect (Table 3), and an increase in moisture content increased the flowability of batter (Fig. 4b, c). The linear

and quadratic effects of time of fermentation showed similar trend like that of moisture content (Fig. 4b). The effect of curd on flowability was marginal as its quadratic effect was significant at $p \leq 0.05$ and exhibited a negative effect (Fig. 4c), while its interaction with time of fermentation offered a strong negative effect (Fig. 4a); it means that an increase in both curd and fermentation time decreased the flowability of batter.

The pourability of fermented *jilebi* batter was between 0.0067 and 0.2740 mms⁻¹. Moisture content exerted the maximum positive effect meaning that an increase in moisture markedly increased the pourability of batter (Fig. 5b, c). The negative quadratic effect of curd dominated over its linear effect ($p \leq 0.01$ and 0.05, respectively) meaning that an increase in added curd decreased pourability of batters (Fig. 5a). However, the interaction effects were more prominent than the linear and quadratic effects to exhibit a complex behaviour of curd and fermentation time. The highly significant negative interaction effect of curd $\times$ time markedly decreased pourability (Fig. 5a). It may be mentioned here that time-dependent viscosity change can occur during pouring/flowing of batter that are typically shear-thinning thixotropic liquids.

Moisture content did not significantly affect the pH of the fermented thick batter. At the same time, an increase in moisture content improved the flowability and pourability of *jilebi* batter due to a decrease in apparent viscosity in addition to its lubrication effect. The pH of curd from the local dairies was 4.1 ± 0.1 ; variation of moisture content was in the range of 53.5 and 62.5%. This meagre change in moisture content of 10% had not significantly affected the pH of the thick fermented batter. It may be mentioned here that pH of curd is not standard, and quality of curd varies with milk quality, inoculum volume, fermentation time, temperature, etc. The curd used for the present study was from partially fat removed cow milk, and possessed moisture and fat contents of 87.2% and 1.5%, respectively.

The effect of added curd and time of fermentation was complex in nature and their combination possessed an important effort. This was reflected by curvilinear nature of curves when these two variables were plotted. The strong interaction effect of added curd and time of fermentation on the response functions like pH, flowability and pourability indicated that the effect of curd on these response functions depended on the duration of fermentation. It means that the organic acids (mostly lactic acid) that were produced during fermentation with curd had attained saturation and any further increase in curd and/or time did not contribute any further effect on pH. The low pH resulting from lactic fermentation suppresses excess activity of alpha amylase and other enzymes during fermentation. In addition, the fermentation process contributes to the bioavailability of minerals by phytate degradation (Rati Rao et al. 2006). The

Table 4 Correlation matrix among the response functions

Parameter	Yields stress	Flow behaviour index	Consistency index	Apparent viscosity	pH	Flowability
Flow behaviour index	−0.248 ^{NS}					
Consistency index	0.841***	−0.353 ^{NS}				
Apparent viscosity	0.842***	−0.120 ^{NS}	0.941***			
pH	0.146 ^{NS}	−0.621**	0.111 ^{NS}	−0.005 ^{NS}		
Flowability	−0.262 ^{NS}	0.166 ^{NS}	−0.840***	−0.799***	−0.328 ^{NS}	
Pourability	−0.211 ^{NS}	0.175 ^{NS}	−0.810***	−0.766**	−0.336 ^{NS}	0.985***

*Significant at $p \leq 0.05$ **Significant at $p \leq 0.01$ ***Significant at $p \leq 0.001$ NS Non-significant at $p = 0.05$

commonly associated organism in curd or *dahi* is lactic acid bacteria; the strains of *Lactococcus lactis*, *L. cremoris*, *L. diacetylactis*, *L. delbrucecki*, *L. bulgaricus* and *Leuconostoc cremoris*, etc. had been reported.

The interaction of curd with time of fermentation offered a strong negative effect meaning that an increase in both these variables decreased the flowability and pourability of batter. Earlier, an increase in yield stress and apparent viscosity was reported by the present authors (Chakkaravarthi et al. 2009b) due to fermentation.

Inter-relations among the response functions The correlation matrix among the response functions is shown in Table 4. The response functions such as pH, flowability and pourability belonged to this present study while yield stress, flow behaviour index, consistency index and apparent viscosity were reported earlier by Chakkaravarthi et al. (2009b). The yield stress was highly correlated ($p \leq 0.001$)

to consistency index. Interestingly, the parameter pH appeared to be non-related with rheological parameters excepting that the flow behaviour index was negatively related with pH. It indicated that a decrease in pH of batter due to fermentation increased the flow behaviour index to shift the batter towards Newtonian characteristics. These results also indicated that a significant change in the chemical properties occurred due to production of low molecular weight compounds and soluble fractions like organic acids and sugars due to fermentation. The rheological parameters like apparent viscosity/consistency index were highly interrelated ($r > 0.77$) with flowability/pourability. It indicated that flowability and pourability decreased when there was an increase in consistency index or apparent viscosity. The flowability and pourability were highly inter-related ($r = 0.985$, $p \leq 0.001$) meaning that a batter having good pourability might also had a good flowability.

Table 5 Results of the optimisation study

Parameters			pH (Y ₁)	Flowability (Y ₂)	Pourability (Y ₃)
Roots of the auxiliary equation	λ_1	0.3049	0.0259	0.0632	
	λ_2	0.0545	0.0053	0.0122	
	λ_3	−0.0598	−0.0059	−0.0291	
Optimum conditions in coded level of variables	x_1	Minimisation	1.6702	−0.2795	−0.7416
		Maximisation	−0.4313	−1.6816	1.6802
	x_2	Minimisation	0.1029	0.9264	−0.7311
		Maximisation	0.6360	−1.2169	1.4553
	x_3	Minimisation	1.3384	0.7313	0.3795
		Maximisation	−1.6810	1.4465	−1.0706
Optimum conditions in actual level of variables	X_1 (%)	Minimisation	64.99	56.29	54.16
		Maximisation	55.55	50.00	65
	X_2 (%)	Minimisation	5.30	7.75	2.82
		Maximisation	6.88	1.39	9.32
	X_3 (h)	Minimisation	21.54	17.21	14.71
		Maximisation	0	22.31	4.37
	Optimum conditions of response function	Minimisation	3.1758	0.0001	0.0001
		Maximisation	4.853	0.0659	0.2429

X_1 , X_2 and X_3 are same as mentioned in Table 2

Optimisation The results of the optimisation study (Table 5) show that the roots of the auxiliary equation ($\lambda_1, \lambda_2, \lambda_3$) presented a situation of saddle point (i.e., mathematical optimisation did not produce results within the range of the experimental variables), and thus, canonical analysis was performed to obtain optimum conditions within the experimental zone. The minimization and maximization of the response functions (Table 5) showed that these conditions varied widely for different response functions. For example, a maximum pH of 4.9 could be attained with a batter of low moisture content of 55.6%, 6.9% of curd and at 0 time of fermentation. On the other hand, to obtain a minimum pH of 3.2, the levels of the variables were 65%, 5.3% and 21.5 h, respectively.

Conclusions

Two gadgets were developed to determine the rheology related parameters like flowability and pourability based on the principle of gravity flow in a simulated condition after defining these terms. Response surface experimental design consisting of moisture content, amount of added curd and time of fermentation was employed to know their effects on the response functions like pH, flowability and pourability of *jilebi* batter. An increase in moisture content improved the flowability and pourability of *jilebi* batters; the interaction of curd with time of fermentation offered a strong negative effect meaning that an increase in both these variables caused a decrease in the flowability and pourability of batter. Optimum conditions

in terms of minimum and maximum pH, flowability and pourability were computed. The response function pH appeared to be non-related with rheological parameters excepting that the flow behaviour index was negatively related to pH.

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