Evaluation of vacuum impregnation as a novel approach for soaking of fried *Gulabjamun* balls

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Abstract Vacuum impregnation of sugar syrup into sub-baric fried *Gulabjamun* was evaluated as a technological approach to prepare a product of most acceptable quality. Sugar syrup concentrations (40, 50 and 60 °Brix) in combination with process time (2, 4 and 6 min) were analyzed for their effect on product quality in terms of its overall acceptability, expansion ratio, hardness, juiciness and sugar content. The effect of the process conditions on the five listed responses during the vacuum impregnation process was evaluated using response surface methodology and modelled using a second order polynomial equation. The optimum combination was obtained as soaking in a syrup of 55 °Brix for 5 min and was experimentally validated for its real time adequacy. The experimental values of the quality parameters thus obtained were found to be in close agreement with the predicted values.

Keywords Vacuum impregnation · Sugar syrup · *Gulabjamun* · Quality · Optimization

Introduction

Soaking is a common unit operation in food processing wherein a product is steeped in a bath of solute(s), often at elevated temperatures for a specified duration, so that the solute/solution (often sugar or salt) diffuses into the core of the food product, imparting flavour to the product and also enhancing its shelf life. The soaking process is generally influenced by the process conditions including composition and concentration of the soaking syrup, process time and temperature and the influx of soaking solutes and moisture into the product influences its sensory acceptance in terms of its juiciness and expansion (Barat et al. 2002).

Vacuum impregnation (VI) is an emerging technique in which the soaking syrup or solution is non-destructively infused into the porous matrices of a product; the migration of solutes and moisture in the process is driven by the differential pressure assisting the concentration gradient. The process has demonstrated its potential in fruit and vegetable products, wherein the mass inflow of the syrup into the large porous matrix results in desirable texture and improved sensory profile of the product. Derossi et al. (2012) elaborated the process protocol for VI in two steps. An initial suction of the food product under partial vacuum pressure for an optimal duration draws out the liquids and gases from its interstices. This is followed by re-establishment of atmospheric pressure in the system and a simultaneous instant immersion in a desired liquid phase with dissolved solutes.

Fito et al. (1996) showed that vacuum impregnation is technique strictly dependent on the food characteristics both at macroscopic and microscopic levels. Porosity of biological tissue was reported as the most important parameter influencing the application of vacuum impregnation, as it influences the influx of the external solution.

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Radziejewska-Kubdzela et al. (2014) highlighted the various avenues of application of VI in food processing, including its application to lower the pH and water activity of a product, alter the thermal properties and improve the texture, colour, taste and aroma of the treated product. Zhao and Xie (2004) have summarized the technical aspects and application of this novel technique in processing of fruits and vegetables and also highlighted the problems arising during VI due to the tendency of fruits and vegetables to float in the solution due to its lower density.

Gulabjamun is a popular dairy sweet prepared by frying balls of a portioned dough prepared by blending and kneading desiccated milk solids (*khoa*), refined wheat flour and a suitable leavening agent (optional) in measured quantities of water; the fried balls are then immersed in a sweetening syrup at moderate temperatures for extended durations (> 3 h) to impart the characteristic succulence and sweetness to the product. Several studies have analyzed the various technological developments and process optimization during both frying and soaking of this popular delicacy (Kumar et al. 2006; Joshi et al. 2012; Chetana et al. 2004). However, analysis of sub-baric processing of *Gulabjamun* is sparsely reported in the public domain. A brief report on the changes in fat and moisture content of the product during vacuum impregnation has been cited in Sharanabasava et al. (2018). An attempt was made to evaluate the effect of vacuum impregnation of *Gulabjamun* with sugar syrup on its physico-chemical and sensory quality attributes and to determine the optimal combination of process parameters to obtain the most acceptable product using Response Surface Methodology.

Materials and methods

Preparation of *Gulabjamun* balls

Required quantities of milk for the experiments was drawn from the Experimental Dairy of ICAR-National Dairy Research Institute, Bengaluru, India. The milk was then standardized to 4.0% fat and 8.5% solids-not-fat (SNF) and heat desiccated (steam pressure: 196.13 kPa) to obtain *khoa* which was blended with 30% *Maida* and calculated quantities of potable water such that the moisture content of the prepared dough would be the ingredients were kneaded in a planetary mixer to obtain smooth dough (De 2003). The prepared dough was manually portioned to units of 10 g each and then rolled to balls (~ 25 mm diameter) for frying.

Sub-baric frying of *Gulabjamun*

The prepared *Gulabjamun* balls were processed in a sub-baric thermal processor (SBTP) that was designed and fabricated in-house (Kumar and Ravindra 2016), consisting of a parallel vacuum frying chamber and a vacuum soaking chamber. Based on preliminary studies conducted, frying at 118 °C for 5 min under a vacuum of 400 mmHg was selected for frying *Gulabjamun* for this study.

Sub-baric soaking of *Gulabjamun*

For sub-baric soaking of the fried *Gulabjamun* balls, the following process was standardized based on preliminary studies. Perforated trays containing the fried *Gulabjamun* balls were loaded in the soaking unit of the SBTP, filled sugar syrup of desired strength in its tank section at the bottom. The tray was held suspended in the headspace of the unit and vacuum (680 mmHg) was created by running the vacuum pump. After a lapse of 5 min, the tray was instantaneously lowered into the syrup bath by activating the automatic hoist system. Once the tray was immersed in the bath, the vacuum was immediately released and the balls were held immersed in the bath at 30 °C for a period of 5 min. The tray was then automatically hoisted and removed from the SBTP to withdraw the soaked product for further analysis.

Combinations of sugar syrup concentrations at 40, 50 and 60 °Brix and soaking times of 2, 4 and 6 min were evaluated in this study. Temperature was not considered as a parameter since preliminary investigations had established that with the vacuum impregnation technique, a product of acceptable quality could be obtained by immersion in sugar syrup at ambient temperature. This is in departure of the conventional practice, where the sugar syrup is held at elevated temperatures of 60–65 °C during soaking of *Gulabjamun* (Chetana et al. 2004).

Determination of textural properties

Joshi et al. (2012) had designated hardness as the most significant parameter to denote the texture of *Gulabjamun*. Textural profile analysis (TPA) was performed using TA.XT Plus Texture Analyzer (Stable Micro Systems, Texture Technologies Corp., Goldaming, UK) equipped with 50 kg load cell and the maximum the greatest force experienced by the food in the primary compression was recorded as the hardness of the sample.

Measurement of juiciness

The method proposed by Jauregui et al. (1981) with slight modifications was employed to estimate this parameter.

One whole *Gulabjamun* ball after soaking was placed in a graduated centrifuging tube (50 ml) and centrifuged at 5000 rpm for 5 min. The volume of supernatant sugar syrup that was expelled from the product was then measured and recorded as juiciness of the product.

Sensory evaluation of the product

The organoleptic quality of the *Gulabjamun* was evaluated by a panel of judges on a 9-point hedonic scale for its sensory parameters like, colour and appearance, flavour, body and texture and overall acceptability; wherein a score of 1 represented ‘dislike extremely’ and score of 9 represented ‘like extremely’.

Expansion ratio (ϵ)

The expansion ratio of the product was determined as the ratio of final cross sectional area (after soaking) to initial cross sectional area (before soaking).

Sucrose estimation by Seliwanoff's colorimetric method

The colorimetric method of Pantulu et al. (2014) reported for ice cream was followed to estimate the sugar content of the soaked product. A filtrate from the macerated sample of the soaked product was extracted with 40% lead acetate solution and incubated after the addition of 0.1% aqueous solution of resorcinol and acidification with concentrated (12 N) HCl. The colour developed was measured for absorbance at 490 nm and quantified with the help of a standard curve drawn using standard sucrose solution.

Experimental design and fitting of models

The coded values of independent variables are summarized in Table 1 and an experimental design based on face-centred central composite design consisting of 13 runs for 3 (X_1 – syrup concentration) $\times$ 3 (X_2 – soaking time) factors was applied to generate data for the optimization (Table 2) The data was optimized using RSM using the

software Design Expert ver. 7.0. (Stat-Ease, Inc., Minneapolis, USA). Five responses, namely, overall acceptability (sensory evaluation), expansion ratio, sugar content, hardness and juiciness for each combination of the process parameters were experimentally determined and the data is tabulated in Table 2. Second order polynomial equations were fitted to the responses in terms of the independent variables (Eq. 1) using regression analysis. The statistical significance of the terms was evaluated using the ANOVA function inbuilt in the software.

A quadratic model was used to describe the response variables

$$Y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_1^2 + \beta_4x_2^2 + \beta_5x_1x_2 \quad (1)$$

where ‘Y’ is the response, β_0 is the constant, β_1 , β_2 are linear coefficients, β_3 , β_4 are the squared coefficients, β_5 is interaction coefficient, x_1 is the syrup concentration and x_2 is the soaking time.

Statistical analysis

All experiments were carried out in triplicate and the experimental data was subjected to statistical analyses in terms of ANOVA using Microsoft Excel 2010 and SPSS (v. 15. 0).

Results and discussions

Effect of process parameters on the quality of the vacuum impregnated product

Overall acceptability (OA) of soaked *Gulabjamun*

Gulabjamun fried using the sub-baric process (118 °C, 5 min, 400 mmHg) and soaked in sugar syrup at different levels of concentration and soaking time (Table 2) reported an overall acceptability score ranging from 7.30 to 8.60 during its sensory evaluation. The panelists remarked on the enhanced juiciness, sweetness and cohesiveness of the product. The surface plot generated for this response in terms of the second order polynomial model fitted for the data of OA of *Gulabjamun* is shown in Fig. 1a. Concentration of sugar syrup, soaking time and the interaction effects of the two parameters significantly affected the OA of *Gulabjamun* ($p < 0.05$). In general, it was observed that OA increased with increasing soaking time. However, soaking in 60 °Brix sugar syrup for extended period resulted in poorer OA scores with the remarks from the panellists that the product was too sweet. Chetana et al. (2004) also indicated a poorer acceptability for samples soaked in syrups of concentration > 60 °Brix, with the acceptability peaking for syrup concentration between 50

Table 1 Coded and actual levels of process variables

Parameters	Coded levels		
	– 1	0	+ 1
X_1 Syrup concentration (°Brix)	40	50	60
X_2 Soaking time (min)	2	4	6

Table 2 Experimental design and data for the response surface analysis (face-centered central composite design)

Run	Factors		Responses				
	Sugar conc. (X ₁) (°C)	Soaking time (X ₂) (min)	OA (Y ₁)	Expansion ratio (Y ₂)	Sugar content (%) (Y ₃)	Hardness (Y ₄) (N)	Juiciness (ml) (Y ₅)
1	50 (0)	4 (0)	8.40	1.28	49.91	3.50	2.25
2	50 (0)	6 (+ 1)	8.50	1.30	54.28	3.21	2.50
3	50 (0)	2 (− 1)	7.30	1.10	46.10	3.23	2.25
4	60 (+ 1)	4 (0)	8.30	1.19	61.82	4.20	2.50
5	60 (+ 1)	2 (− 1)	7.40	1.12	57.2	4.33	1.75
6	50 (0)	4 (0)	8.25	1.21	50.12	3.55	2.40
7	40 (− 1)	4 (0)	7.85	1.23	42.42	2.79	3.50
8	50 (0)	4 (0)	8.35	1.22	51.22	3.75	2.30
9	50 (0)	4 (0)	8.60	1.29	50.45	3.50	2.25
10	50 (0)	4 (0)	8.30	1.25	51.85	3.42	2.10
11	40 (− 1)	2 (− 1)	7.52	1.14	39.47	2.80	3.25
12	40 (− 1)	6 (+ 1)	7.80	1.22	45.03	2.62	3.75
13	60 (+ 1)	6 (+ 1)	8.25	1.26	65.45	3.24	2.75

Values within the bracket indicates the coded values

and 60 °Brix. However, in their case, the poor score was attributed to higher viscosity of syrup leading to poor penetration to the core of the product, thus adversely affecting the sweetness and texture of the product. In this study, the hydrodynamic force on account of the pressure differential during the sub-baric impregnation process ensured adequate penetration of the syrup, hence, there was no subjective differentiation in terms of textural characteristics. However the sample was deemed too sweet by the panelists at higher concentration of the syrup.

Expansion ratio (ER) of soaked Gulabjamun

An increase in volume to the tune of 10–30% was recorded for all the combinations of process conditions evaluated. Joshi et al. (2012) have elucidated the influence of volume expansion on the body and texture of conventionally soaked *Gulabjamun* and reported an expansion of nearly 40% for the acceptable product. It was observed that expansion ratio of product increased with increase in soaking time and decreased with increase in sugar concentration (Fig. 1b). Both the process parameters i.e. concentration of the sugar syrup and soaking time exerted a linear effect on the expansion ratio of *Gulabjamun* during sub-baric soaking. Statistical analysis using ANOVA indicated while the soaking time exerted significant influence on this response, it was not affected significantly by the syrup concentration ($p < 0.05$). The quadratic and interactive effect of the independent variables was also insignificant for this response.

Sugar content (SC) of soaked Gulabjamun

The sugar content of sub-baric soaked *Gulabjamun* estimated by Seliwanoff's method varied between 39.47 and 65.45% (Table 2). The sugar content of the soaked product has a significant influence on the sensory profile of the product on account of two influences, namely, the sweetness it imparts to the final product as well due to its effect on the product texture, primarily its hardness (Joshi et al. 2012; Chetana et al. 2004). Both of the main factors i.e., concentration of the sugar syrup and soaking time had profound effect on the sugar content of the soaked *Gulabjamun* (Fig. 1c). The quadratic and interactive effects were also observed to be significant in their influence on this response. The faster influx of the sugar syrup into the product could be on account of the hydrodynamic mechanism of vacuum impregnation as discussed by Derossi et al. (2012).

Hardness (HA) of soaked Gulabjamun

Hardness of the soaked product was observed to increase with increasing syrup concentration (attributed to the increased solids content due to influx of sugar) and decrease with increase in soaking time (due to the increased moisture uptake) (Fig. 1d). Rao et al. (2002) and Chetana et al. (2004) have reported on the increased hardness of *Gulabjamun* immersed in higher concentration syrups. Both the main factors, in isolation and interaction, had significant effect on the hardness of the product during

Fig. 1 Response surface plots for the effect of process parameters on the quality of the vacuum impregnated product **(a)** on the OA of *Gulabjamun*, **(b)** on the expansion ratio (ER) of *Gulabjamun*, **(c)** On the

sugar content of *Gulabjamun*, **(d)** On the hardness of *Gulabjamun*, **(e)** on the juiciness of *Gulabjamun*)

soaking ($p < 0.05$). Statistical analysis deduced that between the two main factors, sugar syrup concentration was the more significant factor affecting hardness in the product.

Juiciness (*J*) of soaked *Gulabjamun*

The juiciness varied inversely with increasing sugar syrup concentration; juiciness was highest when soaked in 40 °Brix due to more absorption of syrup (Table 2). The

effect of sugar syrup concentration and soaking time on the juiciness of *Gulabjamun* was found to be significant ($p < 0.05$). ANOVA also revealed that the quadratic effect for syrup concentration and the interactive effect of the main factors also had significant influence on the juiciness of the soaked product. However, among two main factors in isolation, syrup concentration had a more profound effect on juiciness. The effect of composition of soaking syrup on the juiciness and overall acceptability of *Gulabjamun* was also discussed by Kushwaha et al. (2017).

Increased juiciness in sub-baric fried and soaked products has been attributed to the enhanced porosity of the fried product (Fito et al. 1996) and also the faster influx of the sugar syrup due to the hydrodynamic mechanism of vacuum impregnation as discussed by Derossi et al. (2012). A significant increase in yield and enhanced influx of the solute during vacuum impregnation was reported for pineapple candy (Barat et al. 2002) and salted Minas cheese (Luciana et al. 2005).

Optimization of sugar syrup concentration and soaking time

In this study, sugar syrup concentration and soaking time conditions were optimized based on maximizing overall acceptability and expansion ratio of the product. The desired goals for each factor and the individual responses were chosen based on a judicious understanding of the requirement of the best quality attributes of the soaked product. Different weights were assigned to each goal to adjust the desirability function. The software was run to obtain the optimum conditions and solutions and the optimized solution having the maximum desirability value i.e. sub-baric soaking of *Gulabjamun* in sugar syrup of concentration of 55 °Brix for a soaking time of 5 min was selected.

The conventional process for the preparation of *Gulabjamun* has been widely reported and the recommended process conditions for soaking of the fried *Gulabjamun* balls are in a sugar syrup of 50–62.4 °Brix at 60–80 °C for 2–6 h (Ghosh et al. 1984; Rangi et al. 1985; Rajorhia and Pal 1989). In contrast, the optimised process conditions in this study using sub-baric impregnation of sugar syrup into the fried *Gulabjamun* balls under ambient temperature for a much lesser duration of 5 min, offer significant advantages to the Dairy Industry in increasing the process throughput. The reduced process time also provides an opportunity to economize the process dynamics by continuous mode of product manufacture.

Validation of optimized sub-baric soaking conditions

To validate the obtained optimized process conditions, experiments were conducted at the derived optimum sub-baric soaking conditions (55 °Brix for 5 min) and the product was evaluated for its overall acceptability, expansion ratio, sugar content hardness and juiciness. The experimental values (mean of three measurements), as well as the predicted values of various the quality attributes were compared and found have a good fit. For all the responses, *t* test was used to calculate the significance difference between predicted and actual response values at

5% level of significance and no significant difference was observed.

Conclusion

Vacuum impregnation of fried *Gulabjamun* balls was evaluated as a novel approach for soaking of the product under different combination of process conditions, namely syrup concentration 40–60 °Brix and process time ranging from 2 to 6 min. The study demonstrated a drastic reduction in the process time, from at least 3 h under conventional processing (as reported in literature) to 5 min required for vacuum impregnation process. The other advantage of the process is the elimination of heating of the sugar syrup as the process was satisfactorily carried out with syrup at ambient temperature. Response surface methodology was employed to model the effects of the process parameters on the quality attributes of the soaked product and an optimal combination of 55 °Brix and 5 min was found to give the most acceptable product.

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