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Optimization of Different Process Variables on Structural and Quality Attributes for the Development of Vacuum Fried Gulab Jamun

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ABSTRACT

Background: Gulab jamun is a delicious dairy food items popular not only the Indian subcontinent but also in all over the world. Now a days, people are health conscious towards the healthy diet having low in fat content. However, Vacuum frying (VF) is one of the best technologies which produce high quality food items having low fat content and better appearance with respect to atmospheric frying (AF).

Methods: For the preparation of gulab jamun, the dough balls were fried under the VF (oil temperature: 125, 135, 145°C, vacuum pressure: 15, 20, 25 cm Hg and time: 8, 10, 12 min) and AF (temperature: 160°C, time: 4 min) conditions. The prepared gulab jamun was compared with different parameters such as moisture content, oil content, color, volume expansion, texture and structure.

Result: The optimized gulab jamun was obtained using response surface methodology at temperature 137.82°C, pressure 25 cm Hg and time 9.38 min. The product had less in oil content, intense in color, smooth and soft texture (texture analyzer) and porous in structure (X-ray micro-CT scan) as compared to atmospheric fried gulab jamun.

Key words: Color, Gulab jamun, Structure, Texture, Vacuum frying.

INTRODUCTION

Gulab jamun is a popular Indian traditional dairy sweet, which is characterized with a brown crust with slightly soft, spongy and uniform granular texture. Apart from India, it is popular not only in Asian continent (Pakistan, Nepal and Bangladesh) but also popular throughout the world (South Africa, Fiji and Jamaica). It contains ingredients as chhena, khoa, refined wheat flour, sugar, refined oil, baking powder and water. These ingredients are molded into smooth spherical dough balls fried in oil and finally dipped into the sugar syrup solution. In the preparation of gulab jamun, frying is one of the important steps, where the food materials are dipped into high-temperature oil for a certain duration and heat and mass transfer occur between the oil and the food material (Sreeraj *et al*., 2020). Frying is a complex operation representing a process that involves several physical and chemical changes, which include starch gelatinization, protein denaturation, water vaporization and crust formation (Pedreschi, 2012). Conventional atmospheric deep fat frying is carried out at a high temperature in the range of 160-200°C (Oyedeji *et al*., 2017). The interaction of food and oil with oxygen at high temperatures leads to the formation of toxic compounds, surface darkening and loss in the nutritional quality of fried products (Hosseini *et al*., 2016). Alternate to conventional frying process, low-pressure frying is defined as the novel frying process which is carried out under pressure well below the atmospheric level, probably below the 6.65 kPa or 50 torrs. Thus, the boiling point of water is reduced in the product. When the temperature of oil reaches the boiling point temperature of water, the water contained in the food is quickly evaporated, resulting in less processing time (Song *et al*., 2007). Moreover, processing at low pressure and temperatures (90 to 140°C) reduces the deterioration and oxidation of frying oil as well as lower oil content penetrating into the product with excellent shelf-life stability (Fan *et al*., 2005). The oil absorption is a surface phenomenon that occurs when the product is removed from the fryer. It happens mainly due to difference in temperature between the product and air temperature during the cooling stages (Moreira *et al*., 1997). During this period, the capillary pressure and surface tension are increased inside the product pores that causes the oil to flow.

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However, some comparative studies between AF and VF have been carried out by various researchers on different food materials like papaya chips and potato slices (Wexler *et al*., 2016; Troncoso *et al*., 2009). As per our knowledge, limited published information is available regarding the effect of low pressure, temperature and time on the quality attributes for the preparation of vacuum fried gulab jamun. Therefore, the present study of our research work was designed to investigate the effects of low pressure frying on the quality attributes and pore structural changes of low pressure fried gulab jamun.

MATERIALS AND METHODS

The research work was carried out in the Department of Agricultural and Food Engineering, IIT Kharagpur in the year of 2020. All the ingredients were procured from Tech market, IIT Kharagpur.

Sample preparation

Gulab jamun dough was prepared by blending a mixture of chhena (40.57%), maida (16.23%), sugar (8.69%), baking powder (0.035%), khoa (28.98%) and refined oil (5.51%). All ingredients were manually mixed for 4-5 min to obtain dough with a smooth and soft texture. The dough's moisture content was maintained in the range of 30±2% (w.b.). The dough was then fragmented into 10 g small dough and rolled in between the hands to make spherical balls (diameter~24.50-25.00 mm). It was made sure that there were no cracks present on the balls' surface during the rolling process. After that, the dough balls were covered by a lid to protect against moisture loss.

Vacuum frying

Vacuum installation system consisted of an aluminum alloy pressure cooker (5L, Prestige Pressure Cooker, TTK Prestige Ltd., India), thermocouples (K-type), a vacuum gauge, a suction valve, a relief valve and a lifting basket with wire mesh (Fig 1). Low-pressure frying was performed at temperatures 125, 135 and 145°C and pressures 15, 20 and 25 cm Hg. The pressure cooker was filled with oil and preheated to the target temperature by an electric heater. A voltage controller controlled the oil temperature during frying. The dough balls were kept in a frying basket that initially remained in the cooker's headspace. Then, the lid was closed and the chamber was depressurized to the required level using a vacuum pump. The frying basket was immersed in the oil bath, where it remained for the required duration. After frying, the fried balls were taken out of the frying medium and held up in the cooker headspace for few minutes. Finally, the fried balls were collected and kept in zipper bags for further analysis. Consequently, AF was carried out at 160°C for 4 min. All the properties of fat frying were analyzed and compared to better insight into the effects of VF.

Quality attributes of gulab jamun

Moisture and oil content

The moisture and oil content of fried gulab jamun was determined according to AACC (1983).

Color measurement

The surface color of the gulab jamun balls was measured using a Chroma-meter (CR-400, KONICA MINOLTA, Japan).

Expansion in volume (EV)

EV (%) of vacuum fried product was compared with atmospheric fried, which is calculated using Eq. 1.

$$EV = \frac{\left(\frac{\pi}{6d^3}\right)_{VF} - \left(\frac{\pi}{6d^3}\right)_{AF}}{\left(\frac{\pi}{6d^3}\right)_{AF}} \times 100 \quad (1)$$

Where 'd' is the diameter of the fried gulab jamun.

Texture analysis

Texture analysis was performed using a texture analyzer (TA-XT2i, Stable Micro Systems, UK). A direct force was applied to the fried ball using a cylindrical probe of 10 mm diameter. Fried gulab jamun balls were subjected to double-cycle compression-decompression tests to a penetration depth of 8 mm. All experiment was performed at pre-test

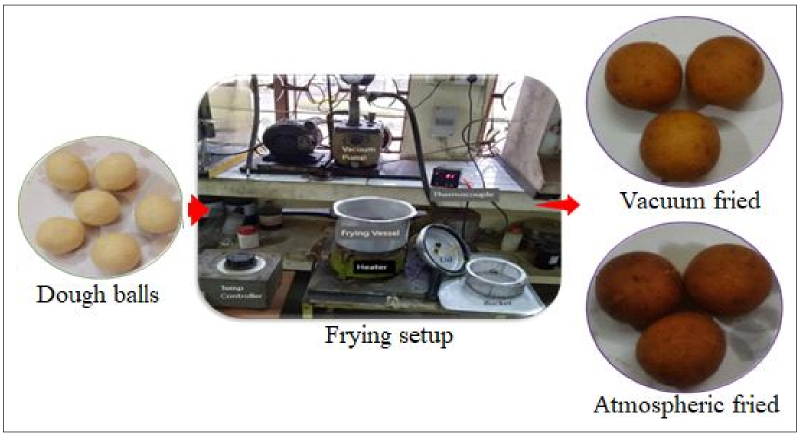


Fig 1: Schematic diagram of vacuum frying.

speed of the probe before compression-10 mm/s, test speed during compression-0.5 mm/s and post-test speed-0.5 mm/s. Data were analyzed using Texture Expert Exceed Software supplied along with the instrument.

Structural properties of optimized gulab jamun

The specimens were tested for porosity, density, the volume of isolated pores, interconnected pores and crust thickness using an X-ray micro-CT (Phoenix V|tome|x M, Waygate Technologies, Germany) (Lykomitros *et al*., 2018). The 3D inner morphology was analyzed using a peak energy level of 100 kV and a constant current of 80 µA was used where each specimen was placed on the stage and fixed to the rotating assembly. Samples were scanned at a special revolution of 22.1 µm to produce 188 serial cross-sections 990/1000-pixel images.

Experimental design and optimization

Numerical optimization for process parameters of vacuum fried gulab jamun was performed to achieve desired properties of the final product using Design-Expert software (StatEase, Minneapolis, USA). Experimental design was selected based on a central composite randomized design (CCRD). The range and center point values of three independent variables *i.e.*, frying temperature, vacuum pressure and frying time (Table 1).

RESULTS AND DISCUSSION

Moisture content

Frying led to a drastic reduction in the initial MC (30%, w.b.) of the gulab jamun ball. However, as expected, the highest reduction in MC (9.934%, w.b.) was observed for gulab jamun fried at higher temperature (145°C), lowest vacuum pressure (25 cm Hg) and 12 min frying. Interestingly, in the absence of vacuum, MC (26.96%, w.b.) of gulab jamun fried in the atmosphere at 160°C temperature for 4 min was surprisingly higher. The reduction in MC for vacuum fried samples even without much oil heating was due to a decrease in the boiling point of water with a decrease in pressure during low-pressure frying (Esan *et al*., 2015). The reduction in boiling point causes unbound water to vaporize easily when oil temperature reaches the boiling point of water (Shyu *et al*., 2005).

Oil content (OC)

The effect of vacuum pressure on oil content was infinitesimal as compared to temperature. On the other hand, the OC of the fried product decreased with an increase in the frying temperature. Garayo and Moreira (2002) have reported that the pressurization step after low-pressure frying can increase and decrease oil absorption capacity in the product depending on the free water and amount of surface oil present in the fried product. It was also observed that OC was considerably increased with an increase in frying time, possibly due to an increase in the opportunity time after removing moisture at higher temperatures (Shyu and Hwang, 2001). The minimum OC was found 20.17% when the oil temperature reached 145°C and 15 cm Hg after 8 min of frying. On the other hand, the oil uptake of atmospheric fried (160°C, 4 min) gulab jamun was observed to be 32.46%. Therefore, the vacuum fried product had lower oil absorption than the AF due to faster development of surface crust at higher temperature frying, which provided a favorable condition for oil absorption (Baumann and Escher, 1995). Moreover, low temperature frying also increased the viscosity of oil, which further resists the oil from pushing into the product due to lower mobility.

Color

The L^* value decreased as the frying time and temperature increased, which suggested that the product was darker. On the other hand, a^* value increased with an increase in oil temperature from 125 to 145°C after 8 to 10 min of frying. In contrast, the b^* value decreased with the increase in temperature. In the case of AF, L^* (28.50) and a^* (17.98) values were only comparable with balls fried at 145°C for more than 10 min in a vacuum. Moreover, b^* (4.34) of atmospheric fried balls was also very low compared to all vacuum fried balls. These results were also confirmed by total color difference values (16.04-19.98), which were found minimum only in the case of low-pressure frying at 145°C. The darker color of atmospheric fried balls might be due to a more intense Maillard reaction occurring in the presence of air (Kumar *et al*., 2006).

Expansion in volume after frying

All vacuum fried sample had shown greater volume expansion compared to volume expansion of atmospheric

Table 1: Experimental combinations of frying temperature, pressure and time for gulab jamun making.

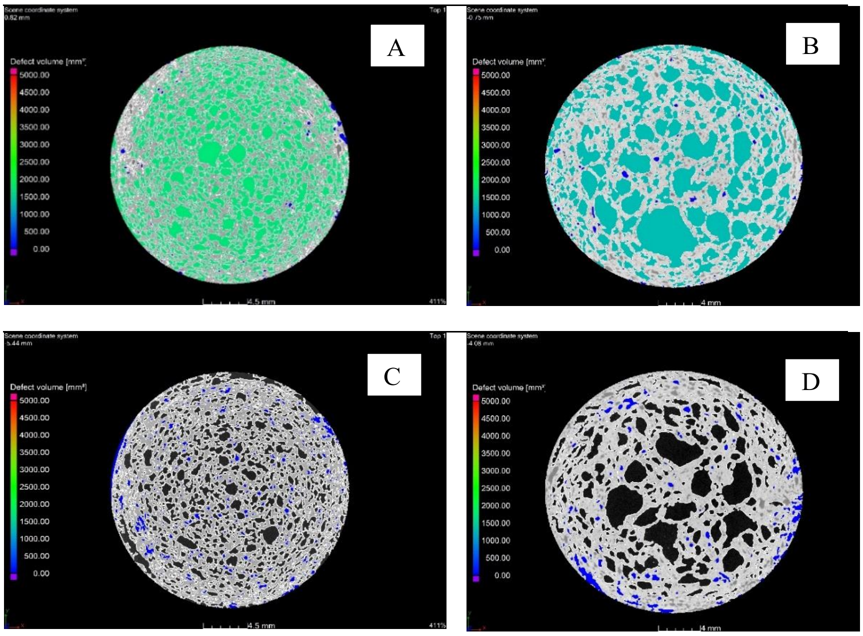
Exp. no.	Frying temperature (°C)	Vacuum pressure(cm Hg)	Frying time (min)
1	125	15	8
2	145	15	8
3	125	25	8
4	145	25	8
5	125	15	12
6	145	15	12
7	125	25	12
8	145	25	12
9	125	20	10
10	145	20	10
11	135	15	10
12	135	25	10
13	135	20	8
14	135	20	12
15	135	20	10
16	135	20	10
17	135	20	10
18	135	20	10
19	135	20	10
20	135	20	10

fried sample. The increase in volume expansion due to low-pressure frying varied from 20.6% to 75.1%. In case of AF, sudden removal of moisture at higher temperatures led to shrinkage of overall shape. This permanent shrinkage of balls also resulted in harder texture, smaller pores and damaged capillaries, which increase the sugar syrup absorption in gulab jamun. On the other hand, the expansion in volume after VF was probably due to gaseous vapor pressure exerted in the radial direction, causing the development in pressure inside the product and formation of surface crust (Yamsaengsung *et al*., 2011). However, the maximum percentage expansion was observed for samples fried at a comparatively lower temperature (125 and 135°C) at greater vacuum pressure (20 and 25 cm Hg).

Texture

The hardness, chewiness and gumminess were significantly decreased as the frying temperature and time increased.

Table 2: Optimized process condition for VF and AF of gulab jamun.

Parameters	Goal	Optimized value (VF)	AF
Temperature (°C)	Is in range	137.82	160
Pressure (cm Hg)	Is in range	25	76
Time (min)	Is in range	9.38	4
Oil content (%)	Minimize	25.69	32.46
MC (%)	Minimize	14.52	26.96
Color (	Is in range	47.15	28.50
Color (	Is in range	20.35	17.98
Color (	Maximize	43.18	4.34
	Desirability	0.77	-
Other properties of optimized gulab jamun			
TCD		43.59	-
EV (%)		71.53	-
Hardness (N)		7.937	12.975
Chewiness (N)		3.128	6.997
Springiness		1.106	0.872
Porosity (%)		43.61	45.88
CP (%)		40.98	44.92
IP (%)		2.63	0.96
Pores Distribution			

(MC: Moisture Content; TCD: Total Color Difference; EV: Expansion in volume as compared to atmospheric fried sample; CP: Connected Pores; IP: Isolated Pores). Pore size distribution of gulab jamun (A) Pore size distribution of vacuum fried gulab jamun (B) Pore size distribution of atmospheric fried gulab jamun (c) Isolated pore distribution of vacuum fried gulab jamun (D) Isolated pore distribution of atmospheric fried gulab jamun.

These changes occurred due to moisture loss, protein denaturation and starch gelatinization (Garcia Vela and Stanley, 1989). Hardness value of the fried sample showed a decreasing trend with increasing vacuum pressure (Oginni *et al*., 2015). Also, it should be noted that the lowest hardness value was observed at 125°C, 25 cm Hg for 8 min of frying. On the other hand, AF produced the product crispier or hard than the low-pressure frying product. Thus, the oil temperature and vacuum pressure are directly related to gulab jamun texture. A lower temperature of the oil and higher vacuum level defined a product with less compactness, firmness and greater springiness. Similar findings have been reported for the frying of donuts by Tan and Mittal (2006).

Optimization

The optimized conditions for corresponding responses were generated from the Design-Expert Software, as reported in Table 2. The selected conditions for the best-optimized processing parameters were obtained for the oil temperature of 137.82°C, the pressure of 25 cm Hg and the time of 9.38 min.

Pore structure

The pore size distribution of vacuum and atmospheric gulab jamun were shown in Table 2. The percentage of porosity values of AF and VF gulab jamun were 45.88% and 43.61%, respectively. However, the size of the pores was seen different. As can be seen, atmospheric fried samples showed the largest proportion of small pores and absorbed the highest amount of oil. The AF sample showed a lower isolated pore percentage (0.96%) compared to VF (2.63%) sample. The atmospheric fried have more interconnected pores than the vacuum fried gulab jamun.

CONCLUSION

The final oil content at constant pressure is a function of temperature, time and remaining moisture. OC of the fried product decreased with an increase in the frying temperature due to free water and the amount of surface oil present in the fried product. The minimum oil content was obtained as 20.17% when the highest oil temperature at 145°C and the lowest vacuum pressure of 15 cm Hg for 8 min of frying, whereas the oil content in AF was observed to be 32.46%. At 160°C for 4 min of frying. AF produced gulab jamun that was darker than low-pressure frying product (lower L_* values). These results were also confirmed by total color difference values (16.04-19.98), which were found minimum only in the case of low-pressure frying at 145°C. The gulab jamun fried under vacuum pressure had higher expansion in volume (%), were softer than gulab jamun fried under atmospheric conditions. The porosity of VF sample was found to slightly lower, but its pore size was different as compared to AF. The best-optimized process conditions for vacuum fried product were obtained at 137.82°C, 25 cm Hg for 9.38 min of frying.

Conflict of interest: None.

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