Jilebi 3: Effect of frying conditions on physical characteristics

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Abstract The process of *jilebi* making includes the frying of specially shaped batter strands to obtain a crisp texture followed by absorption of sugar syrup. The effects of frying temperature (150–180 °C) and time (15–300 s) on the physical characteristics have been investigated; these are moisture and fat contents, density, colour, textural attributes and microstructure. Among the textural parameters obtained by shearing the *jilebi* strands, shear failure force and the number of minor fractures increase markedly with an increase in time of frying. The brightness of the sample is lower when fried at higher temperatures like 180 °C compared to that of 150 °C; the hue or dominant wavelength of batter prior to frying is 578.0 nm, and after frying, it is between 564.8 and 591.3 nm indicating an overall shift towards yellow colouration during frying. The density of the *jilebi* strands decreases along with moisture content, while fat content increases gradually with an increase in frying time. The microstructure and image analysis of the fried products indicate the creation of porous structure consisting of several pores that are separated by thin cell walls of thickness between 10 and 15 µm. The eccentricity of pores/vacuoles in *jilebi* is between 0 and 0.92 indicating a close resemblance to elliptical shapes. The samples fried at 160 °C for 180–240 s have been judged as the best sample both as fried and fried-sugar syrup soaked products.

Keywords *Jilebi* · Frying · Colour · Texture · Microstructure · Imaging

Introduction

The popularity of *jilebi* can be described due to its attractive shape, crisp texture and juicy mouth feel. The product, popular throughout the Indian subcontinent, is prepared from refined wheat flour (*maida*) that involves the process of batter preparation, fermentation, creation of typically shaped batter strands, deep-fat frying in oil followed by soaking in sugar syrup (Chitale 2000; Berry 1992; Rati Rao et al. 2006; Chakkaravarthi et al. 2009a). The general characteristics of *jilebi* have been reported by Chakkaravarthi et al. (2009a). Rati Rao et al. (2006) have mentioned about the raw materials used for *jilebi* preparation and the fermentation process of batter. The role of fermentation conditions on the rheological status of the fermented batter (Chakkaravarthi et al. 2009b), and the measurements of pourability and flowability of batter (Chakkaravarthi et al. 2011) have been reported. It is felt that the details of *jilebi* preparation process need to be investigated in order to understand the processing steps, process optimisation, quality control of finished product, scale-up studies and for the design of machines for large-scale production.

Frying is an integral part of *jilebi* preparation. It is obvious that under-fried *jilebi* offers a raw taste along with soggy texture while an over-fried product is associated with a crisp texture but lacks attractive appearance and juicy mouth feel. The appearance, particularly the colour of the strand is a critical attribute that directly affects the consumer preference. Similarly, the textural attributes are equally important as a crisp product is preferred by consumers. As texture is likely to be affected by micro-

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structure, scope exists to monitor the structural changes that can happen during frying. Structure of food has been related to quality change experienced during food processing such as drying and deep-fat-frying, especially at the microscopic scale (Adedeji and Ngadi 2010; Mellema 2003; Donald 2004; Aguilera 2005). There has been renewed interest in studying microstructural properties of food such as porosity and pore size distribution primarily because of their importance in defining the food quality and for better understanding of the transport properties of foods that leads to the production of porous foods or food having low density. However, published data on frying characteristics of *jilebi* are not available.

Simultaneous heat and mass transfer occurs in a short span of time during frying; deep-fat or immersion frying results in countered flow of water vapour (bubbles) and oil at the surface of the food, and physico-chemical alterations of major food components. Important factors that affect the process of frying and attributes of the fried product are the physical properties (size, shape, density and surface area), composition of product particularly the initial solid content, properties of frying oil (oil type and its aging), and various frying parameters like temperature of oil, time of frying and the post-frying conditions (Ziaifar et al. 2008). However, the mechanism of oil uptake by fried batters is still a poorly understood subject, and only a little is reported in the literature concerning the criteria for oil reduction in batter fried products (Shih and Daigle 1999; Bhat and Bhattacharya 2001). Nevertheless, batter materials and their interactions during frying are believed to play an important role in determining the uptake of oil and the quality of the fried product.

A detailed investigation on the process of batter frying is expected to improve our understanding on *jilebi* and to predict a suitable condition for conducting the frying operation. Hence, scope exists to study the changes in *jilebi* batter/strands with particular reference to quality attributes like appearance/colour and texture. It is also interesting to note that a liquid-like batter material attains a hard solid-like texture during frying of traditional foods like *boondi* (Bhat and Bhattacharya 2001) and *jilebi* (Chakkaravarthi et al. 2009a) though the aspects of frying of batter alone is a less investigated topic.

The objectives of the present study are (a) to study the effect of frying temperature and time on physical properties like density, moisture and fat contents, colour and textural attributes, and (b) microstructure and imaging characteristics, and sensory attributes during frying of *jilebi* strands.

Materials and methods

Materials Refined wheat flour (*maida*) and refined sunflower oil were procured from a local super market, while

curd was procured from a local dairy (Chakkaravarthi et al. 2011). *Jilebi* batter was prepared as mentioned earlier by Chakkaravarthi et al. (2009b).

Frying The frying trials were conducted at different temperatures of 150, 160, 170 and 180 °C, and the samples were withdrawn at regular intervals of 15–30s. Temperature was recorded by employing a digital thermometer inserted into the hot oil, and the temperature of oil was controlled upto a deviation of ± 2 °C by circulation of oil. Three trials were conducted using a locally made shallow flat-bottom type batch frying pan, frequently used for frying of *jilebi*. The ratio of sample to oil was maintained at 1:10. At the end of specified frying times, samples were taken out of hot oil followed by immediate cooling, packing and sealing in dark polyethylene pouches. The moisture and fat contents were determined by following the AOAC (2005) methods in triplicates.

Colour A colourimeter (Model # LABSCAN XE, Hunter Associate Laboratory, Virginia, USA) was employed to measure the colour of raw and fried samples; the illuminant employed was D₆₅, meaning average daylight having a colour temperature of 6500°K and the standard observer of 10° over the visible range of 400–700 nm. The tristimulus data in terms of X, Y and Z were converted to CIE parameters of Y (brightness), and xy values (chromaticity coordinates) as per the CIE method (Hutchings 1994) to obtain later the dominant wavelength or hue, and chroma or purity employing the chromaticity plot of x versus y; brightness was reported as Y%. Four replicates were carried out for all determinations, and reported as arithmetic mean and standard deviation (SD).

Density The diameters of the strands were measured at 5 locations of 10 strands each using a vernier calliper with a least count of 0.02 mm. *Jilebi* strands of known length were weighed to obtain the density of samples.

Texture A texture measuring instrument (Model TAHD, Stable Microsystems, Surrey, UK) was used to measure the texture of *jilebi* strands by employing the principle of shearing using a Warner-Bratzler attachment. A load cell of 50 kg and the crosshead of 1 mm/s were employed for complete shearing of individual *jilebi* strands. The force-deformation data, obtained from the shearing experiment, were analysed to determine failure force and the number of fractures. The failure force is the force at which an individual strand gets completely sheared into two pieces. The number of fractures was noted by counting the number of occasions when force drops by ≥ 0.1 N during shearing (Ravi et al. 2007). The number of samples tested each time was 10 and the values are reported as mean $\pm$ standard deviation (SD).

Fig. 1 Effect of temperature and time of frying on physico-chemical quality of *Jilebi* strands during frying at different temperatures ($n=3$)

Sensory assessment A panel consisting of 10 judges evaluated the *jilebis* after frying, that had been fried for different times between 60 and 240 s. Further the fried-sugar syrup soaked *jilebis* were also evaluated by the

same panel of judges. The specific sensory attributes that were evaluated were appearance, texture and the extent of juicy mouth feel; the latter attribute was evaluated only for fried-sugar syrup soaked *jilebis*. A nine-point scale was

used for evaluation where 5 is the limit of acceptance, and 1 and 9 denoted for dislike extremely and like extremely, respectively. The results reported here are the mean±standard deviations (SD).

Microstructure and image analysis The samples were dried by using the increasing concentration of ethyl alcohol followed by mounting on aluminium stubs with conductive adhesive, and finally coating with gold employing a sputter coater. They were viewed at a low (50, 200 and 500×) or at a moderate magnification of 2000×. The representative photomicrographs at different frying times were obtained. All examinations were made at an accelerating voltage of 15 kV using a scanning electron microscope (Model 435 VP, Leo Electron Microscopy, Cambridge, UK). Imaging in terms of size and shape were performed by an imaging software that was developed. The software program had the specific features of calculating area, shape and size of cells, and thickness of cell wall (Russ 2005). The software served the purpose of clearly detecting the edges between the cells.

The eccentricity (e) of an ellipse-shaped microstructural body was expressed (Eq. 1) by considering the lengths of semi-major (a) and semi-minor (b) axes. The eccentricity values indicate the deviations from an ideal circle.

$$e = \left(\frac{a^2 - b^2}{a^2} \right)^{0.5} \quad (1)$$

The typical range for eccentricity is $0 \leq e \leq 1$ where a low e value indicates the closeness to a circle. A high value of e , close to 1, means the prominence of an elliptical shape wherein magnitudes of a and b are wide apart. The cross-sectional area of an ellipse-shaped microstructural object was approximated by Eq. (2) by considering the cross-sectional area of a circle. These theoretical aspects have been employed during the imaging of the *jilebi* strands.

$$\text{Area} = \pi a b \quad (2)$$

Statistics The response functions were approximated by a second degree polynomial with linear, quadratic and interaction terms using the method of least squares (Little and Hills 1978). The coefficients of the polynomials in the actual level of variables were used to generate 3-D response surface plots to aid in visualisation of the effects of frying time and temperature. The extent of suitability of these polynomials was reported in terms of multiple correlation coefficients (R) and the significance of R values was examined at a probability (p) of 0.01.

Results and discussion

Moisture and fat contents The frying trials of the *jilebi* strands have been conducted at different temperatures (150,

Fig. 2 Photomicrograph of *jilebi* batter prior to frying

160, 170 and 180 °C) and times (upto 300 s). As expected, moisture content decreases as the frying process progresses (Fig. 1) exhibiting a sharp decrease at the beginning of frying while flattens off at the later stage. The moisture content curve at the highest temperature of 180 °C is distinctly placed in the lowest position meaning highest rate of moisture loss. The fat content of the sample shows a steeper rise at temperatures of 170 and 180 °C compared to slower rate of absorption for 150 and 160 °C samples. However, these two latter samples are not significantly different in their fat content ($p \leq 0.05$). The moisture and fat content graphs are not exactly complementary to each other though shows an overall inverse trend.

It is obvious that frying is a simultaneous process of heat and mass transfer. High moisture containing sample like *jilebi* batter has to release a significant amount of moisture to create a pressurised zone inside the strand. The loss of moisture allows the oil to enter and fill the pores/voids created in the strand. A longer time allows more oil to enter possibly by the process of diffusion and capillary flow; the latter mechanism is expected to dominate over the former process because capillaries or tunnels are created during the latter phase of frying of *jilebi* batter strands; these capillaries or tunnels are visible in their microstructure. Gelatinisation of starch occurs (Llorca et al. 2007) at the outer surface at the beginning of frying process but an increase in temperature of sample creates vacuoles and cavities in the inner areas at the same time. Moisture is converted into steam and escapes slowly from the outer surface because of the formation of the hard crust (Aguilera and Gloria 1997).

Starchy materials are unique in their thermal gelation properties. Oil uptake increases with increased removal of water from the sample during frying (Gamble and Rice 1987). Shih and Daigle (1999) have indicated that a dominant factor for frying appears to be the wheat flour because of the presence of the hydrophobic wheat gluten, which has a greater affinity for oil than that from other cereal sources like rice flour. The leavening effect of gluten in wheat flour also makes the wheat batter (like *jilebi* batter in the present study) more porous, which may enhance its moisture release and oil uptake during frying. As a result, increased viscosity is actually accompanied by an increased oil uptake. Moreover, during frying, the material undergoes chemical reaction and physical transformation at a high operating temperature range of 150–180 °C. Finally, starting with a raw product, frying joins dehydration to cooking, with starch gelatinisation, protein denaturation, aromatising and colouring via Maillard reactions, and finally oil uptake.

The rate of vaporisation of moisture is proportional to the temperature difference between the oil and the boiling point of water (Vitrac et al. 2002). As the crust presents low thermal conductivity, it affects heat and mass transfer and is

Fig. 3 Photomicrographs of the cross-sections of strands during frying at 160 °C at frying times of (A) 60 (B) 120, and (C) 180 s

Fig. 4 Photomicrograph of the cross-section of a *jilebi* strand at 3 min of frying at 160 °C showing pores, vacuoles and channels

partly responsible for the decrease in the dehydration rate at the latter stages of frying which is also true for the present study. Moreira et al. (1999) have introduced a physical relation between oil absorption and porosity stating that the mechanism of oil uptake may be caused by capillary forces. Indeed, when a fluid displacement such as oil absorption occurs in micro-canals like the crust pores, the viscosity or capillary forces become very important. Capillarity is the ability of a narrow pore to draw a liquid upwards, inwards or outwards. It occurs when the adhesive intermolecular forces between a liquid and a solid are stronger than the cohesive intermolecular forces in the liquid. In the case of frying of batter materials, it may be a combination of capillary flow as well as diffusional flow because of the presence of porous inner structure and a smooth outer surface.

Oil absorption is also dependant on pore radius. Small pores cause higher capillary pressures and then higher oil content (Moreira et al. 1997). Moreira and Barrufet (1998) have stated that surface tension decreases with increasing temperature, resulting in a capillary pressure reduction. There is no significant effect of temperature on pore size distribution (Adedeji and Ngadi 2010); some of the pores have been reported not perfectly cylindrical in shape which is also true for the present study.

Texture The textural attributes have been determined in terms of failure force and the number of fractures (Fig. 1) during complete shearing of *jilebi* strands. An increase in the time of frying increases the failure force as the soft batter material changes to a semi-solid mass, and finally to a brittle solid offering the desirable crisp texture. The curve obtained with the lowest frying temperature of 150 °C is placed at the lowest position meaning that a low frying

Fig. 5 Photomicrographs of the outer surfaces of strands at a frying temperature of 160 °C at times of (A) 60, (B) 120, and (C) 180 s

temperature is associated with slow liquid-to-solid phase transition.

The number of fractures reflects the brittleness or crispy characteristics of the product. A large number of fractures indicate the desirable crisp texture. However, the crispness of the product does not appear during the initial phase of frying (till 60s of frying) as the samples do not lose enough moisture in that phase of frying (Fig. 1) to exhibit any failure. However, at the latter stage of frying, nearly all the moisture present in the batter is lost to yield the rigid-strand structure and results in brittle fracture. It is interesting to note that the crispest product has been obtained during frying at 180 °C.

Density The density of the strands decreases as the frying process continues (Fig. 1). An increase in temperature of frying decreases density. However, we are unable to conclude the effect of temperature here. It is possible that the frying of high moisture containing starchy material is a complex phenomenon that affects the density of the fried products. These factors are possibly the rate of moisture loss and the entrance of oil, expansion of strands due to gelatinisation of starch, the formation of steam inside the product to cause expansion, and the structural features like the presence of pores and vacuoles, etc. in the strands that allow the migration of moisture and oil.

Colour The fundamental CIE colour parameters like brightness, hue and chroma have been determined at different stages of frying of *jilebi*. The brightness is the ratio of the light reflected by product compared to incident light. It shows a decreasing trend with time of frying (Fig. 1). Lowest brightness is obtained when the samples are fried at the highest temperature of 180 °C. The hue of

the sample indicates the dominance of the specific wavelength in the visible human range (400–700 nm) to offer the perception of colour of the samples. The hue of the batter is 578.0 nm while it is between 564.8 and 591.3 nm for the fried samples. The hue is non-significantly ($p \leq 0.05$) affected when fried at the lowest temperature of 150 °C. On the other hand, hue increases with time of frying at 160, 170 and 180 °C meaning a shift towards the development of yellow/red colouration during frying at these temperatures.

The chroma reflects the sample's own colour contributed by the pigments present in it; it is also due to the development of compounds arising out of Maillard reaction that occurs at the latter stages of frying. The chroma of samples increases with time and/or temperature of frying (Fig. 1). The overall inference that can be drawn from these three fundamental colour indices is that *jilebi* batter before frying is dull white in colour while frying process increases the dullness and colour progressively shifts towards yellow and finally offers a red-brown appearance. In addition, the highest temperature of 180 °C is undesirable as it produces the lowest brightness to offer a dull appearance in the samples.

Microstructure and imaging The photomicrographs of batter prior to frying (Fig. 2), and fried products at their cross-sections (Figs. 3 and 4) and outer surfaces (Fig. 5) at different time of frying are presented when fried at a temperature of 170 °C. The fermented *jilebi* batter prior to frying shows loosely bound spherical particles (Fig. 2) of diameter between 5 and 30 μm ; these particles appear to be weakly bonded by leached out materials that arise due to hydration and subsequent fermentation. In addition, the fermentation degraded products are also visible.

Fig. 6 Sample image of the cross-section of 160 °C-2 min fried *jilebi*

Table 1 Eccentricity and area of pores during frying at 170 °C for different times

Frying time (s)	Range of eccentricity (–)	Eccentricity (–)	Range of the areas of air cells (μm^2)	Area of air cells (μm^2)
60	0.47–0.92	0.70 $\pm$ 0.17	19375–12220625	1655000 $\pm$ 979375
120	0.32–0.66	0.52 $\pm$ 0.13	58750–16784375	3988750 $\pm$ 757863
180	0–0.68	0.38 $\pm$ 0.27	706250–16962500	5843750 $\pm$ 533880

Values are mean $\pm$ standard deviation (SD)

The cross section of the *jilebi* strands at different time of frying is shown in Fig. 3 at a low magnification of 50X. The one minute fried sample generally appears to be a compacted mass having only a few pores and vacuoles (Fig. 3a). An increasing number of such pores and vacuoles are formed as the frying process progresses. It is interesting to note that small pores are distributed at the periphery of the samples while large vacuoles exist in the inner part (Fig. 3b, c). It is possible that a high pressure is developed at the centre of the product that induces the fusion of a number of pores to create large vacuoles (Fig. 4). In this latter micrograph, some small pores appear to open in a common large vacuole; the formation of a channel parallel to the length of the strand is also visible. It may be hypothesised here that these channels are filled with oil once the moisture escapes at the latter stage of frying.

The outer surface of fried *jilebi* strands at different time of frying (Fig. 5) indicates a nearly non-porous surface

devoid of vacuoles or open cells. Instead, we have observed only a few small opening or pores. Earlier, Bhat and Bhattacharya (2001) have reported similar observation during frying of Bengal gram based batter droplets called *boondi*.

A sample image analysis is shown in Fig. 6 that distinctly identifies the air cells, thickness of cell walls and the fusion of several pores to form a larger vacuole. The thickness of cell walls varies between 10 and 15 μm which means a soft textured product due to low thickness of cell walls. The other details of the image analysis of the *jilebi* cross-sections are shown in Table 1. The eccentricity, as determined by using Eq. (1), is between 0 and 0.92 meaning that the shape of the cells is between a circle and ellipse. Interestingly, the eccentricity of the samples decreases as the frying process progresses. This means that though the cells formed at the beginning of the frying process are more elliptical in shape, they tend to be

Table 2 Sensory attributes of fried and fried-sugar syrup soaked *jilebis*

<i>Jilebi</i>				
	Fried sample		Fried-sugar syrup soaked sample	
	Frying time (s)	Sensory score	Frying time (s)	Sensory score
Appearance	60	The product is too soft and appears uncooked	60	The product is too soft and appears uncooked
	120	6.32 $\pm$ 1.41	120	6.51 $\pm$ 1.38
	180	6.64 $\pm$ 1.70	180	7.33 $\pm$ 0.83
	240	7.17 $\pm$ 1.83	240	7.70 $\pm$ 1.04
	300	Over fried	300	Over fried
Texture	60	The product is too soft and appears uncooked	60	The product is too soft and appears uncooked
	120	6.14 $\pm$ 1.30	120	5.87 $\pm$ 2.12
	180	6.23 $\pm$ 1.61	180	6.90 $\pm$ 1.34
	240	7.87 $\pm$ 1.06	240	8.03 $\pm$ 0.80
	300	Over fried	300	Over fried
Juicy mouth feel		Not performed	60	The product is too soft and appears uncooked
			120	6.81 $\pm$ 1.12
			180	6.94 $\pm$ 1.60
			240	7.29 $\pm$ 1.42
			300	Over fried

approaching a circular shape as the frying time increases. An increase in the average area of the cells has also been noticed during frying (Table 1). The area of the air cells varies widely meaning the simultaneous existence of small as well as big cells in the fried samples.

Lisinska and Golubowska (2005) have observed that in case of French fries, oil is mainly located in the surface of the potatoes where cells undergo maximum deformation. In the present study, we have noticed the development of a heterogeneous porous structure wherein the inner core is soft and moist while a dry hard crust is formed at the periphery. Pedreschi et al. (1999) have shown that oil envelopes the surface of potato cells like an ‘egg-box’ and is mainly trapped in voids as a result of cell rupture during cutting. However, oil penetrates the intact cells because of the composition of potato parenchyma but in the present case this phenomenon may not be true because of the absence of such a well organised plant structure. However, a crust is formed mainly during the final stage of frying. In addition, the interconnectivity between the pores has been found to be limited, and fried potato porosity has been identified as being the result of a few large pores rather than the small ones.

Sensory assessment A preliminary assessment of the products at temperatures of 150, 160, 170 and 180 °C for different time intervals upto 300 s have indicated that frying at a low temperature like 150 °C requires a very high time for frying, and thus not a pragmatic temperature of frying. On the other hand, a high temperature like 170 or 180 °C offers a product with higher fat content. In addition, non-uniformity in the colour of finished product also occurs. Further, the brightness of the sample is on the lower side while too coloured product has been obtained as reflected by high chroma values (Fig. 1). Hence, we have conducted the sensory assessment of samples fried at 160 °C for different time intervals of 60–300 s. The *jilebi* sample fried for 60s is too soft and under-cooked and is not a desirable product. Further, *jilebi* fried for 300 s appears to be an over-fried/over-cooked sample and thus is rejected by the panel (Table 2). The samples fried for 180–240 s have been judged as the best sample both as fried and fried-sugar syrup soaked products.

Conclusions

The frying of *jilebi* batter strands at different temperatures and times indicates the gradual development of a rigid structure after 60s of frying. The presence of pores, vacuoles and tunnels in the product has been detected but the outer smooth surface reveals the mechanisms of

capillary and diffusional flow for the migration of moisture and oil. Hard and crisp product can be obtained when fried at a temperature of 180 °C but the brightness is lowest at this condition. The suitable condition for frying of *jilebi* batter strands is 160 °C for 180–240 s.

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References

- Adedeji AA, Ngadi M (2010) Characterisation of pore properties of deep-fat-fried chicken nuggets breading coating using mercury intrusion porosimetry technique. *Int J Food Sci Technol* 45:2219–2226
- Aguilera JM (2005) Why food microstructure? *J Food Eng* 67:3–11
- Aguilera JM, Gloria H (1997) Determination of oil in fried potato products by differential scanning calorimetry. *J Agr Food Chem* 45:781–785
- AOAC (2005) Official methods of analysis, 18th edn. Association of Official Analytical Chemists, Gaithersburg
- Berry SK (1992) Role of air in foods. *Indian Food Ind* 11(2):40–46
- Bhat KK, Bhattacharya S (2001) Deep fat frying characteristics of chickpea flour suspensions. *Int J Food Sci Technol* 36:499–507
- Chakkaravarthi A, Punil Kumar HN, Bhattacharya S (2009a) *Jilebi*—An Indian traditional sweet: attributes, manufacturing practices and scope for large scale production. *Indian Food Ind* 28(2):30–36
- Chakkaravarthi A, Punil Kumar HN, Bhattacharya S (2009b) *Jilebi* 1: effect of moisture content, curd addition and fermentation time on the rheological properties of dispersions. *J Food Sci Technol* 46:543–548
- Chakkaravarthi A, Punil Kumar HN, Bhattacharya S (2011) *Jilebi* 2: Flowability, pourability and pH of batter of batter as affected by fermentation. *J Food Sci Technol*. doi:10.1007/s13197-011-0326-z
- Chitale SR (2000) Commercialization of Indian traditional foods: *Jeelebi, Ladoo and Bakervadi*. In: Proc. International Conference on Traditional Foods. Central Food Technological Research Institute, Mysore, India, pp 331.
- Donald A (2004) Food for thought. *Nat Mater* 3:579–581
- Gamble MH, Rice P (1987) Effect of pre-fry drying of oil uptake and distribution in potato crisp manufacture. *Int J Food Sci Technol* 22:535–548
- Hutchings JB (1994) Food Colour and Appearance. Blackie Academic and Professional, London
- Lisinska G, Golubowska G (2005) Structural changes of potato tissue during French fries production. *Food Chem* 93:681–687
- Little TM, Hills FJ (1978) Agricultural experimentation: design and analysis. Wiley, New York
- Llorca E, Hernando I, Perez-Munuera I, Quiles A, Larrea V, Lluch MA (2007) The structure of starch granules in fried battered products. *Food Hydrocolloids* 21:1407–1412
- Mellema M (2003) Mechanism and reduction of fat uptake in deep-fat fried foods. *Trends Food Sci Technol* 14:364–373
- Moreira RG, Barrufet MA (1998) A new approach to describe oil absorption in fried foods: a simulation study. *J Food Eng* 35:1–22
- Moreira RG, Sun X, Chen Y (1997) Factors affecting oil uptake in tortilla chips in deep-fat frying. *J Food Eng* 31:485–498
- Moreira RG, Castell-Perez ME, Barrufet MA (1999) Deep fat frying: fundamentals and applications. Gaithersburg, Aspen Publisher, p 350

- Pedreschi F, Aguilera JM, Arbildua J (1999) Use of confocal laser scanning microscopy in frying of potato products. *Microsc Anal* 37:21–22
- Rati Rao E, Vijayendra SVN, Varadaraj MC (2006) Fermentation biotechnology of traditional foods of the Indian subcontinent. In: Shetty K, Paliyath G, Pometto A, Levin RE (eds) *Food biotechnology*, Ch 3.18. CRC Press (Taylor & Francis Group), Boca Raton, pp 1718–1753
- Ravi R, Roopa BS, Bhattacharya S (2007) Analysis of the uniaxial compression textural attributes of crisp-snack foods. *J Text Stud* 38:135–152
- Russ JC (2005) *Image analysis of food microstructure*. CRC Press, Boca Raton, pp 127–209
- Shih F, Daigle K (1999) Oil uptake properties of fried batters from rice flour. *J Agr Food Chem* 47:1611–1615
- Vitrac O, Dufour D, Trystram G, Raoult-Wack AL (2002) Characterization of heat and mass transfer during deep-fat frying and its effect on cassava chip quality. *J Food Eng* 53:161–176
- Ziaiiifar AM, Achir N, Courtois F, Trezzani I, Trystram G (2008) Review of mechanisms, conditions, and factors involved in the oil uptake phenomenon during the deep-fat frying process. *Int J Food Sci Technol* 43:1410–1423