Influence of flour type on physico-chemical characteristics during deep frying

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Abstract The study focuses on understanding the influence of nutrients on frying oil degradation as well as its role in oil uptake by the fried substrate. Raw substrates were prepared taking refined wheat flour (rich in carbohydrate), soy flour (rich in protein) and gram flour (with both in a definite proportion) which were subjected to frying in sunflower oil at 185–200 °C. Analysis of the fried oil, substrate and fried product was carried out. Increase in acid value with respect to the composition of the flour was not significant. Higher rate of oxidation and peroxide value were observed in the oil used for Gram flour snacks, which could be due to significant amounts of sodium and potassium salts. Fried oil with soy flour based snack showed higher total polar material% which could be due to accelerated oxidation. Oil absorption was promoted by starch and gluten and controlled by protein and insoluble fiber. Oil absorbed by refined-wheat flour and soy flour based snack were 30% and 9.33%. Gram flour-based snack absorbed 4.52% oil with superior oil quality comparatively.

Keywords Frying · Protein · Starch · Carbohydrate · Insoluble dietary fiber · Oil absorption · Flour · Nutrients

Introduction

Deep frying is a process which entails cooking the food by immersing in hot edible oil or fat. It is far popularly used in several food industries and households since long period of time due to its ability to enhance several desirable sensory attributes which includes flavour, colour and texture of the raw material. During frying, the oil undergoes several chemical changes such as hydrolysis, oxidation and polymerization, cyclization and pyrolysis (Tynek et al. 2001) which results in the formation of several high molecular weight polar compounds and polymeric triacylglycerols in the oil being fried. The flavour, colour and safety parameters such as total polar material/total polar compounds, acid value, and peroxide value of the fried oil are very crucial to maintain the quality of the fried snack. Polar compounds or polar materials are a good indicator of the quality of used frying fats and oils indicating the total amount of newly formed compounds having higher polarity than that of triacylglycerols. The food being fried on the other hand undergoes several physical and chemical changes consisting of dehydration, starch gelatinization, protein denaturation, aromatizing and colouring via Maillard reaction and most importantly oil uptake in addition to structural transformation (Ziaifar et al. 2008).

Simultaneous heat and mass transfer operations makes frying one of the most complex unit operation. Heat transfer occurs hastily owing to high heat capacity of the oil and mass transfer involves both moisture loss from the food and oil uptake by the food. The pores formed in the substrate due to moisture loss drives the mechanism of oil uptake. From a study by Mohamed et al. (1998), thinner

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and less viscous batter forms a porous product due to high moisture release which is accompanied by increased oil uptake.

The proteins and carbohydrates present in the substrate tend to interact strongly with lipids especially with their thermo oxidative transformation products such as Maillard reaction products, protein cross linking products (Roe and Faulks 1991) resulting in less oil absorption. Water absorption and water solubility indices of starch are found to increase with frying time. The starch in the crust region exhibits much higher water absorption ability and water solubility than that contained in the core region (Fan et al. 1997). Amongst the proteins such as egg yolk, skimmed milk, gluten, whey and ovalbumin, taken for study, ovalbumin was able to reduce the oil absorption and improve the crispness of the fried batter (Gazmuri and Bouchon 2009). On coating chicken nuggets with corn starch, the porosity as well as oil absorption is determined to be excessive in the final fried product. Pre-gelatinized tapioca starch as a coating is found to lower the oil content, preserve the water content, improve the coating pick up and volume in the final product. It was observed that the rate of aggregation of protein is slower than the rate of denaturation leading to finer network of protein chains with less opacity and less holding strength of water due to the presence of small voids between the molecules. During the frying of cod fish fillets, denaturation of proteins takes place resulting in release of water into the frying oil, which causes increase in the diacylglycerol content in the oil due to hydrolysis of triacylglycerol. It is also reported that the acid value of oil fried with cod fillets was two times higher than the oil fried with potato slices and the colour of the cod fish fried oil was 13 times darker than the oil fried with potato slices. The formation of oligomeric and dimeric triacyl glycerols were higher in French fries, fried in oils with different fatty acid composition, while the formation of oxidized triacylglycerols and diacylglycerols were higher in deep fried oils (Li et al. 2017). Protein sources from barley, corn, sorghum, soy and wheat have also been stated to lessen oil absorption in battered and breaded fried foods (Brannan et al. 2014). In South-Asian and Indian cuisines, frying is often carried out with foods coated with flours of various types which give additional flavour to the fried foods which are popular (Dogan et al. 2005).

There are only a few studies contributing to the influence of components present in the substrate on frying oil degradation. However, no reports exist on the comparison of foods with varying composition and its influence on frying oil degradation as well as changes in the fried material. It is of interest to investigate on the influence of different flours on frying oils which can provide us with the data on the quality changes of frying oils. In the present study, three flours with varying nutritional composition

were chosen for frying study. Therefore, this study mainly focuses on the important physico-chemical changes in the frying oil as well as the fried snack with respect to different flour types, which would reveal the real impact of nutrients in controlling the formation of degradative compounds in oil as well as oil absorption in the fried material. The flour selection was based on its protein and carbohydrate content that is in series as follows: refined wheat flour < gram flour < soy flour in terms of protein composition and vice versa for carbohydrate composition. The main objective of the study is to carry out frying studies on flours of different composition and determine the main physico-chemical properties of frying oil like AV, PV and TPM which can affect oil quality during frying.

Materials and methods

Materials

Refined sunflower oil, refined wheat flour (RWF), gram flour (GF), soy flour (SF) and salt, were obtained from a local supermarket in Hyderabad city. Testo 270 (Cooking oil tester) was procured from M/S Testo India Ltd. It was used to measure the percentage of total polar material (%TPM) formed in fried oil at every frying cycle.

Petroleum ether, diethyl ether, silica (60–120 mesh size and 70–230 mesh size), starch, hexane, ethyl acetate, acetic acid, hydrochloric acid, concentrated sulphuric acid, boric acid, sodium hydroxide, potassium sulphate, copper sulphate were purchased from M/s SDFCL, Mumbai. Phenolphthalein, potassium hydroxide, sodium thiosulfate, glacial acetic acid, chloroform, potassium iodide were purchased from M/s Sigma Aldrich.

The microstructure of dough and snack were observed using Scanning Electron Microscope/Energy Dispersive X-Ray Spectroscopy (SEM/EDS) from Central Facility Laboratory, Osmania University, Hyderabad.

Soxhlet apparatus and hot air oven was used for estimation of fat and moisture in the substrate respectively. Oxidative stability was analysed by using Metrohm 892 Professional Rancimat. The fryer used for the frying of snacks was procured from a local company M/s Sowbhagya, Hyderabad.

Frying process

Frying of snack prepared from RWF in sunflower oil

Oil (4 L) was taken in a benchtop deep fryer (5.5 L) and was heated to 190 °C. To the RWF, salt (1% weight of the flour) and water were added to obtain a hydration level of 52.5% and was kneaded until smooth dough was formed. From the kneaded dough, three dough balls each weighing approximately 120 g was taken and was rolled into sheets. The sheets were cut into desired shapes and were subjected to frying once the oil reached the set temperature. The process was carried out in 3 batches, with each batch having a hold time of 3 min, thus completing one cycle. After the completion of every cycle, the temperature of the oil was brought down to 70 °C and the samples were drawn and stored 2 °C for further physico-chemical analysis. A total of 17 cycles were carried out, taking the remaining oil left out in the fryer and formed TPM (%) into concern.

Frying of snack made from GF in sunflower oil

Oil (4 L) was taken in a benchtop deep fryer (5.5 L) and was heated to 190 °C. To the GF, salt (1% weight of the flour) and distilled water were added to obtain a hydration level of 46.5% and was kneaded until smooth dough was formed. From the kneaded dough, three dough balls each weighing approximately 128 g was taken and was rolled into sheets. The sheets were cut into desired shapes and were subjected to frying once the oil reached the set temperature. The process was carried out in 3 batches, with each batch having a hold time of 3 min, thus completing one cycle. After the completion of every cycle, the temperature of the oil was brought down to 70 °C and the samples were drawn and stored at 2 °C for further physico-chemical analysis. A total of 19 cycles were carried out, taking the remaining oil left out in the fryer and formed TPM (%) into concern.

Frying of snack made from SF in sunflower oil

Oil (4 L) was taken in a benchtop deep fryer (5.5 L) and was heated to 190 °C. To the SF, salt (1% weight of the flour) and distilled water were added to obtain a hydration level of 61% and was kneaded until smooth dough was formed. From the kneaded dough, three dough balls each weighing approximately 110 g was taken and was rolled into sheets. The sheets were cut into desired shapes and were subjected to frying once the oil reached the set temperature. The process was carried out in 3 batches, with each batch having a hold time of 3 min, thus completing

one cycle. After the completion of every cycle, the temperature of the oil was brought down to 70 °C and the samples were drawn and stored at 2 °C for further physico-chemical analysis. A total of 19 cycles were carried out, taking the remaining oil left out and formed TPM (%) into concern.

Physico-chemical analysis

Analysis of oil

Analysis such as acid value, peroxide value, oxidative stability index and determination of TPM were carried out according to AOCS methods (references; Ca 5a-40; Cd 8-53; Cd 12b-92; Cd 20-91).

Analysis of dough and fried snack

Protein The protein content of the refined wheat flour, gram flour, soy flour was determined by Kjeldahl method (AOAC 1990).

Moisture content The moisture content of the dough was calculated using hot air oven method (AOAC 1990) at 105 °C until a constant weight was achieved.

Fat The fat absorbed by snack prepared from refined wheat flour, gram flour, soy flour was determined using Soxhlet method (AOAC 1990) with hexane as a solvent.

Microstructure of Dough and fried Snack The microstructure of the dough and snack was obtained by Scanning Electron Microscope/Energy Dispersive X-Ray Spectroscopy (SEM/EDS) (Erić 2017).

Results and discussion

The effect of frying on snacks prepared with 3 kinds of flours in sunflower oil was carried out and the physico-chemical parameters are shown in Table 1.

Variation in physico-chemical properties of fried oil with respect to different food materials

The present study was focussed on the degradation of sunflower oil subjected to deep frying of snack with respect to AV, PV and formation of TPM (%). The study brings out the influence of the composition with respect to protein and carbohydrate content in various flours on deep fried oil. The different properties are discussed below based on the results (Table 1).

Table 1 Changes in physico-chemical properties of refined sunflower oil while frying snack from RWF, GF and SF

Cycle No.	Properties										
	Substrate used for frying	AV (%)	PV (ppm)	TPM (%) by Testo	TPM (%) by chromatography	Np (mL)	P (mL)	$^a Np_n P_n$	$^a (Np_n/P_n) / (Np_{n+1}/P_{n+1})$	$^a Np_n / Np_{n+1}$	$^a (Np_n/Np_{n+1}) / (P_n/P_{n+1})$
1	RWF	0.2 ± 0.04	6.32 ± 0.05	8.5 ± 0.03	4.83 ± 0.2	3660	340	10.76	1.13	1.06	1
	GF	0.35 ± 0.02	8.33 ± 0.05	8 ± 0.05	4.79 ± 0.5	3680	320	11.5	1.206	1.042	1.002
	SF	0.42 ± 0.04	14.6 ± 0.05	8 ± 0.03	5.49 ± 0.3	3680	320	11.5	1.21	1.04	0.99
2	RWF	0.21 ± 0.02	6.3 ± 0.05	9.5 ± 0.05	6.06 ± 0.5	3450	362	9.53	1.12	1.06	0.99
	GF	0.35 ± 0.02	8.4 ± 0.03	9.5 ± 0.03	6.12 ± 0.3	3532	370.7	9.53	1.12	1.04	0.95
	SF	0.56 ± 0.02	12.6 ± 0.03	9.5 ± 0.03	6.91 ± 0.3	3522	369.7	9.53	1.24	1.05	0.96
17	RWF	0.7 ± 0.11	4.18 ± 0.05	36 ± 0.05	24 ± 0.3	629.92	362.08	1.73	–	–	–
	GF	0.91 ± 0.02	6.3 ± 0.05	29.5 ± 0.03	24.36 ± 0.3	1298.78	543.46	2.39	1.076	1.079	0.98
	SF	0.64 ± 0.02	26.2 ± 0.03	32 ± 0.03	27.12 ± 0.3	1136.96	535.04	2.13	1.09	1.1	0.99
19	RWF	–	–	–	–	–	–	–	–	–	–
	GF	0.9 ± 0.02	6.2 ± 0.02	33 ± 0.05	26.54 ± 0.3	1103.84	543.68	2.03	–	–	–
	SF	0.7 ± 0.02	26.9 ± 0.02	36.5 ± 0.03	29.64 ± 0.3	924.56	531.4	1.74	–	–	–
Average	RWF							5.26	1.12	1.12	0.99
	GF							5.26	1.12	1.12	0.99
	SF							4.49	1.11	1.08	0.99

RWF, refined wheat flour; GF, gram flour; SF, soy flour; AV, acid value; PV, peroxide value; TPM (%), total polar material in percentage; Np, non polar; P, polar

^a The ratios between Np and P in various combinations; All the analysis were carried out in triplicates and the values reported are means ± standard deviation

Variation in AV

The fried oil used for preparing snack from GF showed highest acid value (0.35 mg/g to 0.91 mg/g), while the lowest was observed in fried oil used for preparing snack from RWF (0.2 mg/g to 0.7 mg/g). It was observed that in case of RWF the maximum range of AV has attained at 10th cycle and continued to remain the same till the end of the process. Fried oil used for preparing snack from SF had an initial value of 0.42 mg/g which was the highest among the three types of flour and it slowly increased attaining a maximum of 0.7 mg/g at the end of the process. However, the increase in AV based on the composition of the flour used was not significant with increase in number of cycles. Similar observation was reported in most of the deep-frying studies. From a deep-frying process for 48 h with two kinds of oils (soybean oil and palm olein) and three of the most common frying foods in Taiwan (French fries, chicken leg fillet and pork chop) Chen et al. (2013) concluded that food type did not have any significant effect on acid value. The difference observed in the study was probably due to the quantity of substrate added. Higher the substrate added while frying, higher was the acid value.

Variation in PV

The fried oil used for preparing snack from RWF showed a peroxide value of 6.32 ppm, 8.36 ppm, 4.18 ppm for the first, 10th and final cycles respectively. Similarly, the peroxide value for fried oil used for preparing snack from GF were 8.3 ppm, 6.3 ppm, 6.2 ppm for first, 10th and final cycles respectively. The peroxide values were found to decrease after few cycles which could be due to the formation of secondary oxidation products. The observation is in compliance with other studies where a decrease in peroxide value at later stages is detected (Zahir et al. 2017) due to decomposition of unstable hydroperoxides into carbonyl, aldehydic compounds with frying or temperature increase. In case of SF, the peroxide value was found to increase from 14.6 to 26.9 ppm. The high value of peroxides observed in case of SF could be due to the presence of iron (USDA 2015), and other trace metals followed by potassium salts (USDA 2015) in the substrate, which could contribute to rapid oxidation of frying oil. Transition metals such as iron caused an increase in the rate of oxidation and thermal degradation of oil while frying meat.

Further in case of GF, foaming was observed while frying which could be due to presence of significant amounts of sodium and potassium (USDA 2015) in them which react with the fatty acid released due to hydrolysis. Increased foaming of oil is caused by sodium or potassium ions which helps in increasing the interface between oil and air thus promoting oxidation (Blumenthal et al. 1985). The

rate of oxidation was more in GF in turn resulting in higher PV.

Variation in TPM (%)

The TPM (%) formed in oil while frying snacks prepared from RWF, GF and SF was found to increase linearly (Figs. 1 and 2) with number of cycles. TPM (%) was measured by Testo which calculates the TPM (%) based on the dielectric constant of the oil. Determination of TPM (%) was found to be the most accurate method for identifying the oil degradation (Fritch 1981). The TPM (%) values for oil with snack prepared from RWF were found in range of 8.5 to 36% by Testo 270 and 4.83 to 24% by column chromatography. Similarly, for oil with snack prepared from GF the values were in the range of 8 to 33% by Testo and 4.79 to 26.54% using column chromatography. For oil with SF based snack it ranged from 8 to 36.5% by Testo and 5.49 to 29.64% by column chromatography. It was observed that there was some difference in the value of TPM (%) using Testo and column chromatography. The values obtained from Testo 270 were about 1.2–1.9 times higher than that of column chromatography results. Similar observation was reported for soybean oil (Chen et al. 2013). The fried oil with SF based snack was found to have highest TPM (%) for the final cycle due to accelerated oxidation (Chen et al. 2013). The changes in TPM (%) with respect to food were not observed predominantly as moisture is the main factor contributing to increase in polar material (Chen et al. 2013). Since the moisture content of the substrate introduced for frying was maintained in similar amounts for all three types of flour, a proportionately linear increase in TPM (%) was observed from one cycle to another.

Fig. 1 Effect of increase in frying cycles on TPM (%) (Column Chromatography) of refined sunflower oil with RWF, GF, SF as substrates

Fig. 2 Effect of increase in frying cycles on TPM (%) (Testo 270) of refined sunflower oil with RWF, GF, SF as substrates

Variation in different ratios of polar and non-polar fractions

The quantity of polar fractions increased with the number of cycles while the quantity of non-polar fractions decreased with the number of cycles. The ratio between Np_n/P_n decreases linearly from initial cycle to final cycle for all types of flour which implies that there is simultaneous decrease in non-polar fractions and increase in polar fractions at each cycle. The quantity of polar fractions formed for each cycle is equal to the amount of nonpolar fractions lost in each cycle. The loss in quantity of non-polar fraction depends on the quantity of oil absorbed by the substrate and the quantity of sample taken for analysis. The ratios of Np_n/P_n ; Np_n/Np_{n+1} ; P_n/P_{n+1} between n th cycle and $(n + 1)$ th were also calculated theoretically and there were no significant changes observed on the average of these ratios with respect to flour types.

From the known value of $r = (Np_n/P_n)/(Np_{n+1}/P_{n+1})$, the TPM (%) for n th cycle can be calculated. A simple mathematical relation was developed which will be useful for calculating the TPM (%) for any cycle directly if the following data are known.

Required data:

1. Quantity of oil taken for frying (QFO).
2. Quantity of oil absorbed during frying (AO)
3. Initial TPM (%).
4. r value*
5. (Np_n/P_n) ratio for every batch.

(Np_n/P_n) ratio is obtained from the following relation:

$$a_n = a_1/r^{n+1}$$

where $a_n = (Np_n/P_n)$, $a_1 = (Np_1/P_1)$, $r = (Np_n/P_n)/(Np_{n+1}/P_{n+1})$, n = Cycle number.

$$(QFO)_1 \times (TPM\%)_1 = P_1 \quad (1)$$

where QFO = Quantity of oil taken for frying; %TPM₁ = Percentage of Total Polar Matter formed after 1st cycle; P_1 = Quantity of polar matter formed after 1st cycle.

$$(QFO)_1 - P_1 = Np_1 \quad (2)$$

$$(Np_1/P_1) = a_1 \quad (3)$$

$$(QFO)_1 - (AO \times n) = (QFO)_n \quad (4)$$

$$(QFO)_n = P_n + Np_n \quad (5)$$

$$a_n = (Np_n/P_n) \quad (6)$$

from (6);

$$Np_n = a_n P_n \quad (7)$$

On substituting (7) in (5).

We get,

$$(QFO)_n = P_n + a_n P_n$$

$$(QFO)_n = (1 + a_n) P_n$$

$$P_n = (QFO)_n / (1 + a_n) \quad (8)$$

From (7) and (8) we get Np_n and p_n values.

% TPM of n th cycle can be calculated by the following equation.

$$nth\ (\%TPM) = P_n / (QFO)_n \quad (9)$$

Note: * r = Average $(Np_n/P_n)/(Np_{n+1}/P_{n+1}) = 1.11$ (produces approximate results).

Variation in oxidative stability of oil

The oxidative stability of initial and final cycles of refined sunflower oil used for frying snack from RWF, GF, SF were analysed using Metrohm 892 professional Rancimat at 110 °C. The stability of fried sunflower oil was found to decrease from 6 to 2.83 h and 4.13 h for SF and GF after first cycle respectively. SF had less induction time (when compared to GF which can be related to their corresponding PV where similar difference was observed. GF was observed to have slightly higher PV than RWF, but the oxidative stability of RWF (2.02 h) was very low when compared with GF. The presence of vitamin E (USDA 2015) in GF in relatively higher amounts, could have preserved the oil to a good extent when compared (USDA 2015) to that in RWF. And it was reported by Choe and Min (2007) that the release of amino acids from food into the oil can prevent or reduce oil degradation during frying whereas starch has not been observed to have similar effect. GF having higher protein content and RWF having

higher starch content prove true to show such effects on frying oil degradation.

Variation in oil absorption

The amount of oil absorbed by snacks prepared from three flours (RWF, GF, SF) showed a wide variation with RWF having a highest of 30% absorption while GF and SF showed an absorption of 4.52 and 9.33% respectively. The oil extracted from fried food when analyzed for Np/P ratio was found to be similar to that observed for the fried oil at different frying cycles. Despite maintaining a similar moisture content in all the three substrates, which is considered as the influencing factor (Gamble et al. 1987) for oil absorption a wide variation among them were observed. In order to understand the possible reason, the microstructures of all the three dough samples (Fig. 3) and the fried snacks (Fig. 4) was carried out using SEM/EDS.

Dough microstructure analysis

The SEM images obtained for all three types of dough samples gave an indication of the composition of the flour. Starch granules in dough from RWF (Fig. 3a) were clearly visible and gluten matrix was more uniform due to absence of any gluten hindering substances (Penella et al. 2008). The hydration level for RWF was fixed as 52.5%, as they produced more uniform and smooth dough as required.

Water requirement for dough development largely depends on the composition and variation in protein, fibre and damaged starch components (Shevkani et al. 2017). GF on the other hand had a hydration level of only 46.5% for the formation of dough. The dough was also found to be sticky with less specific volume (Mohammed et al. 2014). This may be due to the presence of fibre in significant quantity, which has a slight negative effect on water absorption and water retention capacity of the dough (Salinas et al. 2012). The SEM images of dough from GF (Fig. 3b) showed visible starch and protein network. In

case of the dough made from SF (Fig. 3c), the image lacked surface details possibly due to the presence of water obstructing the structure or may be the network was beyond the resolution of SEM indicating the protein network at molecular level (Bache and Donald 1997). The hydration level for SF was found to be 61%, which is higher than the other two types. This was probably due to increased protein content (Amarjeet et al. 1995) which has greater affinity for water due to the presence of both hydrophilic and hydrophobic amino acids. The observations noted with respect to the dough were also reflected on the microstructure of the snacks prepared from all three dough.

Microstructure analysis of the surface of fried snack

Moisture evaporation from the substrate while frying leads to ruptures and formation of surface irregularities such as voids, holes and cracks (Rahimi and Ngadi 2015). The outer surface of snack prepared from SF (Fig. 4c) showed more fractures and cracks. GF (Fig. 4b) had less ruptures than SF and more ruptures than RWF (Fig. 4a). An increase in internal pressure of the products while frying has a major impact on the occurrence of rupture on the crusted surface (Nagao et al. 1997). The composition of the flour had a major impact on the quantity of ruptures. SF had more fractures on the surface because of the high proportion of protein and significant quantity of fibre (USDA 2015) present in them which acts a barrier against water evaporation. In contrast RWF had fewer fractures which are assumed to be because of the comparatively weaker barrier film formed by the protein, which reduces the inner resistance to water evaporation due to positive vapour pressure created (Dana and Saguy 2006). The internal vapour bubbles were assumed to be broken down to several smaller ones in the substrate with stronger barrier films than with weaker film. In substrates with strong barrier film, many small holes and cracks were formed instead of having low number of big holes and cracks on the surface which in case is observed in weak barrier

Fig. 3 Photomicrographs of Dough from **a** RWF; **b** GF; **c** SF; measured using SEM/EDS

Fig. 4 Photomicrographs of outer surface of fried snack prepared from **a** RWF; **b** GF; **c** SF; measured using SEM/EDS

substrate (Rahimi and Ngadi 2015). Since GF had significant quantity of both fibre (USDA 2015) and protein it had formed comparatively a stronger film than RWF. Thus, with increase in the composition of protein and fibre in the substrate the formation of small ruptures and cracks increases.

Oil absorption based on dough microstructure

During frying, simultaneous heat and mass transfer take place leading to removal of water from the substrate and absorption of oil which involves three different oil fraction stages following the absorption mechanism such as, (a) Structural oil (STO), (b) Penetrated Surface Oil (PSO) and (c) Surface oil (SO) (Bouchon et al. 2003). Among the three types of flour, snack from RWF had the highest percentage of oil absorption during frying which was estimated as 30% (Yadav and Rajan 2012). Snack from GF had the lowest with 4.52% and snack from SF had about 9.33%. The high oil absorption in snack from RWF was mainly due to the changes happening in the starch molecules such as gelatinization (Llorca et al. 2007) as well as hydrophobicity or lipophilicity (Subagio 2006) of wheat gluten which has greater affinity for oil than the other two substrates (Shih and Daigle 1999). In frying of RWF snack, due to higher starch content, the pore formation is higher and hence higher the oil absorption. It was reported by Dana and Saguy (2006) that foods with larger size of ruptures on the surface had less internal resistance due to the formation of positive vapour pressure which leads to increased suction of oil into the food. This was observed in the microstructure of RWF. The oil absorption of snack made from gram flour was found to be the lowest (Yadav et al. 2012) because of the presence of protein and insoluble dietary fibre. Addition of fibre to dough was reported to decrease the oil content upto 20% in poori (Yadav and Rajan 2012). Many studies suggest that ingredients that are used to reduce oil absorption contain non-digestible carbohydrates i.e., fibres (Brannan et al. 2014). Further several studies report that oil

absorption decreases with increase in product thickness (Baumann and Escher 1995). This was the case in GF, where due to less elastic nature of the dough, the sheets formed was slightly thicker when compared with the other two. Thin chips were found to show increased vulnerability to stretching which produced highly permeable and brittle outer surfaces susceptible to oil infiltration. Chips with increased thickness was found to withstand high steam pressures due to their strong structure, which was not ruptured resulting in flat smooth surface. The flat smooth surface caused easy draining of oil, which was also a benefitting factor in preventing excess oil absorption. The oil absorption in SF was over 10% and the reduction in the absorption may be due to the lack of starch molecules in the flour, thus limiting the gelatinization and thus controlling pore formation. It is also due to the presence of nearly half the proportion of protein, which has both hydrophilic and hydrophobic amino groups and over 15% fibre, thus limiting oil absorption. According to Bouchon and Pyle (2004), stronger and more elastic network may act as a barrier against oil absorption due to less permeable outer layer, which was observed in case of SF.

Colour development of the snack

The colour of the snack obtained after frying was visually analysed. The reason for colour formation was due to the Maillard reaction which takes place between reducing carbohydrate and free amino acid side chain of protein producing polymerized protein and brown pigments (Mohammed et al. 2014). The colour of the final product with respect to increased intensity in darkness is in the following order: RWF < GF < SF (Fig. 5). This is in accordance with the protein content which follows the same sequence.

Fig. 5 Fried snack prepared from **a** RWF; **b** GF; **c** SF

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