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ABSTRACT

Fried products impose a health concerns due to considerable amount of oil they contain. Production of snack foods with minimal oil content and good management of oil during frying to minimise the production of toxic compounds continue to be challenging aims. This paper aims to investigate the possibility of producing a fat-free food snack by replacing frying oil with a non-fat medium. Glucose was melted and its temperature was then brought to 185°C and used to fry potato strips, to obtain a product referred here as glucose fries. The resulting product was compared with French fries prepared conventionally under conditions that resulted in similar final moisture content. The resulting products were also examined for crust formation, texture parameters, colour development and glucose content. Stereo microscope images showed that similar crusts were formed in the glucose fries and French fries. Texture parameters were found to be similar for both products at 5mm and 2 mm penetration depth. The maximum hardness at 2mm penetration depth was also similar for both products, but different from cooked potato. The colour development which characterised French fries was also observed in glucose fries. The glucose content in glucose fries was found to be twice the content of French fries, which is to be expected since glucose absorbed or adhered to the surface. In conclusion, glucose fries, with similar texture and colour characteristics to that of French fries, can be prepared by using a non-fat frying medium.

Practical Application:

Frying has always been carried out using a medium that is essentially fat, which inevitably enters the product and has health implications. This paper explores whether we could use non-fat frying medium, like molten glucose, to obtain fat free French fries - known as Glucose fries.

Introduction

Fried foods are very popular for their unique organolaptic properties such as color, texture and flavor. Recently, the amount of oil absorbed during frying has become one of the most important quality factors. This is because the current nutrition guidelines recommend consumers to lower the intake of dietary fat, especially saturated fat. Fat is believed to play a role in the development of several diseases such as cardiovascular diseases (Diniz and others 2004; Prospective Studies Collabortion, 2007), obesity, and type II diabetes (Hu and others 2001) and may contribute to the risk of sill birth (Frias and others 2011). In addition, some toxic compounds might be produced due the degradation of oil under the high frying temperatures (160-180°C) and become a potential hazard to consumers (Vahcic and Hruskar 1999; Billek 2000). Despite the awareness of consumers about the negative impacts of fatty foods, the consumption of such snacks is still significant (Dueik and Bouchon 2011).

During the last two decades, understanding the mechanism and lowering oil uptake of chips and French fries during frying has received considerable research attention with methods such as blanching (Pedreschi and Moyano 2005), drying (Krokida and others 2001; Song and others 2007), vacuum frying (Garayo and Moreira 2002; Yagua and Moreira 2011), and high pressure (Al-Khusaibi and Niranjan 2011), being used in conjunction with frying. However, the oil content in the fried products is still significant, and the production of snack foods with minimal oil content and good management of oil during frying to minimise the production of toxic compounds, continuing to be challenging aims.

During frying the formation of crust is essential for the development of product texture (Luyten and others 2004). Moreover, Maillard reactions take place in the crust between sugars and amino acids, which are responsible for the colour and flavour development (Marquez and AÑOn 1986; Rodriguez-Saona and Wrolstad 1997).

Glucose is a monosaccharide that is found in natural products such as fruits, juices and honey, in addition to it being a key component of blood. Glucose can be found into two forms of the D-configuration: alpha–D–(+)–glucose and Beta–D– (-)–glucose. Their melting points are 146 and 150 °C, respectively (Tzia and others 2012). When sugars, including glucose, are heated above the melting temperature, either in crystalline form or as syrup, they undergo caramelization which results in the so-called caramel colour and flavour development. The temperature of molten glucose can be brought up to normal frying temperatures (160-190 °C) at which Maillard reactions and colour development can occur. Luna and Aguilera (2014) have recently studied and modelled transient colour development in various types of molten sugars over a range of temperatures between 160°C and 200°C. The aim of this paper is to investigate the possibility of producing a fat-free potato snack, referred to as glucose fries here, using molten glucose as a frying medium. The crust, texture and colour of the new product is compared with conventionally produced French fries prepared in palm olein, under otherwise similar conditions of temperature and frying time required to attain similar values of final moisture contents.

Materials and Methods

Samples preparation

Potatoes (*Solanum tuberosum L.*) Maris Piper variety was purchased from local suppliers and were peeled manually, cut into x 10 x 45 mm strips, and blanched at 85°C for 5 minutes in a 7-L capacity water bath with a ratio of potato to water of 1:60 (w/v). Some strips were cooked in the same water bath at 95 °C for 8 minutes and used to compare the colour and texture with French fries and glucose fries.

Glucose fries were prepared by frying the strips in molten glucose (Dextorse anhydrous, Brenntag Limited, UK) at 185°C for 2 minutes in a 3L capacity domestic fryer controlled by a temperature process controller (CAL9500P, CAL control Ltd, UK). The frying time of 2 mins was chosen by undertaking preliminary experiments which showed the development of golden-yellow colour and an acceptable final moisture content of 64% (expressed on a dry weight basis). To compare the resulting product, conventional French fries having the same final moisture content were prepared by frying the blanched strips in Palm Olein (Britannia Food Ingredients, UK), at the same temperature (185°C) for 3.5 minutes.

Moisture content

The moisture content of blanched French fries and glucose fries was determined by drying the samples in a vacuum oven at 50°C and 0.5 bar, for at least 24 hours until a constant weight was achieved.

Microscopic analysis

Cross-sections of the samples were prepared by cutting the samples with a sharp blade prior to microscopic analysis. The sections were viewed under a Stereo Microscope with integrated LED illumination and a digital camera (Leica EZ4-D, Leica Microssystems, Wetzlar, Germany). The images were acquired and transferred to a computer with LAS EZ software, v1.30.

Texture measurement

The texture of the products was analysed by Brookfield texture analyser fitted with 25 kg loading cell (CT3, Brookfield Engineering Laboratories, USA). A single cycle puncture test was carried out using a 2 mm probe with a test speed of 1 mm/s at room temperature. The penetration depth was either 5 mm to study the texture of the core or 2mm which accounted mainly for the crust region. The data were collected and analysed by software provided by the analyser manufacturer (TexturePro CT v1.2 software). The test was carried out on 6 samples (from two batches, taking 3 replicates from each batch), each sample punctured at 2 random positions. An average value is reported with deviations.

Colour measurement

The colour of fresh potato and cooked samples was measured using HunterLab colorimeter (Color-Quest®, Hunter Association Laboratory, USA). CIE Lab L* (lightness), a* (redness) and b* (yellowness) colour space values were obtained at 8 different positions on 3 samples aligned to each other taken from two separate batches.

Oil and Glucose content determination in the product

The oil content was determined by the Soxhlet extrcation, according to the AOCS method (Am 5–04) after drying and grinding the samples. Extraction of glucose was carried out according to Rodríguez-Galdón and others (2010) with some modifications. 5 grams of ground samples were weighed in centrifuge tubes and mixed with 10 ml of 30% ethanol. The tubes were then placed in an ultrasound bath for 10 minutes and then centrifuged at 10000 rpm for 10 minutes. The supernatant was carefully recovered in a test tube with screw cover. Another 5 ml of the ethanol solution was added to the tubes containing the pellet and the tubes were again placed in ultrasound bath and centrifuged as above. The supernatant was recovered in the same test tube. The solution was filtered by passing through a 0.45 μm filter GHP (Waters Corporation, Millford, MA, USA).

Glucose content was determined by means of High Performance Anion Exchange Chromatography with Pulsed Amperometric Detection (HPAEC-PAD) (Osman and others 2010). A Dionex system (Dionex corporation, Surrey, UK) consisting of a GS50 gradient pump, an ED50 electrochemical detector with a gold working electrode, a LC25 chromatography oven, and an AS50 autosampler was used (Dionex corporation, Surrey, UK). The column used was a pellicular anion-exchange resin based column, CarboPac PA-1 analytical (4 × 250 mm). It was maintained at 25 °C and elution was performed using gradient concentrations of sodium hydroxide and sodium acetate solutions at a flow rate of 1 ml/min.

Statistical analysis

Two batches of each treatment and control samples were produced under the same conditions. Each batch was analysed for moisture, colour, and texture as described above. The mean values of all the samples drawn from the two batches (each batch with 3 replicates) are reported ± standard deviation. The differences between means were assessed by one-way analysis of variance (ANOVA) using SPSS statistics (v17.0 for Windows).

Results and Discussion

The frying process is characterised by mass transfer between food and frying medium, with the medium being absorbed by product and moisture being transferred to the medium. Fried products are characterised by a significantly reduced moisture content compared to the raw materials. The moisture content of the raw sample was 82.65 ± 1.93 and it was reduced to 64.21±1.82 in French fries and 65.35±3.67 in glucose fries. Statistical analysis showed that there is no significant difference between the moisture contents of the final products.

The development of crust is very essential in French fries and it accounts for the crispy texture. Figure 1 shows cross-section microscope images of glucose fries (1a) and French fries (1b). A crust region can be noticed in both sets of products. Frying temperature and evaporation of water play key roles in formation of a crust region in fried products. During frying, water vapour is formed and transferred through the surface of the product due to pressure and concentration gradients. This results in the development of pores and crust formation (Sahin and Sumnu 2009). In both frying processes, conventional frying and glucose frying, the difference between the saturation temperature of water (100°C) and the frying medium was high enough to result in a high vaporization rate. It has been reported that the crust is well defined under high frying temperatures (>150°C) and it was less distinguished at low frying temperatures (e.g., 120 °C) (Nawel and others 2009).

Change in texture of samples

During frying, changes in texture of products occur due to physical, chemical and microstructural changes. Texture is an important parameter to study the sensory quality of fried products. In order to examine texture development in prepared samples, A penetration test was carried out with a 2-mm diameter probe. As mentioned earlier, the depth of penetration was either 5 mm to study the internal texture of the samples or 2 mm which was intended to study the crust texture properties. Figure 2 shows examples of force-distance curves of different samples at different penetration depths. When the probe penetrates to 5mm (figure 2, a-c) in the samples, a maximum stress is reached after which the sample breaks, and this is true for all samples. With regard to the 2mm penetration graphs (2 d-f), this is only true in the case of the cooked sample since the surface breaks and the probe continues travelling through the depth. In the case of the French fries and glucose fries, instead, a maximum force is reached at the target penetration depth (2 mm) followed by recovery without the sample disintegration. This suggests that the product has some elasticity at 2mm depth which is due to the crust. Lima and Singh (2001) studied the mechanical properties of the crust of fried potato cylinders and reported that the crust showed viscoelastic behaviour. It has also been shown by Ross and Scanlon (2004) that the elastic modulus of potato crust increases with frying time, due to the changes occurring in crust thickness. Examples of the force-distance curves are also shown in figure 3.

The texture analysis parameters are shown in table 1; these are hardness, deformation at hardness and hardness work which is the energy at the maximum hardness. In general, the values of the three parameters decrease as the samples get cooked; this is the case for, both, 5mm and 2mm penetration tests. The values of these parameters for French fries and glucose fries are not significantly different ($p > 0.05$). In the case of the 2 mm penetration test, the maximum hardness is recorded at 1.0 mm for cooked samples, while it was 1.6 and 1.78mm in the case of French fries and glucose fries. The difference between cooked samples and fried samples (glucose and French fries) may be attributed to the mechanical properties of the crust which strongly influences the strain at the maximum stress. In order to eliminate the possibility of glucose glass transition influencing measurements, all texture measurements were carried out at room temperature. At this temperature, any glucose adhering to the sample surface could be removed because the glucose tended to solidify rapidly on cooling to 20°C. Thus, the vitreous glucose was removed so it does not contribute to the force required to penetrate the sample. Moreover, the texture force-time analysis at 2 mm penetration depth is used to distinguish the effect of the crust, as mentioned earlier.

Change in colour of samples

The colour is one of the essential parameters determining the acceptability of fried products. In colour measurement, L*a*b* colour space is most common and suitable for direct comparison with sensory data (Hunt and Pointer 2011). Luminosity colour component (*L**), which ranges from 0 to 100, tends to decrease with the frying temperature and time since potato strips get darker (Pravisani and Calvelo 1986; Nourian and Ramaswamy 2003) due to Maillard reactions. In table 2, the L* value for the blanched and cooked samples was not significantly different, this is also true in the case of parameters a* and b*. The lightness value (L*) decreased in French and glucose fries with marginally lower values being observed in the case of glucose fries. This might be due to the fact that glucose gets caramelized at high temperature influencing the product colour. The colour parameters for glucose and French fries are significantly different from the blanched and cooked samples. The values of a* and b* observed in this work are similar to those reported for fried French fries by (Segnini and others 1999). There was no significant difference found between the French fries and glucose fries in terms of a* values, while the difference was significant in the case of b*, which shows more darkening to occur in the case of French fries.

It is noteworthy that the colour developed by any product during frying depends on the product as well as the frying medium, the frying time and water removed in the process. The key question is whether the kinetics of colure change in glucose will affect the data reported in this study. Using glucose for frying involves melting the glucose in an oven at 150°C. The melting process is a slow and very critical process. Fresh molten glucose is initially colourless. Exposure to high temperatures, above the melting point, causes caramelization, and thermal degradation of saccharides accompanied by brown colour development and production of a caramel flavour (Belitz and others 2009). Recently, Luna & Aguilera (2014) studied changes occurring in molten sugars crystals (Crystalline glucose, fructose and sucrose) at temperatures in the range 160 – 200 °C. The study reported that, amongst the sugars studied, Glucose showed the lowest change in lightness. Further, perceptible changes in colour began after 15 mins at 190C and changes in colour over 5 minute intervals thereafter was relatively small up to 20 mins. In this study the frying times as well as the duration of glucose usage were significantly lower, so the influence of glucose colour change on product colour is expected to be negligible.

Nevertheless, it is true that chemical changes will occur if the glucose is used for extended periods of time. After prolonged usage, the glucose tends to appear darker and thicker. In addition to caramelizaion, maillard reactions also occur due to the reactions between the carbonyl group (>C=O) of glucose and amino group of a protein or amino acid in any product (Newton 2007). Thus a major disadvantage of this process is the limitation placed by these reactions on the duration of use of glucose. This is an area which needs further investigation, together with sensory evaluation which will eventually determine consumer acceptability of any product employing this novel frying method.

Glucose content in fried samples

Frying in a glucose medium causes transfer of glucose into the product, in addition to glucose that might adhere to the surface. The glucose contents of fresh potato, French fries and glucose fries are presented in figure 4. The amount of glucose in glucose fries increases from 5.3 g/100g dry matter in fresh samples to 10.4 g/100g dry matter. This roughly doubling of glucose content undoubtedly increases product carbohydrates content, which remains a health concern for some. However, the fat has been virtually eliminated and this is a major advantage. An attempt can be made to estimate the total Calories (kcal) associated with glucose and fat in fresh potato, French fries and Glucose fries, assuming that there is no fat in fresh potato and glucose fries and all other components remain the same. Table 3 shows the results of such an estimation made on the basis that glucose will yield 4 kcal/g and oil will yield 9 kcal/g. It can be clearly seen that the calories associated with French fries will be significantly higher than glucose fries per 100g potato dry matter. In general, the amount of glucose in potato tubers is very critical for chips and French fries production. The initial amount of glucose differs between varieties and even among cultivars of the same variety, this is due to differences in starch to glucose conversion process during postharvest storage (Bradshaw and Ramsay 2009). The use of potato with low reducing sugars (glucose and fructose) is essential in the production of chips and French fries to avoid excessive darkening (Gould 2001). Reconditioning potato tubers at temperatures higher than storage temperatures is a common strategy employed to reduce the level of reducing sugars, and seems to be appropriate for glucose frying to reduce the final total amount of glucose.

Conclusion

In this paper, molten glucose was used as a frying medium instead of oil to prepare fried potato product known here as glucose fries. Frying in glucose produced a product of similar properties to French fries. Stereomicroscope images showed that a crust was formed in both the types of fries. Texture and colour analysis revealed that glucose fries developed a similar texture and colour to that of French fries, although the latter was marginally lighter when the two products were fried to the same final moisture content. The glucose content in glucose fries was roughly twice that of French fries, but the oil content is virtually eliminated, resulting in significantly lower calorie content. This work demonstrates that a fat-free snack food can be produced by using non-fat frying medium with melting point close to normal deep fat frying temperatures. Further research is still needed to understand mechanisms and human sensory effects.

Author Contributions:

K. Niranjan: Designed the study and interpreted the results

M. Al-Khusaibi: Did the experimental work, analysis and helped draft the paper

Azmil Haizam Ahmad Tarmizi: Did the experimental work, analysis and helped to draft the paper

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Table 1: Texture evaluation of French fries fried at 185^{o}C for 2 minutes, glucose fries fried at 190^{o}C for 2 min and strips blanched at 95^{o}C either for 5 or 8 minutes.

Sample	At 5mm penetration depth			At 2mm penetration depth		
	Hardness (N)	Deformation at hardness (mm)	Hardness work (mJ)	Hardness (N)	Deformation at hardness (mm)	Hardness work (mJ)
Fresh potato	7.52±0.60 a	3.88±1.32 a	25.95±2.66 a	7.92±1.02 a	1.28±0.09 a	10.20±1.06 a
Blanched 85°C,5min	4.13±0.67 b	1.32±0.26 b	13.27±1.88 b	5.50±0.67 b	1.30±0.14 ab	5.82±0.55 b
Cooked samples (95°C, 8 min)	2.06±0.21 c	1.05±0.19 b	4.47±0.53 c	2.36±0.22 c	1.00±0.06 c	2.29±0.14 c
Glucose fries	1.28±0.18 d	1.80±0.20 c	3.45±0.51 c	1.28±0.16 d	1.78±0.20 d	1.55±0.24 d
French fries	1.38±0.27 d	1.47±0.15 bc	3.15±0.49 c	1.48±0.19 d	1.55±0.18 d	1.63±0.21d

Values represent means ± standard deviation

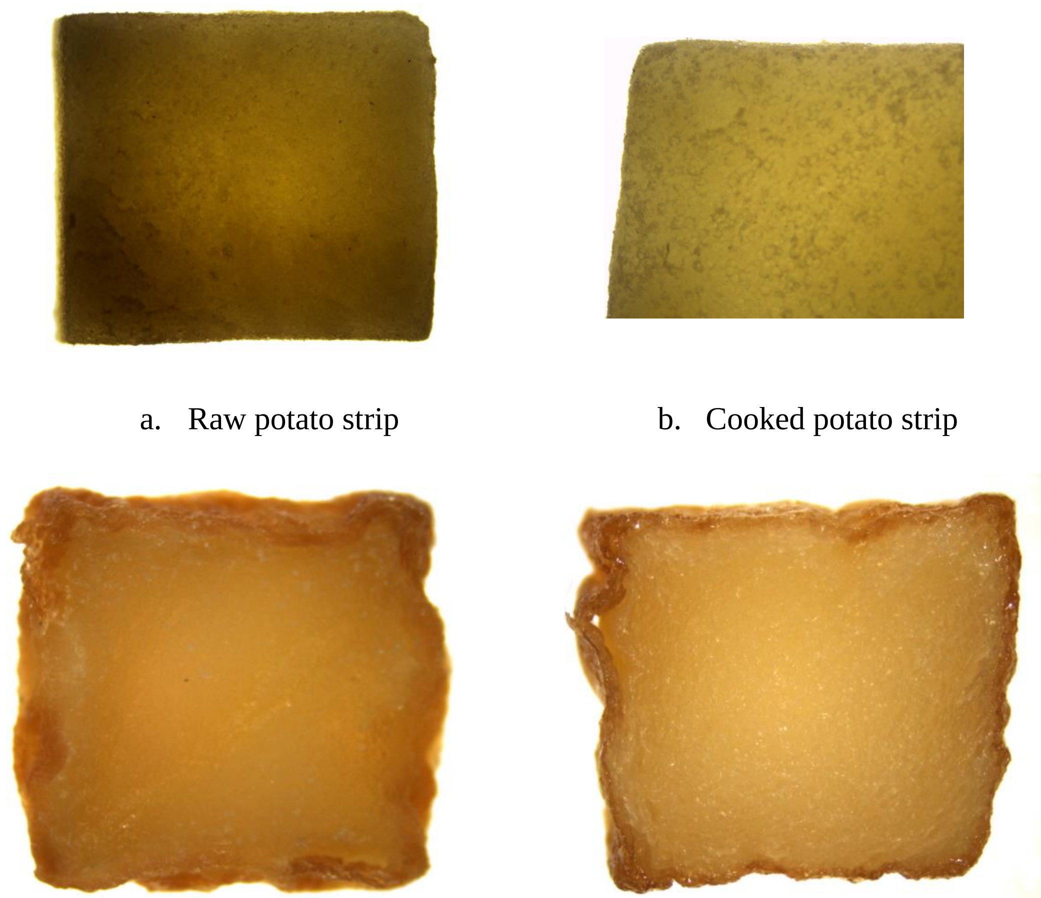
Means followed by different letters are significantly different at 95% confidence level

Table 2: Colour parameters of potato and fries

Samples	Colour parameters		
	L*	a*	b*
Fresh potato	62.49±1.81 a	0.69±0.15 a	13.36±0.83 a
Blanched (85°C, 5min)	58.33±1.24 b	-2.63±0.28 b	4.32±0.85 b
Cooked (95°C,8min)	59.25±1.06 b	-2.87±0.20 b	4.78±0.79 b
French fries	54.79±2.70 c	-7.39±0.52 c	19.36±1.68 c
Glucose fries	48.45±1.23 d	-6.02±0.97 d	16.94±1.02 d

Table 3: The estimated Calories associated with glucose and oil: a comparison between fresh potato, French fries and glucose fries, taking the calorie contents of glucose and oil to be 4 and 9 kcal/g, respectively

Product	Glucose content (g/100g potato dry matter)	Oil content (g/100g potato dry matter)	Total kcal (or Cal) associated with oil and glucose/100g potato dry matter
Fresh potato	5.29±0.39	negligible	21.2
French fries	4.18±0.29	23.21±0.87	225.6
Glucose fries	10.42±0.21	negligible	41.7



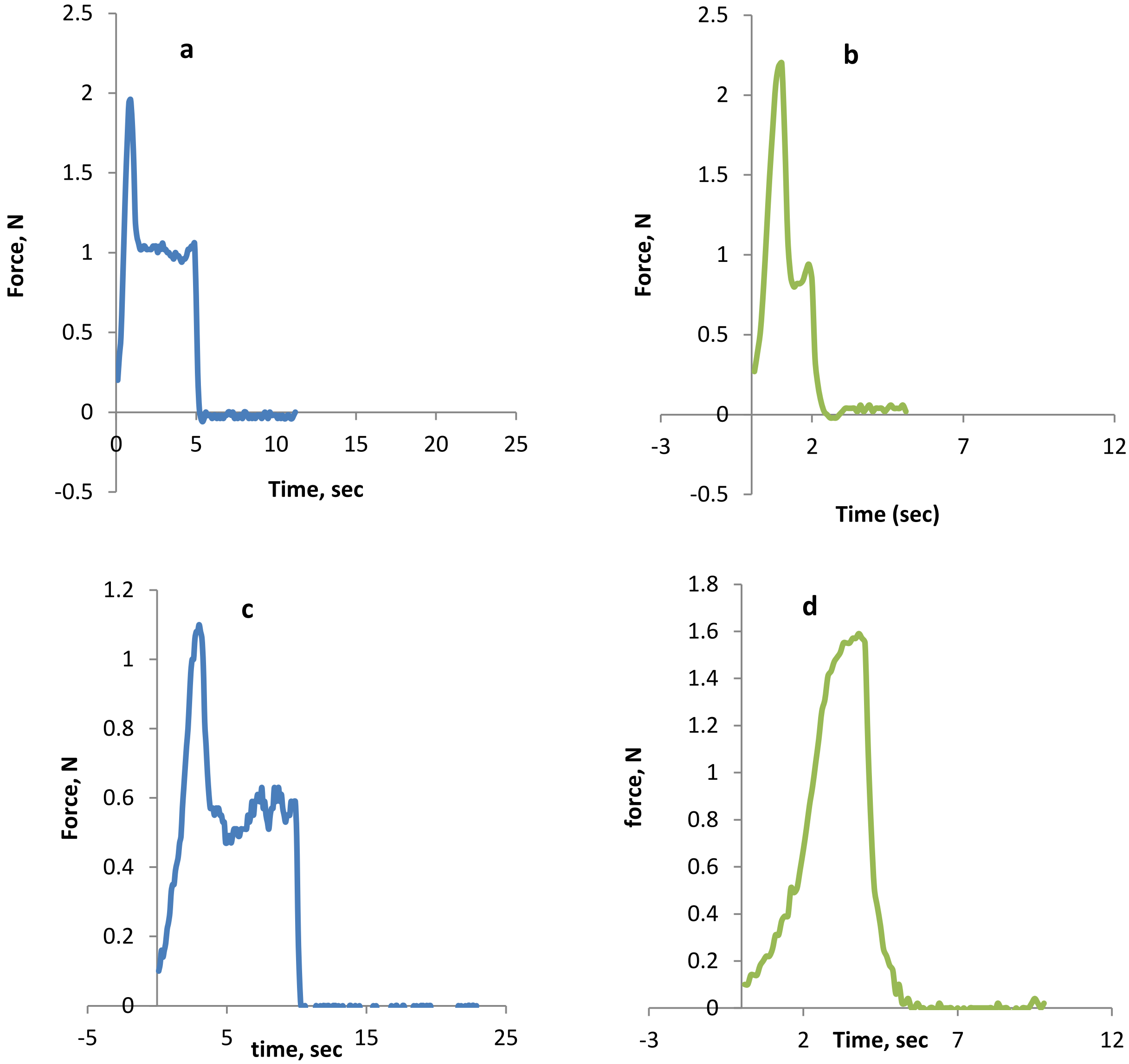
a. Raw potato strip

b. Cooked potato strip

c. Glucose-fries

d. French fries

Figure 1: Images from Stereomicoscope (at 8X magnification) for a cross-section of raw (a), cooked (b), fried in glucose (c) and fried in palm olein (d) potato strips.



a
Force, N
Time, sec
2.5
2
1.5
1
0.5
0
-0.5
0
5
10
15
20
25
b
Force, N
Time (sec)
2.5
2
1.5
1
0.5
0
-0.5
-3
2
7
12
c
Force, N
time, sec
1.2
1
0.8
0.6
0.4
0.2
0
-5
5
15
25
d
force, N
Time, sec
1.8
1.6
1.4
1.2
1
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0.6
0.4
0.2
0
-3
2
7
12

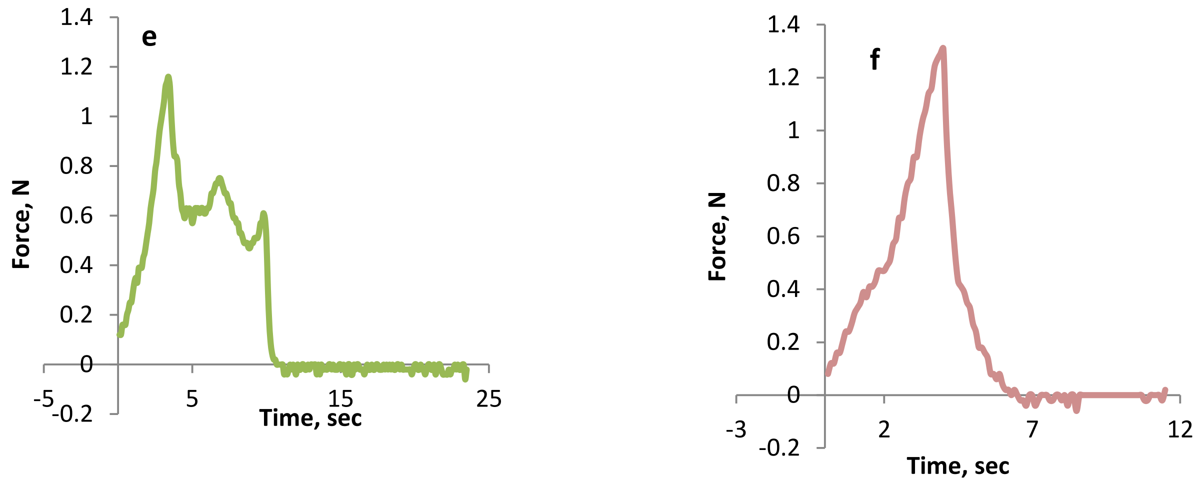
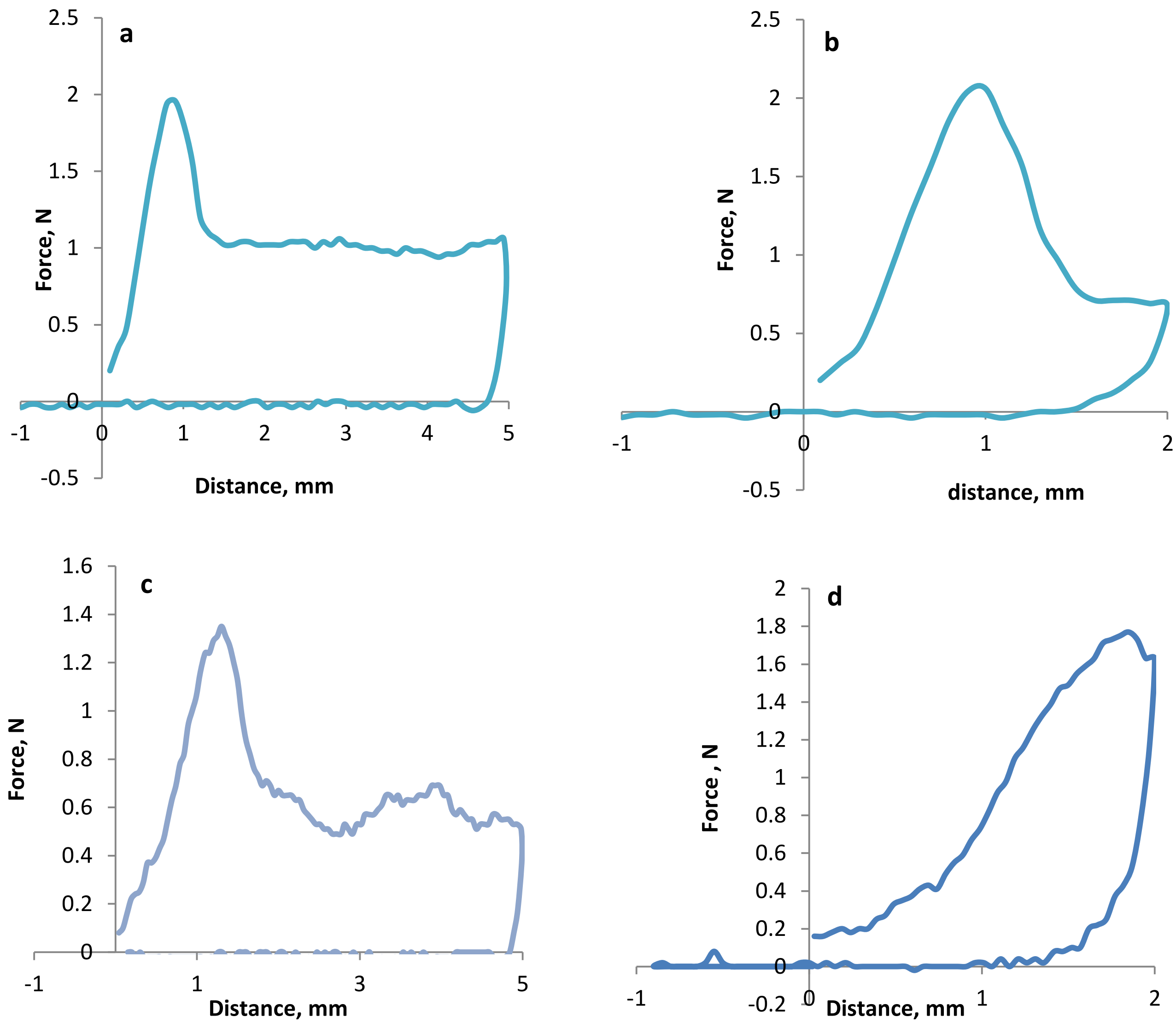
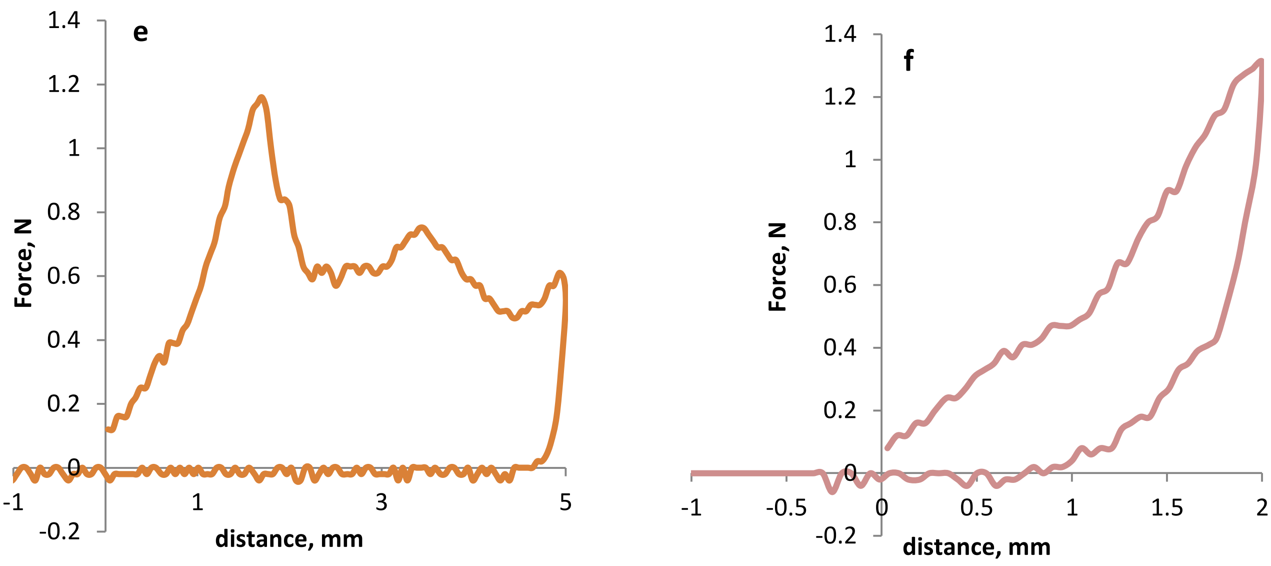


Figure 2: Examples of Force-time curves of blanched sample, French fries and glucose fries at 5 mm penetration depth (a ,c, e) and 2mm penetration depth (b, d, f)


a
b
c
d
Force, N
Force , N
Distance, mm
distance, mm



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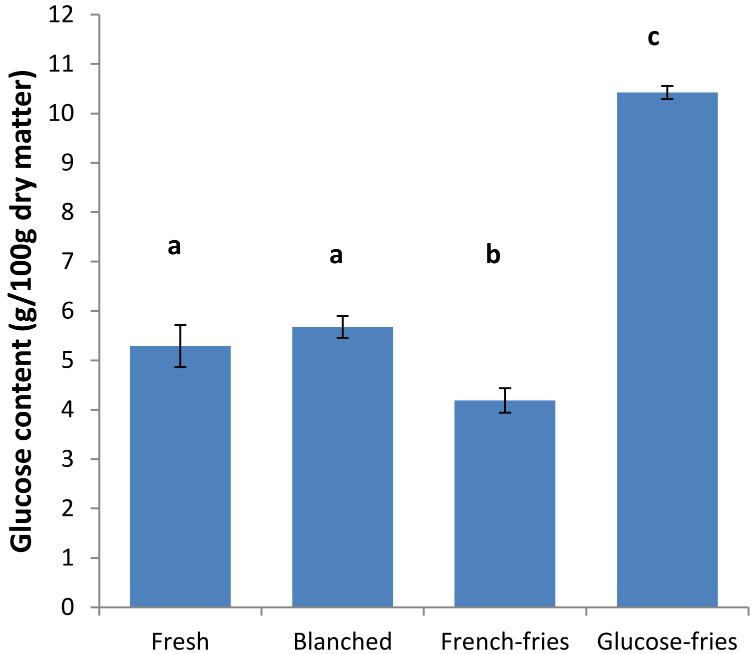

Figure 4: Glucose content in fresh, blanched and fried samples, g/100g dry matter. (Different letters indicate significant difference, $p>0.5$