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1 **Food Engineering and Physical Properties**

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3 **On the possibility of non-fat frying using molten glucose**

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21 **ABSTRACT**

22 Fried products impose a health concerns due to considerable amount of oil they contain.
23 Production of snack foods with minimal oil content and good management of oil during frying to
24 minimise the production of toxic compounds continue to be challenging aims. This paper aims to
25 investigate the possibility of producing a fat-free food snack by replacing frying oil with a non-
26 fat medium. Glucose was melted and its temperature was then brought to 185°C and used to fry
27 potato strips, to obtain a product referred here as glucose fries. The resulting product was
28 compared with French fries prepared conventionally under conditions that resulted in similar
29 final moisture content. The resulting products were also examined for crust formation, texture
30 parameters, colour development and glucose content. Stereo microscope images showed that
31 similar crusts were formed in the glucose fries and French fries. Texture parameters were found
32 to be similar for both products at 5mm and 2 mm penetration depth. The maximum hardness at
33 2mm penetration depth was also similar for both products, but different from cooked potato. The
34 colour development which characterised French fries was also observed in glucose fries. The
35 glucose content in glucose fries was found to be twice the content of French fries, which is to be
36 expected since glucose absorbed or adhered to the surface. In conclusion, glucose fries, with
37 similar texture and colour characteristics to that of French fries, can be prepared by using a non-
38 fat frying medium.

39

40 **Practical Application:**

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

44 **Introduction**

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

56 During the last two decades, understanding the mechanism and lowering oil uptake of chips and
57 French fries during frying has received considerable research attention with methods such as
58 blanching (Pedreschi and Moyano 2005), drying (Krokida and others 2001; Song and others
59 2007), vacuum frying (Garayo and Moreira 2002; Yagua and Moreira 2011), and high pressure
60 (Al-Khusaibi and Niranjana 2011), being used in conjunction with frying. However, the oil
61 content in the fried products is still significant, and the production of snack foods with minimal
62 oil content and good management of oil during frying to minimise the production of toxic
63 compounds, continuing to be challenging aims.

64 During frying the formation of crust is essential for the development of product texture (Luyten
65 and others 2004). Moreover, Maillard reactions take place in the crust between sugars and amino

66 acids, which are responsible for the colour and flavour development (Marquez and AÑOn 1986;
67 Rodriguez-Saona and Wrolstad 1997).

68 Glucose is a monosaccharide that is found in natural products such as fruits, juices and honey, in
69 addition to it being a key component of blood. Glucose can be found into two forms of the D-
70 configuration: alpha-D-(+)-glucose and Beta-D- (-)-glucose. Their melting points are 146 and
71 150 °C, respectively (Tzia and others 2012). When sugars, including glucose, are heated above
72 the melting temperature, either in crystalline form or as syrup, they undergo caramelization
73 which results in the so-called caramel colour and flavour development. The temperature of
74 molten glucose can be brought up to normal frying temperatures (160-190 °C) at which Maillard
75 reactions and colour development can occur. Luna and Aguilera (2014) have recently studied and
76 modelled transient colour development in various types of molten sugars over a range of
77 temperatures between 160°C and 200°C. The aim of this paper is to investigate the possibility of
78 producing a fat-free potato snack, referred to as glucose fries here, using molten glucose as a
79 frying medium. The crust, texture and colour of the new product is compared with conventionally
80 produced French fries prepared in palm olein, under otherwise similar conditions of temperature
81 and frying time required to attain similar values of final moisture contents.

82

83 **Materials and Methods**

84 **Samples preparation**

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

88 same water bath at 95 °C for 8 minutes and used to compare the colour and texture with French
89 fries and glucose fries.

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

98 **Moisture content**

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

102 **Microscopic analysis**

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

107 **Texture measurement**

108 The texture of the products was analysed by Brookfield texture analyser fitted with 25 kg loading
109 cell (CT3, Brookfield Engineering Laboratories, USA). A single cycle puncture test was carried
110 out using a 2 mm probe with a test speed of 1 mm/s at room temperature. The penetration depth
111 was either 5 mm to study the texture of the core or 2mm which accounted mainly for the crust
112 region. The data were collected and analysed by software provided by the analyser manufacturer
113 (TexturePro CT v1.2 software). The test was carried out on 6 samples (from two batches, taking
114 3 replicates from each batch), each sample punctured at 2 random positions. An average value is
115 reported with deviations.

116 **Colour measurement**

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

121

122 **Oil and Glucose content determination in the product**

123 The oil content was determined by the Soxhlet extraction, according to the AOCS method (Am
124 5–04) after drying and grinding the samples. Extraction of glucose was carried out according to
125 Rodríguez-Galdón and others (2010) with some modifications. 5 grams of ground samples were
126 weighed in centrifuge tubes and mixed with 10 ml of 30% ethanol. The tubes were then placed in
127 an ultrasound bath for 10 minutes and then centrifuged at 10000 rpm for 10 minutes. The
128 supernatant was carefully recovered in a test tube with screw cover. Another 5 ml of the ethanol
129 solution was added to the tubes containing the pellet and the tubes were again placed in

130 ultrasound bath and centrifuged as above. The supernatant was recovered in the same test tube.
131 The solution was filtered by passing through a 0.45 µm filter GHP (Waters Corporation,
132 Millford, MA, USA).

133 Glucose content was determined by means of High Performance Anion Exchange
134 Chromatography with Pulsed Amperometric Detection (HPAEC-PAD) (Osman and others
135 2010). A Dionex system (Dionex corporation, Surrey, UK) consisting of a GS50 gradient pump,
136 an ED50 electrochemical detector with a gold working electrode, a LC25 chromatography oven,
137 and an AS50 autosampler was used (Dionex corporation, Surrey, UK). The column used was a
138 pellicular anion-exchange resin based column, CarboPac PA-1 analytical (4 × 250 mm). It was
139 maintained at 25 °C and elution was performed using gradient concentrations of sodium
140 hydroxide and sodium acetate solutions at a flow rate of 1 ml/min.

141 **Statistical analysis**

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

147

148 **Results and Discussion**

149 The frying process is characterised by mass transfer between food and frying medium, with the
150 medium being absorbed by product and moisture being transferred to the medium. Fried products

151 are characterised by a significantly reduced moisture content compared to the raw materials. The
152 moisture content of the raw sample was 82.65 ± 1.93 and it was reduced to 64.21 ± 1.82 in French
153 fries and 65.35 ± 3.67 in glucose fries. Statistical analysis showed that there is no significant
154 difference between the moisture contents of the final products.

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

166

167 **Change in texture of samples**

168 During frying, changes in texture of products occur due to physical, chemical and microstructural
169 changes. Texture is an important parameter to study the sensory quality of fried products. In
170 order to examine texture development in prepared samples, A penetration test was carried out
171 with a 2-mm diameter probe. As mentioned earlier, the depth of penetration was either 5 mm to
172 study the internal texture of the samples or 2 mm which was intended to study the crust texture

173 properties. Figure 2 shows examples of force-distance curves of different samples at different
174 penetration depths. When the probe penetrates to 5mm (figure 2, a-c) in the samples, a maximum
175 stress is reached after which the sample breaks, and this is true for all samples. With regard to the
176 2mm penetration graphs (2 d-f), this is only true in the case of the cooked sample since the
177 surface breaks and the probe continues travelling through the depth. In the case of the French
178 fries and glucose fries, instead, a maximum force is reached at the target penetration depth (2
179 mm) followed by recovery without the sample disintegration. This suggests that the product has
180 some elasticity at 2mm depth which is due to the crust. Lima and Singh (2001) studied the
181 mechanical properties of the crust of fried potato cylinders and reported that the crust showed
182 viscoelastic behaviour. It has also been shown by Ross and Scanlon (2004) that the elastic
183 modulus of potato crust increases with frying time, due to the changes occurring in crust
184 thickness. Examples of the force-distance curves are also shown in figure 3.

185 The texture analysis parameters are shown in table 1; these are hardness, deformation at hardness
186 and hardness work which is the energy at the maximum hardness. In general, the values of the
187 three parameters decrease as the samples get cooked; this is the case for, both, 5mm and 2mm
188 penetration tests. The values of these parameters for French fries and glucose fries are not
189 significantly different ($p > 0.05$). In the case of the 2 mm penetration test, the maximum hardness
190 is recorded at 1.0 mm for cooked samples, while it was 1.6 and 1.78mm in the case of French
191 fries and glucose fries. The difference between cooked samples and fried samples (glucose and
192 French fries) may be attributed to the mechanical properties of the crust which strongly
193 influences the strain at the maximum stress. In order to eliminate the possibility of glucose glass
194 transition influencing measurements, all texture measurements were carried out at room
195 temperature. At this temperature, any glucose adhering to the sample surface could be removed

196 because the glucose tended to solidify rapidly on cooling to 20°C. Thus, the vitreous glucose was
197 removed so it does not contribute to the force required to penetrate the sample. Moreover, the
198 texture force-time analysis at 2 mm penetration depth is used to distinguish the effect of the crust,
199 as mentioned earlier.

200 **Change in colour of samples**

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

215 It is noteworthy that the colour developed by any product during frying depends on the product as
216 well as the frying medium, the frying time and water removed in the process. The key question is
217 whether the kinetics of colour change in glucose will affect the data reported in this study. Using

218 glucose for frying involves melting the glucose in an oven at 150°C. The melting process is a
219 slow and very critical process. Fresh molten glucose is initially colourless. Exposure to high
220 temperatures, above the melting point, causes caramelization, and thermal degradation of
221 saccharides accompanied by brown colour development and production of a caramel flavour
222 (Belitz and others 2009). Recently, Luna & Aguilera (2014) studied changes occurring in molten
223 sugars crystals (Crystalline glucose, fructose and sucrose) at temperatures in the range 160 – 200
224 °C. The study reported that, amongst the sugars studied, Glucose showed the lowest change in
225 lightness. Further, perceptible changes in colour began after 15 mins at 190C and changes in
226 colour over 5 minute intervals thereafter was relatively small up to 20 mins. In this study the
227 frying times as well as the duration of glucose usage were significantly lower, so the influence of
228 glucose colour change on product colour is expected to be negligible.

229 Nevertheless, it is true that chemical changes will occur if the glucose is used for extended
230 periods of time. After prolonged usage, the glucose tends to appear darker and thicker. In
231 addition to caramelizaion, maillard reactions also occur due to the reactions between the carbonyl
232 group (>C=O) of glucose and amino group of a protein or amino acid in any product (Newton
233 2007). Thus a major disadvantage of this process is the limitation placed by these reactions on the
234 duration of use of glucose. This is an area which needs further investigation, together with
235 sensory evaluation which will eventually determine consumer acceptability of any product
236 employing this novel frying method.

237

238 **Glucose content in fried samples**

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

258

259 **Conclusion**

260 In this paper, molten glucose was used as a frying medium instead of oil to prepare fried potato
261 product known here as glucose fries. Frying in glucose produced a product of similar properties

262 to French fries. Stereomicroscope images showed that a crust was formed in both the types of
263 fries. Texture and colour analysis revealed that glucose fries developed a similar texture and
264 colour to that of French fries, although the latter was marginally lighter when the two products
265 were fried to the same final moisture content. The glucose content in glucose fries was roughly
266 twice that of French fries, but the oil content is virtually eliminated, resulting in significantly
267 lower calorie content. This work demonstrates that a fat-free snack food can be produced by
268 using non-fat frying medium with melting point close to normal deep fat frying temperatures.
269 Further research is still needed to understand mechanisms and human sensory effects.

270

271 **Author Contributions:**

272 K. Niranjan: Designed the study and interpreted the results

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

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

276

277

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351 Food Technology and Biotechnology 37(2): 107 – 112.
- 352 Yagua CV, Moreira RG. 2011. Physical and thermal properties of potato chips during vacuum
353 frying. Journal of Food Engineering 104(2): 272 – 283.

354 Table 1: Texture evaluation of French fries fried at 185°C for 2 minutes, glucose fries fried at 190°C for 2
 355 min and strips blanched at 95°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

356

357

358 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

359

360

361

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

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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

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a. Raw potato strip



b. Cooked potato strip



c. Glucose-fries



d. French fries

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

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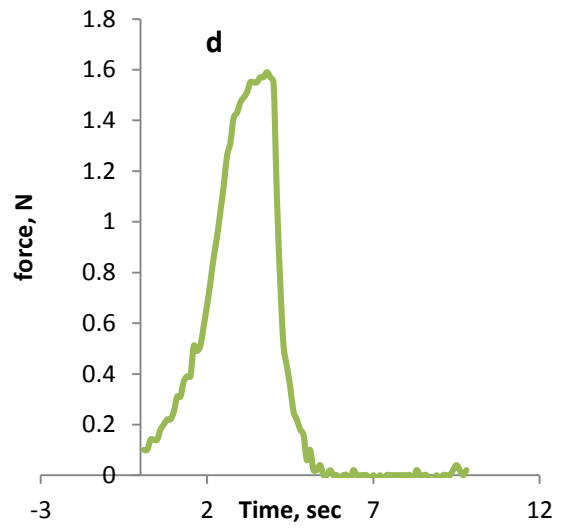
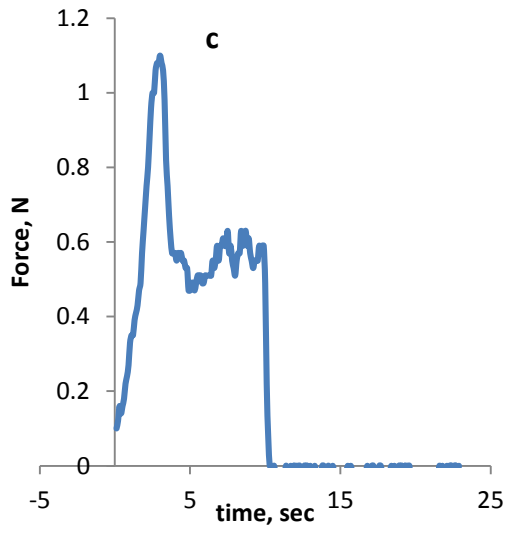
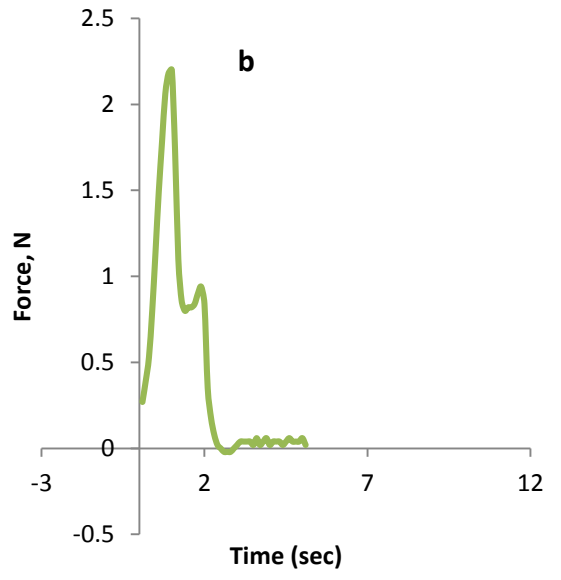
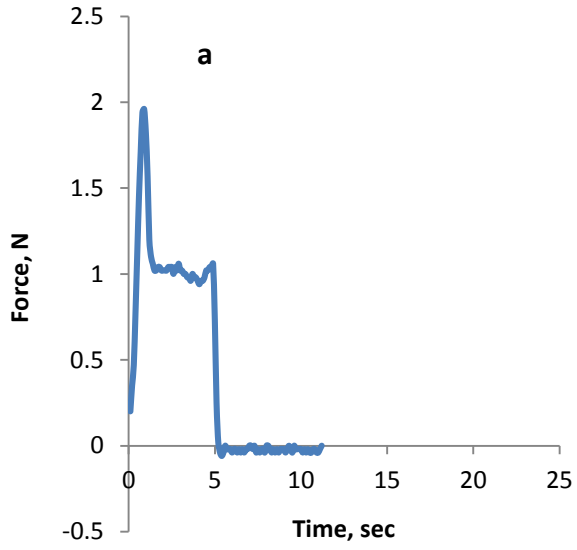
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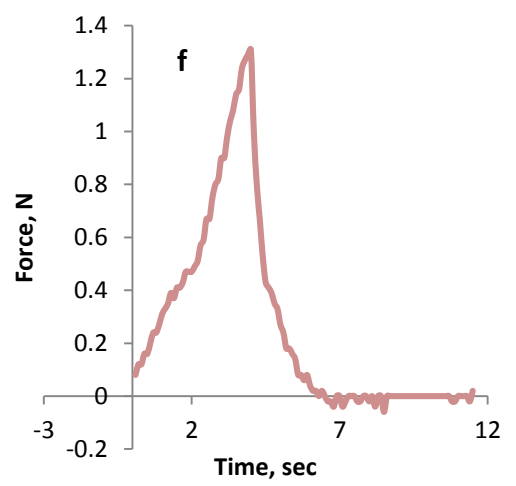
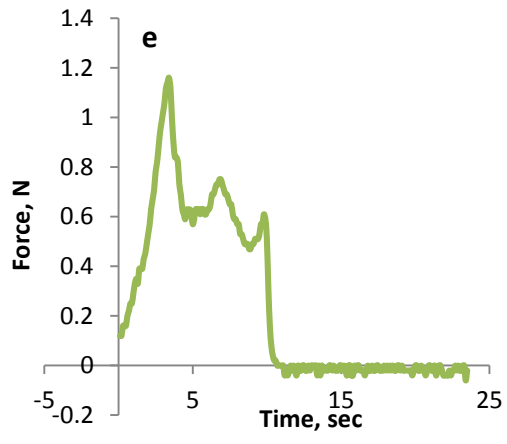


Figure 2: Examples of Force-time curves of blanched sample, French fries and glucose fries at 5 mm penetration depth (a ,c, e) and 2mm penetration depth (b, d, f)

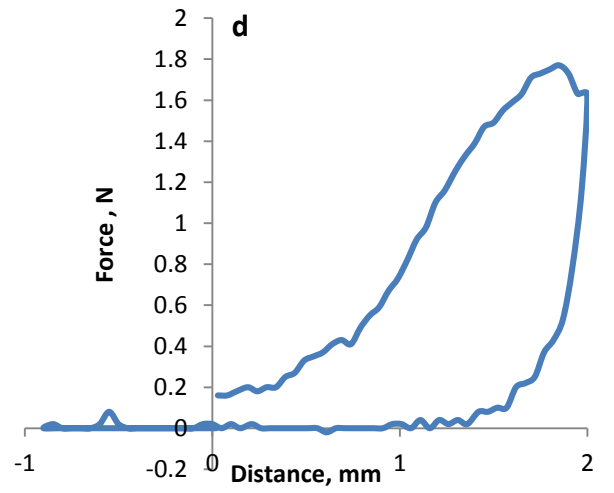
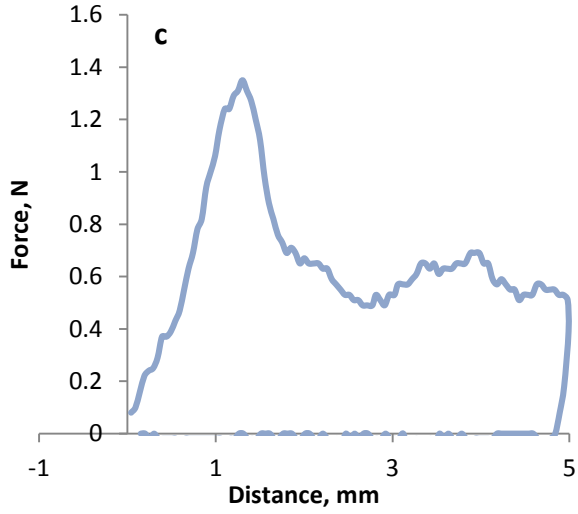
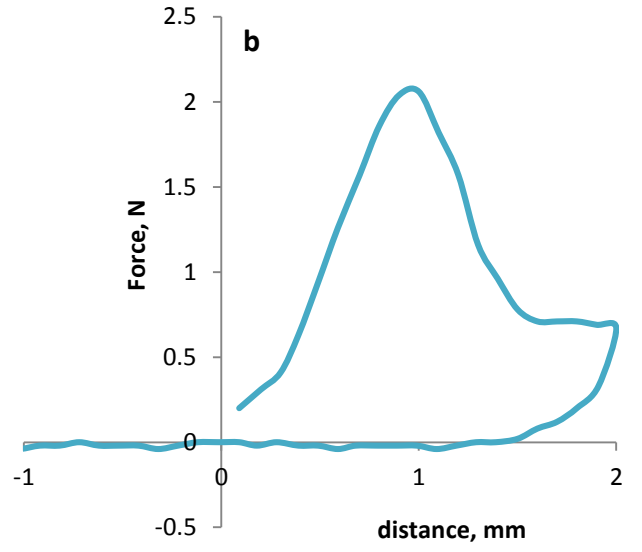
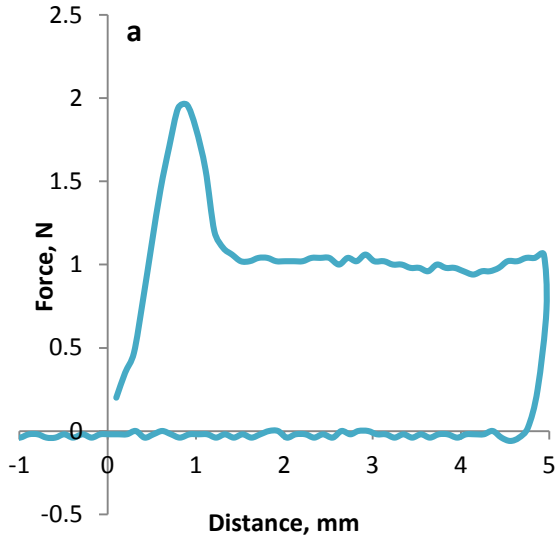
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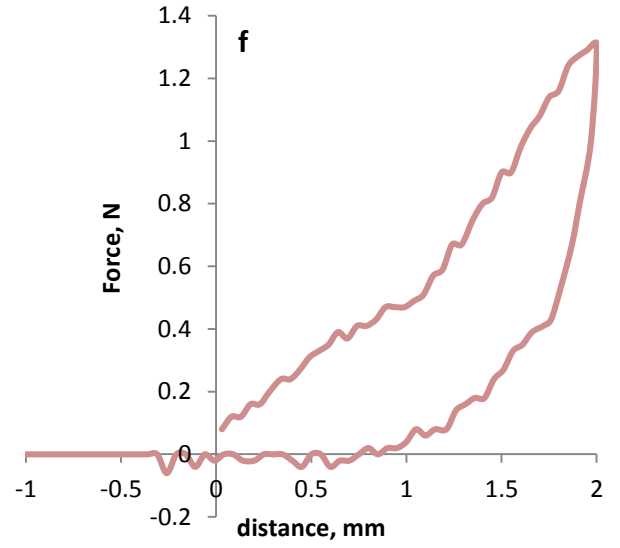
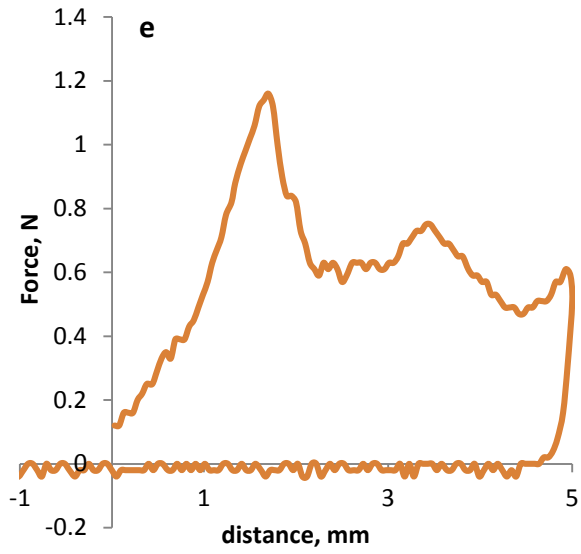
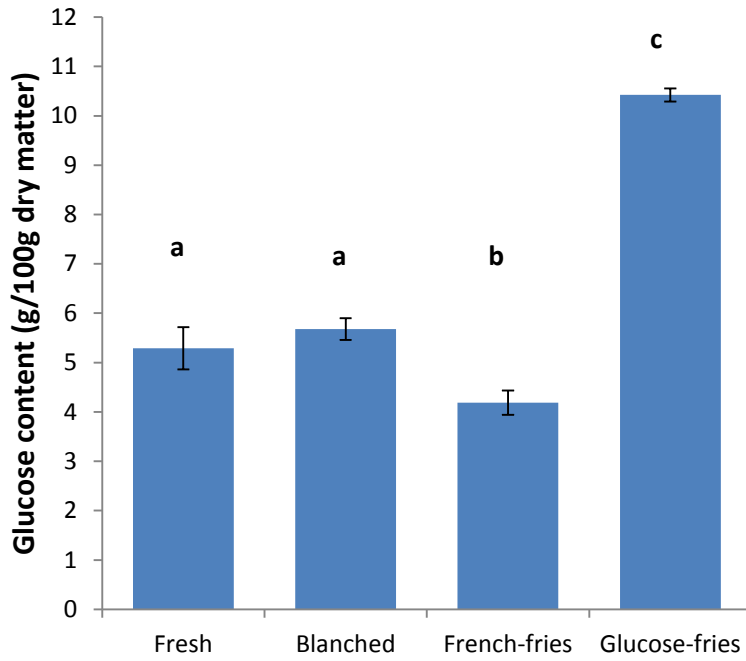


Figure 3: Examples of Force-distance curves of blanched sample, French fries and glucose fries at 5 mm penetration depth (a ,c, e) and 2mm penetration depth (b, d, f)



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

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