CHANGES IN THE STARCH AND FIBER FRACTIONS OF FRENCH FRIES: RESPONSE OF FREEZING

Pinky Raigond¹, Brajesh Singh¹ and Bhawana Kaundal¹

ABSTRACT: The changes in the starch and fiber contents of French fries were determined in response to freezing duration. Three Indian potato processing cultivars with high dry matter and low reducing sugars viz. Kufri Frysona, Kufri Chipsona-1 and Kufri Chipsona-3 were used for this study. French fries were prepared, par fried and frozen from these cultivars following the standard protocols. All the determinations were done after full frying of the previously frozen fries. Resistant starch and cellulose contents increased to appreciable amount during freezing of fries. The increase in resistant starch and cellulose content was significant after 30 days of storage. After 180 days, the resistant starch content was 9.49, 9.66 and 8.25 mg/100 mg FW and cellulose content was 11.91, 12.49 and 10.47 mg/100 mg FW in French fries prepared from Kufri Frysona, Kufri Chipsona-1 and Kufri Chipsona-3, respectively. Starch and amylose content first increased up to 48 hours, then decreased up to 15 day and again increased for up to 180 days of freezing. Similar trend was observed for reducing sugar content also. The study suggests that freezing of par-fried French fries up to 180 days may increase the health benefits since the RS content increases up to 9.13% (mean of three cultivars) during this process.

KEYWORDS: Cellulose, freezing, French fries, resistant starch, sugars

INTRODUCTION

Potato is the fourth most important vegetable crop and is a wholesome food. It is mainly utilized in the form of table stock (31%), frozen French fries (30%), chips and shoestrings (12%) and dehydrated products (12%) (Miranda and Aguilera, 2006). Due to changed eating habits nutritionists and food processors are giving much attention to the quality and nutritional value of the fried and dehydrated products. Starch is the most abundant fraction of the tuber dry matter, besides this, tubers also contain non starch polysaccharides (NSPs) such as cellulose, hemicelluloses and pectin, which confer several health benefits. Among the carbohydrates, sucrose, glucose and fructose are the major constituents (Marecek et al., 2013). Potatoes are highly popular due to their preparation in many ways including baking, boiling, roasting, microwaving and frying. The method of processing and storage (temperature and duration) alters the composition as well as the nutritional quality of the food.

Fried potato products such as chips and French fries are enjoyed by one and all due to the unique and delicious sensory characteristics. Texture of French fries is affected by the content of starch and NSPs (Golubowska, 2005). During French fry processing, potato tissue undergoes major changes due to the thermal processes, such as blanching, pre-drying, par-frying, freezing and deep frying. Loss of water from potato tissue during these processes increases the carbohydrate and NSP content of finished products (Lisinska and Golubowska, 2005). French fries have a significant internal volume, external surface and good crust differentiation. Crust formation is desirable in fried foods and is a complex process in which many factors such as temperature of oil, frying time and method used are involved (Goni et al., 1997).

Potatoes are often less favored due to the high glycaemic index of their carbohydrates.
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(Livesey, 2005). The glycaemic index of the potato is quite high especially after baking, boiling and frying (Nayar, 2014). High resistant starch (RS) content on the other hand can help in lowering the glycaemic index of potato and its products and RS has gained lot of importance due to its potential health benefits. Resistant starch is a product of starch and its degradation that resists absorption and digestion in the small intestine and passes to the large intestine, where it acts as a substrate for bacterial fermentation. Content of RS in food mainly depends on the method of cooking and storage. It also depends on the degree of gelatinization and retrogradation during cooling of the cooked foods (Garcia-Alonso and Goni, 2000). Being starch rich food, potatoes have the potential for development of RS during cooking and other forms of processing. In boiled potatoes the RS content ranges from 1.04 to 1.24%, which is known to increases in response of cooling/freezing to 1.51 to 1.69% (Raigond et al., 2014). Resistant starch III is the major form of resistant starch found in cooked and cooled potatoes.

During cooking of potatoes, starch undergoes gelatinization and amylose forms double helices. Amylose double helices aggregate to form highly thermostable B-type crystalline structure during cold storage of cooked potatoes, and this structure formed by amylose retrogradation is named as RSIII. The chances of RSIII formation are high in the starchy foods which are cooked under high moisture levels (Mahmood et al., 2006). Potato starch becomes rapidly digestible by α-amylases after cooking. However, when potatoes are cooled after cooking, the digestibility of potato starch changes. This change in digestibility after cold storage of cooked potatoes increases the nutritional properties of potato (Mishra et al., 2008). The increase in RS content of cooked and cooled potatoes is well documented in literature. In boiled, microwaved and pressure cooked tubers of Indian potato cultivars (Kufri Bahar, Kufri Jyoti and Kufri Sindhuri) RS content ranged from 1.17 to 1.33 mg/100 mg DW, which increased to 9-39% after cold storage (Raigond et al., 2014).

In India, potato processing industry has shown tremendous growth during the past decade (Sandhu et al., 2014). For the preparation of fried potato products, generally the cultivars having high dry matter (20% or above) and low reducing sugars are preferred, since the products prepared from such cultivars results in better texture, high yield and low oil absorption. Par fried French fries are generally stored at -18 to -20°C for varying length of time in restaurants and are finish fried at the time of serving. Limited literature is available on the changes occurring during freezing of par fried French fries and the influence of freezing period on the starch, sugars and fiber contents of the finished product. Therefore, an experiment was planned where potato French fries were par fried and stored at -20°C up to 180 days and the analysis was carried out at periodical interval from the finished fry French fries. The purpose of the present study was to determine the changes in starch, amylose, fiber and sugars from finish fried French fries as influenced by freezing duration so as to find out the appropriate freezing duration for getting maximum resistant starch content in the final product.

**MATERIALS AND METHODS**

**Sample preparation**

French Fries were prepared from three processing cultivars viz. Kufri Frysona, Kufri Chipsona-1 and Kufri Chipsona-3 produced at Central Potato Research Station, Jalandhar using the recommended package of practices.
Potatoes were washed and peeled manually and were cut into sticks (1x1 cm thick and ~7 cm long) with the help of French fry cutter. Short and defected sticks were removed. After washing the sticks were blanched in hot water (60-80°C) for 5 min. Excess water was removed from surface of sticks. Sticks were par-fried in cotton seed refined oil for 2 min at 180°C. Excess oil was removed from the surface with the help of blotting paper. Par-fried French fries were frozen at -20°C and stored for up to 180 days. These frozen fries were taken out at periodical intervals (24 and 48 hours, 15, 30, 60, 120 and 180 days) and finished fried at 180°C until bubbling stops. French fries prepared by deep frying the potato sticks without freezing were named as Control. For biochemical analysis finished fried French fries were used directly. All the samples used for biochemical estimations were pooled samples (i.e. external and internal part together) of finish fried French fries.

Biochemical estimations

**Total starch:** Starch content was determined according to the modified method of McCready et al. (1958). The samples (1 g) were suspended in 6.5 ml of 52% perchloric acid and 5 ml of distilled water. The samples were incubated for 24 hour at room temperature (25°C). After incubation, the samples were centrifuged and residue was extracted with 6.5 ml of 52% perchloric acid and centrifuged again. Both the supernatants were combined and final volume was raised to 50 ml with distilled water. For colour development, 50 µl of sample and 950 µl of distilled water was boiled in presence of 2 ml of anthrone-sulphuric acid reagent (200 mg anthrone in 100 ml chilled concentrated sulphuric acid). After boiling (8 min) samples were cooled to room temperature and absorbance was recorded at 620 nm.

**Amylose:** The amylose content was determined from samples by using Amylose/Amylopectin Assay Kit (Megazyme).

**Resistant starch:** RS content was analysed from French fries using the methodology described by Goni et al. (1996) with slight modifications. Main steps involved were the sample (500 mg) incubation with pepsin (40°C, 60 min, pepsin in KCl-HCl buffer pH 1.5) to make the sample protein free, incubation with α-amylase [37°C, 16 hours, α-amylase-11500U in Tris-maleate buffer pH 6.9] to hydrolyze digestible starch, incubation of residues with 600 µl of amyloglucosidase-180U (60°C, 45 min) to hydrolyze RS. The glucose was determined using glucose-peroxidase assay kit (Sigma Chemicals). RS was calculated as follows:

\[
\text{Resistant Starch (mg/ 100 mg) = mg units of glucose × 0.9.}
\]

**Cellulose:** Cellulose content from French fries was estimated using the methodology described by Thimmaiah (2009). Sample (500 mg) was extracted in acetic/nitric acid reagent (10:1 ratio) and heated in water bath at 100°C for 30 min. Samples were brought to room temperature and centrifuged at 10,000 rpm for 20 min. Supernatant was discarded and residue was washed with distilled water. To the residue, 10 ml of 67% sulphuric acid was added and incubated for 1 hour at room temperature. This sample (1 ml) was raised to 100 ml with distilled water. To 1 ml of diluted solution, 10 ml of anthrone reagent was added and mixed. Samples were heated in boiling water bath for 10 min and cooled to room temperature. Optical density was measured at 630 nm.

**Reducing sugars:** Sugar content was determined by the method developed by Somogyi (1952). Samples (10 g) were made protein free by using lead acetate and
potassium oxalate. The sample was filtered and volume was raised to 20 ml with distilled water, and 100 µl of extract was mixed with 900 µl of distilled water. After adding 1 ml Nelson alkaline reagent the samples were boiled for 20 min and cooled in chilled water to stop the reaction. Nelson’s arsenomolybdate reagent (1 ml) was added and vortex mixed. To these samples 7 ml of distilled water was added and optical density was measured at 620 nm.

**Sucrose:** The method described by Van Handel (1968) was followed for the estimation of sucrose content. Sucrose content was measured by the addition of 100 µl of 30% potassium hydroxide to the samples (100 µl extract + 900 µl distilled water). The samples were boiled for 10 min and cooled in chilled water. After bringing the samples to room temperature, 3 ml of 0.15% anthrone solution prepared in 76% sulphuric acid was added. The samples were incubated at 40°C for 15 min and optical density was measured at 620 nm. Regression equations from standard curve for biochemical analysis are given in Table 1.

**Statistical analysis:** All the analysis was performed in three replications using complete randomized block design (CRBD) and the data was subjected to statistical analysis. The ANOVA was performed at 5% level of significance.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Regression Equation</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>Y = 12.23X + 0.026</td>
<td>0.996</td>
</tr>
<tr>
<td>Amylose</td>
<td>Y = 0.255X – 0.008</td>
<td>0.999</td>
</tr>
<tr>
<td>Resistant Starch</td>
<td>Y = 22.7X – 0.019</td>
<td>0.998</td>
</tr>
<tr>
<td>Cellulose</td>
<td>Y = 3.325X – 0.019</td>
<td>0.999</td>
</tr>
<tr>
<td>Reducing Sugars</td>
<td>Y = 5.72X + 0.006</td>
<td>0.998</td>
</tr>
<tr>
<td>Sucrose</td>
<td>Y = 10.08X – 0.109</td>
<td>0.985</td>
</tr>
</tbody>
</table>

**RESULTS AND DISCUSSION**

**Changes occurring in starch and amylose content of French fries**

For the production of French fries, potato cultivars with high dry matter, appropriate starch content and low reducing sugars are desirable and the cultivars with these attributes were selected for the study. Starch content in raw tubers of Kufri Frysona, Kufri Chipsona-1 and Kufri Chipsona-3 was 14, 15 and 17 g/100 g FW (Table 2) and 13, 12 and 16 g/100 g FW in control French fries prepared from these cultivars, respectively (Fig. 1). Starch content was high in raw tubers compared to French fries since different processing steps like washing, blanching and par-frying lead to leaching of starch granules into water as well as in oil, thereby decreasing the starch content in fries. Freezing of par-fried French fries at -20°C first increased the starch content up to 48 hours and then decreased up to 15 days of storage and henceforth increased up to 180 days in finish fried French fries (Fig. 1). Starch content was comparatively higher in French fries prepared from Kufri Chipsona-3 before as well as after freezing. The trend of starch content was similar in all the cultivars during storage up to 180 days. The decrease in starch content on 15th day of storage was significantly lower in Kufri Frysona (9 g/100 g FW) compared to Kufri Chipsona-1 (15 g/100 g FW) and Kufri Chipsona-3 (16 g/100 g FW). Starch content was significantly high in finish fried French fries prepared from Kufri Chipsona-3 (32 g/100 g FW) after 180 days of freezing of par-fried French fries. Starch content was low in control French fries compared to par-fried and frozen French fries possibly due to the immediate rise in temperature during deep frying, which might have resulted in the thermo-chemical breakdown of starch of whole French fries (i.e. external and internal
Table 2. Chemical composition of raw tubers of processing potato cultivars

<table>
<thead>
<tr>
<th>Biochemical parameters</th>
<th>Kufri Frysona</th>
<th>Kufri Chipsona-1</th>
<th>Kufri Chipsona-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SE</td>
<td>Mean ± SE</td>
<td>Mean ± SE</td>
<td></td>
</tr>
<tr>
<td>Dry matter (%)</td>
<td>23.8 ± 3.22</td>
<td>22.8 ± 2.12</td>
<td>23.7 ± 2.62</td>
</tr>
<tr>
<td>Starch (g/100 g FW)</td>
<td>14 ± 2.83</td>
<td>15 ± 1.08</td>
<td>17 ± 2.70</td>
</tr>
<tr>
<td>RS (mg/100 mg DW)</td>
<td>1.56 ± 0.06</td>
<td>1.83 ± 0.15</td>
<td>1.32 ± 0.10</td>
</tr>
<tr>
<td>Amylose (mg/100 mg DW)</td>
<td>20 ± 1.56</td>
<td>19 ± 3.01</td>
<td>18 ± 3.55</td>
</tr>
<tr>
<td>Reducing sugars (mg/100 g FW)</td>
<td>106 ± 10.62</td>
<td>60 ± 4.96</td>
<td>41 ± 7.79</td>
</tr>
<tr>
<td>Sucrose (mg/100 g FW)</td>
<td>107 ± 19.09</td>
<td>149 ± 16.52</td>
<td>146 ± 20.5</td>
</tr>
<tr>
<td>Cellulose (mg/100 mg DW)</td>
<td>1.35 ± 0.16</td>
<td>1.72 ± 0.24</td>
<td>1.47 ± 0.10</td>
</tr>
</tbody>
</table>

Fig. 1 Effect of storage duration of par-fried French fries on starch and amylose content of finish fried French fries (standard error bars represents standard error of interaction between variety and duration of storage)

Composition as well as nutritional value of potato is affected by the method of processing. Digestible and indigestible fractions of starch in potato products are affected by the processing treatments such as blanching, drying, par-frying and deep frying (Garcia-Alonso and Goni, 2000). During French fry preparation, heat treatment such as blanching and frying cause the occurrence of a ‘skeleton’ in the potato tissue due to significant dehydration. This skeleton majorly consists of various portions of carbohydrates and the tissues contain high concentration of carbohydrates and NSPs (Lisinska et al., 2007).

Amylose content was maximum in finish fried French fries (control) prepared from Kufri Chipsona-I (7.8 mg/100 mg FW) followed by Kufri Chipsona-3 (7.2 mg/100 mg FW) and Kufri Frysona (3.9 mg/100 mg FW). During low temperature storage, amylose content followed the same pattern as that of starch content. It increased up to 48
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hours, decreased on 15th day and then again increased up to 180 days of freezing (Fig. 1). Like RS, amylose content was also high in finish fried French fries prepared from Kufri Chipsona-1 throughout the freezing period. Foods with high amylose content tend to show high RS content (Rosin et al., 2002). In all the cultivars, maximum amylose content was observed in finish fried French fries prepared after 180 days of freezing and it ranged from 25.6 to 26.3 mg/100 mg FW. Along with amylose, storage conditions and presence of other food components are also related to starch retrogradation (Rosin et al., 2002).

Changes occurring in fibre content of French fries

RS content was maximum in the finish fried French fries (control) prepared from Kufri Chipsona-1 (1.45 mg/100 mg FW), followed by Kufri Chipsona-3 (0.90 mg/100 mg FW) and Kufri Frysona (0.70 mg/100 mg FW). RS content increased in French fries prepared from all the cultivars with increase in storage duration from 24 hours to 180 days (Fig. 2). Although gradual increase was observed in RS content of finish fried French fries prepared from par-fried and frozen French fries throughout storage but significant increase was observed after 60 days and the RS content was 8.12, 8.60 and 7.57 mg/100 mg FW in Kufri Frysona, Kufri Chipsona-1 and Kufri Chipsona-3, respectively. Finish fried French fries prepared after 180 days of freezing contained highest RS content (8.25 to 9.66 mg/100 mg FW) and there was no significant difference amongst the cultivars. During frying most of the moisture in the food is replaced by oil. In case of French fries, more oil is absorbed at the surface of the fries and internal part remains relatively hydrated. Also rapid pasting of starch occurs on immersing the potato sticks in hot oil and this creates a layer of starch on the flesh. Starch pasting begins during blanching and this pasted layer of starch protects the internal part of fries from excessive fat penetration and also helps in retaining considerable moisture (Lisinska et al., 2007). The presence of moisture in the internal part of French fries allows gelatinization of starch, which is highly digestible (Garcia-Alonso and Goni, 2000). The possible mechanism behind the formation of resistant starch at -20°C in par fried French fries can be that the samples were not frozen.
as in case of cryogenic freezing, in which cryogens (liquid nitrogen or liquid carbon dioxide) are in direct contact of the sample and freezing takes place uninterruptedly. Par fried French fries were brought to room temperature and then they undergo short cold treatment before freezing, during this period RS might have formed because of starch retrogradation. RS formation depends on the degree of gelatinization and retrogradation during cooling of cooked starch foods (Garcia Alonso and Goni, 2000). Moreover during par frying and finish frying amylose-lipid complexes are formed, which lead to significant increase in RS content. Frying decrease the amount of digestible starch along with increase in the dietary fiber content (Ghidurus et al., 2010). Amylose is the main starch constituent that affect RS formation in fried samples heated in absence of water (Goni et al., 1997). Formation of resistant starch during cold storage of cooked starchy food depends on several factors including amylose content, amylose: amylopectin ratio, starch granule structure and size, amylose chain length and processing method as well as temperature during storage (Ozturk et al., 2009).

Cellulose is a type of dietary fiber and is present in vegetables as one of the main constituent (Zia-ur-Rehman et al., 2003). Cellulose content (Fig. 2) was maximum in finish fried French fries (control) prepared from Kufri Chipsona-1 (3.33 mg/100 mg FW), followed by Kufri Chipsona-3 (2.13 mg/100 mg FW) and Kufri Frysona (1.82 mg/100 mg FW). The results showed that the dietary fibers (resistant starch and cellulose) were higher in French fries prepared from Kufri Chipsona-1 and the minimum in Kufri Frysona. During storage from 24 hour to 15 days, cellulose content was higher in Kufri Chipsona-3 and from 30 days to 180 days of freezing, cellulose content was higher in Kufri Chipsona-1. Significant increase in cellulose content was observed after 30 days of freezing of par-fried French fries. Freezing period from 48 hours to 15 days decreased the cellulose content in finish fried French fries prepared after par-frying and freezing compared to finish fried French fries prepared without par-frying and freezing. Maximum cellulose content was observed in finish fried French fries after 180 days of freezing (10.47 to 12.49 mg/ 100 mg FW) and there was no significant difference amongst the cultivars. During French fries preparation, structure of potato tissue is irreversibly changed. NSPs in potato tissues increase during heat treatment due to loss of non-fiber substances (Asp, 1996). Golubowska (2005) reported high cellulose content in par fried and finish fried French fries as compared to raw tubers and the content of cellulose was higher as compared to other non starchy polysaccharides. High percentage of cellulose in dry substance of French fries was likely due to wash out of the soluble fraction from tissue during processing and another reason is the formation of resistant starch. Deep fat frying reduces an appreciable amount of in-vitro digestible starch and significantly increases both the resistant starch and water-insoluble dietary fibers which mainly includes cellulose, hemicellulose and lignin. The resultant increase in water-insoluble dietary fiber was probably due to partial conversion of starch in cooked potato to indigestible form by amylopectin enzymes. Cooking and baking decreases the content of NSPs, whereas microwave cooking and deep frying in oil increase the NSP content (Thed and Phillips, 1995).

**Changes occurring in sugar content of French fries**

Reducing sugar content was 43, 95 and 68 mg/100 g FW and sucrose was 123, 130
and 126 mg/100 g FW in finish fried French fries (control) prepared from Kufri Frysona, Kufri Chipsona-1 and Kufri Chipsona-3, respectively (Fig. 3). Reducing sugars first decreased in finish fried French fries prepared after freezing compared to control French fries and then increased up to 48 hours of freezing and again a decrease was observed on 15th day of freezing. Significant increase in reducing sugars in finish fried French fries prepared from all the cultivars was observed after 120 days of freezing. Reducing sugar content was 144, 182 and 114 mg/100 g FW in finish fried French fries prepared from Kufri Frysona, Kufri Chipsona-1 and Kufri Chipsona-3, respectively at the end of freezing period. In raw potatoes used for processing purposes, the reducing sugars should be ideally within 150 mg/100 g FW and dry matter should be 20% or above. The cultivars selected for this study qualify these two parameters. Low reducing sugars in potato cultivars is important to avoid the production of dark coloured products and high dry matter is important to reduce the oil uptake. The colour of French fries prepared from all the cultivars was golden after 180 days of freezing. Even after low temperature storage of par-fried French fries up to 180 days, the reducing sugar content was within the acceptable range except for Kufri Chipsona-1 (182 mg/100 g FW). In finish fried French fries of Kufri Chipsona-1 and Kufri Chipsona-3 prepared after freezing, sucrose content increased after 24 hours of freezing and then a decrease was observed up to 15 days. Whereas in Kufri Frysona, sucrose content decreased after 24 hours and then an increase was observed up to 30 days of freezing. Sucrose content decreased in finish fried French fries on 60th day and increased up to 180 days of freezing in all the cultivars. Cooking methods such as roasting and frying lead to increased reducing sugars and sucrose content (Murniece et al., 2011). Alpha amylase with an optimum activity at 70-75°C is reported to cause the hydrolysis of starch to sugars in cooked sweet potatoes (Walter et al., 1975). Lewthwaite et al. (1997) have reported starch to sugars conversion during microwave cooking, and Takahata et al. (1992) have reported hydrolysis of starch during steam cooking in sweet potatoes. The immediate rise in temperature during cooking inside the tubers could have resulted in thermo-chemical breakdown of starch.

![Fig. 3. Effect of storage duration of par-fried French fries on reducing sugars and sucrose content of finish fried French fries (standard error bars represents standard error of interaction between variety and duration of storage)](image)
CONCLUSION

This is the first study where effect of storage period of par-fried French fries was studied with regard to starch, fiber and sugar fractions in the final fried French fries. Our results suggested that low temperature storage of par-fried French fries increases the fiber content (resistant starch and cellulose) to appreciable amount in finish fried French fries. Content of RS as well as amylose was maximum in French fries prepared from Kufri Chipsona-1, before as well as after freezing. The major changes in the chemical composition of French fries compared to raw tuber composition were due to thermal processes such as blanching, pre-drying, par-frying and finish frying. French fries were found to have high RS content ranging from 0.70% to 9.66%. These results suggest that freezing of par-fried French fries increases the RS content in general up to 180 days of freezing and RS content increased up to 9.13% (mean of three cultivars), which is a desirable characteristic on health point of view, since high RS is known to be a healthy attribute and is inversely related to Glycaemic index in carbohydrate rich foods.

LITERATURE CITED


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