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ORIGINAL ARTICLE

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Abstract In this study the influence of coating with different hydrocolloids on the oil absorption and quality attributes of French fries was investigated. Our results revealed that hydrocolloid coatings reduced the moisture loss during frying, and hence, reduced the oil uptake of French fries. Among the studied gums as a single layer coating, combination of carboxy methyl cellulose and pectin (0.5 and 1% w/w) lead to the lowest oil uptake of French fries. In samples coated with two and three-layer hydrocolloids, the oil absorption reduced further and the moisture content of final products was higher than the blank samples.

Keywords French fries · Hydrocolloids · Oil uptake · Edible coating

Introduction

Deep fat frying is a dry cooking process which is involved of immersing food pieces in hot vegetable oils (Moyano et al. 2002). This process is used for the preparation of special foods which have an internal soft structure with a fragile and tender crust (Garcia et al. 2002) to keep flavor of food inside it (Moyano et al. 2002).

One of the important quality attributes of deep fat fried products is the amount of oil content in these products. Fried foods with low oil content can have a hard and unfavorable texture. However, higher oil usage is not economical for the process and leads to a high-fat product that can be unattractive (Moreira et al. 1999). Today customers are looking for food products with lower oil contents and this is driving force for many recent works that are aiming at reducing the oil content of final products.

The oil uptake during deep fat frying depends on many factors such as oil quality, frying temperature and duration, food composition (e.g. moisture and solid content, porosity), pre-frying treatments (i.e. partial drying and blanching), food size, and takes place during frying (minor part) and when the food is taken out of the frying oil and cold down to ambient temperature (majore part), Therefore it is important to remove the product carefully. For example, correct shaking and draining of the fried product when removing can reduce the final oil content of the food significantly (Pinthus et al. 1995; Daraei Garmakhany et al. 2008; Stier and Blumenthal 1990).

Low frying temperature or excess loading of the fryer can increase the oil uptake. When the frying temperature is low, it takes more time to have the favorable color and flavor in the product which leads to higher oil uptake (Rimac-Brncic et al. 2004). On the other hand it has been reported (Moreira et al. 1999) that higher frying oil temperatures causes quick crust formation and hence, lower oil uptake.

One of the factors affecting oil uptake is the surface area of the food and it can be predicted that foods with different shapes have various oil uptakes (Mellema 2003). Coating the food can be an effective method to reduce the oil uptake

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during deep fat frying. There are different coating materials, among there, hydrocolloids are more attractive because they are good barrier to fats. Some of the common used hydrocolloids are proteins, cellulose derivatives, alginates ect. That can be done either by immersion or by spraying (Williams and Mittal 1999; Sakhale et al. 2011)

There are many works in the literature on reducing the oil uptake by coating. For instance, Williams and Mittal (1999) reported a lower oil uptake by coating the samples with gellan gum. Aminlari et al. (2005) coated potato chips with proteins by immersing blanched potato slices in to solutions of sodium caseinate, whey protein concentrate, and egg white powder. These treatments reduced the oil uptake significantly as they reported a 14.5% decrease in oil uptake by coating with sodium caseinate.

Yadav and Rajan in their study were incorporated fiber in poories; to reduce the oil uptake while frying, and also to study and optimize level of fiber incorporation in accordance with acceptability of the product. Their results showed that oat bran had significant ($p \leq 0.05$) positive effect on moisture retention and negative effect on oil absorption, while wheat bran had reverse effect. Based on compromise optimization, it was recommended to incorporate 3.0 g wheat bran and 11.0 g oat bran (per 100 g wheat flour) for making fibre rich (4.2% total dietary fibre, 1.3% soluble dietary fibre) poori with lower oil content (20% less as control) and optimum acceptability (88.6).

In another study Garcia et al. (2002) coated French fries with methyl cellulose (MC) and hydroxyl propyl methyl cellulose (HPMC) and found that MC is more effective than HPMC in reducing the oil uptake. When adding sorbitol to the formulations, they obtained a 40.6% decrease in oil uptake of the French fries by using a formulation of 1% MC and 0.5% sorbitol. Garcia et al. (2002) reported that the coated products are similar to the uncoated ones in terms of texture, but they are different in terms of color.

Daraei Garmakhany et al. (2008) found that immersing potato slices in pectin, guar and CMC solutions can reduce the oil uptake and led to better quality and texture for final products in comparison with blank sample. The results of Khalil (1999) revealed that coating with combination of calcium chlorides and pectin or sodium alginate can reduce the oil uptake of French fries significantly. The lowest oil uptake reported for samples coated with a mixture of 0.5% calcium chloride and 5% pectin.

Rovedo et al. (1999), Olewnick and Kulp (1993) reported that the final texture of fried products affected by food composition, therefore interactions between proteins, starch and their fractions (amylose and amylopectin) were most important for final products quality and texture. In the present work, we aimed to investigate the effect of single and multiple coating layering with different hydrocolloids on oil uptake and quality attributes of potato French fries

Material and method

Preparation of gums suspensions

Carboxymethyl cellulose (CMC), pectin from citrus peel, guar and xanthan gums were provided from Provisco Company of Iran. Aqueous suspensions of 0.5, 1% CMC, 0.5%, 1% pectin, 0.3, 0.5% and 1% guar gum and 0.5, 1 and 1.5% xanthan gum (w/v) were provided and used for coating formulations.

Pectin was selected due to its ability to react with calcium content of potato tissue and formation hard and dense structure that can decrease oil absorption. CMC was selected due to its gel formation ability in higher temperature that can form a thin film on the potato stripes during frying and so this film act as a barrier agent against oil absorption. By respect to the profitable properties of pectin and CMC gums and in order to study, the effect of the interaction between pectin and CMC gums on fat reduction of final potato stripes the mixture of these gums (at 0.5 and 1% concentration) was prepared for dipping process. Guar and xanthan gums were selected due to their good gelling properties.

The gum concentrations were chose according to economic aspect (all studied gums) and convenience to use as edible covers for dipping of strips in their suspensions (guar and xanthan gums).

All of the above concentrations weighed and slowly dispersed in boiled distilled water and homogenized by commercial blender. The ratio of suspensions volume to potato slices was 3:1 (w/v) and the solution was kept under constant stirring until it attained ambient temperature.

Sample preparation

Potato variety Kenebk was purchased from Seed and Plant breeding Institute of Jahad Agricultural Organization, Golestan county of Iran and immediately its physicochemical properties were analyzed (AOAC methods 2005, 18th edition) and moved to a cold store at 5–7°C with relative humidity of 80% according to our previous study (Daraei Garmakhany et al. 2010). Before frying, potatoes were removed from cold store and kept at ambient temperature ($25 \pm 2°c$) for 2 weeks in order to decrease the amount of reducing sugars which have been increased during cold storage then, after peeling with an abrasive peeler (Esfahan machine); they were converted to pieces of $6 \times 1 \times 1 (cm^3)$ by means of a domestic striper. The blanching was performed in boiling water (90–95°C) for 4 min then the products were washed immediately with cool water.

Coating procedure and frying process

For single coating layer, blanched samples of potato were dipped in the coating suspensions for 1 min and rinsed to removal excessive gum.

For double coating layer, mixture of pectin 1% and CMC 1% were selected as first layer and guar gum 1% and xanthan gum 1% were selected for second layer. For double layer coating, blanched strips were dipped 1 min in first layer, then drained for excessive gum removal and dipped 1 min in second layer too and rinsed to removal excessive gum. For triple coating layer, after double layering, strips dipped in CMC 1% for 1 min and drained until excessive gums were separated. The weight of potato strips before and after each step of coating process were measured for determination of coating pick-up percentage.

Coated and uncoated (control) samples fried in a controlled temperature domestic deep fat fryer (Teafall) filled with 2.5 L of commercial frying (blended of sun flower and soy bean oils) oil which purchased from local market. Frying conditions were 2.5 min at 175°C (Daraei Garmakhany et al. 2008).

Experiments

Dry matter and moisture content of the raw potato and French fries were measured based on AOAC methods (2005, 18th edition). Analysis of reducing sugars and sucrose, performed by the Lin Aynon (Fehling) method as described by AOAC methods (2005, 18th edition).

Water content

Water content (WC) of potato strips was determined by measuring their weight loss after drying in an oven at 105°C until a constant weight was reached.

Lipid content

Lipid content (LC) of fried products was determined on dried samples by using continuous Soxhlet extractions. For extraction of lipid, petroleum ether (Merck Company) was used.

Fat and water contents were measured after frying the coated samples. The purpose of these measurements was to observe the any changes in product composition due to coating (Susanne and Gauri 2002).

Fat reduction due to coating, in the coated product relative to the uncoated one was calculated as follows:

Fat reduction due to coating

$$= \frac{LC(aftr\ coating) - LC(before\ coating)}{LC(before\ coating)} \times 100 \qquad (1)$$

Where LC-coated and LC-uncoated are the lipid contents of the coated and uncoated samples respectively. For each coating formulation, results were obtained using all samples from at least three different batches.

Water loss during frying

$$= \frac{(\text{initial water} - \text{water after frying})}{\text{initial water}} \qquad (2)$$

Decrease in water loss due to coating

$$= \frac{((\text{water loss; non} - \text{coated}) - (\text{water loss; coated}))}{\text{water loss; non} - \text{coated}} \qquad (3)$$

$$\text{Fat uptake} = \frac{(\text{final fat content} \times \text{mass after frying} - \text{initial fat content} \times \text{mass before frying})}{\text{dry mass}} \qquad (4)$$

Coating pick-up calculations

Coating pick-up was calculated from the difference between coated weight and non-coated weight of raw potato sample. It can be formulated as in equation 5 (Parinyasiri et al. 1991);

$$\%\ \text{Coating Pick} - \text{Up} = (C - I)/I \times 100 \qquad (5)$$

Where;

C weight of raw coated potato strips (g)
I initial weight of raw non-coated potato strips (g)

Frying yield calculations

Percentage of frying yield was obtained by considering the weight of the fried potato strips and the raw potato strips after coating. It can be formulated as equation 6 (Parinyasiri et al. 1991);

$$\%\ \text{Frying Yield} = (CW/C) \times 100 \qquad (6)$$

Where

CW cooked weight of coated potato strips (g).
C weight of non-cooked coated potato strips (g).

Colorimetric measurements

The color parameters (Hunter L, a, b) were measured with a Data color, color reader (Text Flash, USA). The three color coordinates ranged from L=0 (black) to L=100 (white), -a (greenness) to + a (redness), and –b (blueness) to + b (yellowness) (Clydesdale 1984). Total color difference (ΔE) was calculated from Equation 7 (Ling et al. 1998);

$$\Delta E = \left[(L - L\ \text{standard})^2 + (a - a\ \text{standard})^2 + (b - b\ \text{standard})^2 \right]^{1/2} \quad (7)$$

Where; standard values referred to the $BaCl_2$ plate (L=96.9, a=0 and b=7.2) used for calibrating the colorimeter. Triplicate readings were carried out at room temperature on three different locations of each slice: the center point and both ends, and the mean values were recorded.

Texture measurement

Texture of coated and uncoated potato strips were measured by use of Instron machine (1140, Instron company of England). Shear and cutting forces were measured based on Warner-Bratzler Shear method on cylindrical samples. Shearing force was formulized as below equation:

$$\text{Shearing force} = \frac{F}{2\pi r^2} \quad (8)$$

Where; F was the required force for cutting the cylindrical potato strips and r was the potato samples radius. Triplicate readings were carried out at room temperature on the center point of each slice (Daraei Garmakhany et al. 2010).

Statistical analysis

This study was conducted on completely randomized design. All these experiments were replicated three times, and the average values are reported. The effect of different concentration of gums on different quality factors of produced french fries were determined using the analysis of variance (ANOVA) method and significant differences of means were compared using the Duncan's test at 5% significant level using SAS software (2001) program.

Results and discussion

Physicochemical analysis of Kenebk variety showed that this variety with high solids content (20.4% w.b), suitable specific gravity (1.09) and low content of reducing sugars (0.62 mg/100 g of sample) and sucrose (0.88 mg/100 g of sample) is appropriate for fried products.

Influence of single layer coating

As it can be seen in Table 1, 1% xanthan gum with 21.6% coating has the highest amount of coating pick up ($p<0.05$). Minimum coating pick up was related to pectin that can be because of its lower gel formation ability.

The higher amount of coating pick up in xanthan gum may be due to ability of thick gel formation. In general, by increasing the gum concentration, the coating percentage was increased (Table 1) which is not uniform and linear relationship.

The maximum moisture loss during frying was related to guar gum. Gums which can be placed on external surface of potato strips act as a barrier to moisture removal during frying and so, reduced the moisture loss of French fries. Generally, coating with hydrocolloids increased the moisture content of final products compared with uncoated samples which is in agreement with the results reported by Khalil (1999), Williams and Mittal (1999), Balasubramaniam et al. (1997). The highest and lowest moisture content was observed respectively for the French fries coated with 1.5% xanthan gum and 0.5% pectin gum. Different gums led to different water increase in fried strips but this differences were not significant ($P>0.05$). Increase in water content due to coating, may be result of barrier properties of coating agents which prevent water loss during frying and by this mechanism water content of coated strips were higher than non coated strips. Water content of coated stripes was higher than non coated strips. Different gums due to different barrier properties and different gel formation ability led to different water retention in fried product. Indeed these properties related to gums structure and its functional groups (Williams and Mittal 1999; Balasubramaniam et al. 1997; Daraei Garmakhany et al. 2008; Sakhale et al. 2011). Different gums led to different decrease in amount of oil absorption in final products. Among different gums that used in this study as a single-layer coating, mixture of pectin and CMC 1% and xanthan gum 1.5% led to highest decrease in fat content and the lowest decrease in amount of fat absorption was observed in pectin gum 0.5% and guar gum 0.5% respectively. Coating with xanthan gum in all concentrations showed the high decrease in fat content. Coating with mixture of pectin and CMC in both concentrations also led to higher decrease in fat content of fried strips, this can be due to synergistic effect of tow gums on each others. Mixture of pectin and CMC gums in both concentrations decreased fat content more than each of them that used alone. Our Result showed that, by increase of gums concentration fat content, decreased. Also, all the coated samples had a lower oil uptake than uncoated samples which was significantly different ($p<0.05$). This can be due to lower

Table 1 Effect of single coating layer with hydrocolloids on quality attribute of potato French fries

Treatment	Dry matter content (% w.b)	Moisture content (%w.b)	Fat content (% w.b)	Coating pick up (% w.b)	Decrease in fat uptake due to coating (% w.b)	Decrease in water loss due to coating (% w.b)	Water loss during frying (% w.b)
blank	44.4±0.17^{a}	55.6 ±0.17^{d}	14.1±0.18^{a}	-	-	-	0.30±0.02^{a}
pectin 0.5%	44.4±0.17^{a}	55.6 ±0.17^{d}	14.1±0.18^{a}	2.4±0.43^{fgh}	47.9±0.13^{d}	0.70±0.14^{abcd}	0.30±0.02^{a}
pectin 1%	27.9±0.16^{bcd}	72.1±0.16^{abc}	7.3±0.83^{b}	3.7±0.48^{efgh}	67.3±0.04^{ab}	1.0±0.33^{ab}	0.09±0.04^{bcd}
guar 0.3%	23.5±0.51^{cd}	76.5±0.51^{ab}	4.6±0.61^{de}	3.6±0.76^{efgh}	57.5±0.11^{bcd}	0.50±0.35^{bcd}	0.04±0.10^{cd}
guar 0.5%	32.5±0.62^{bc}	67.5±0.62^{bc}	6.0±0.40^{bcd}	5.6±0.53^{cdef}	49.7±0.16^{cd}	0.60±0.17^{abc}	0.15±0.10^{bc}
guar 1%	30.2±0.82^{bcd}	69.8±0.82^{abc}	7.1±0.15^{bc}	4.9±0.55^{defg}	60.2±0.09^{abcd}	0.41±0.52^{d}	0.12±0.05^{bcd}
CMC 0.5%	35.6±0.57^{ab}	64.4±0.56^{cd}	5.6±0.32^{bcde}	8.7±0.60^{bcde}	56.7±0.07^{bcd}	0.41±0.13^{cd}	0.19±0.14^{ab}
CMC 1%	35.2±0.51^{ab}	64.8±0.51^{cd}	6.1±0.06^{bcd}	9.7±0.85^{bcd}	65.1±0.05^{abcd}	0.60±0.26^{abcd}	0.20±0.03^{ab}
xanthan 0.5%	30.2±0.13^{bcd}	69.8±0.13^{abc}	4.9±0.75^{bcde}	10.5±0.01^{bc}	66.4±0.06^{abc}	0.62±0.17^{abcd}	0.12±0.08^{bcd}
xanthan 1%	29.3±0.60^{bcd}	70.7±0.60^{abc}	4.7±0.84^{cde}	21.6±0.18^{a}	62.3±0.14^{abcd}	1.0±0.18^{a}	0.11±0.05^{bcd}
xanthan 1.5%	20.2±0.42^{d}	79.8±0.42^{a}	5.3±0.84^{bcde}	21.6±0.25^{a}	75.7±0.04^{a}	0.82±0.09^{abcd}	−0.00±0.06^{d}
mixture gum 0.5%**	25.1±0.22^{bcd}	74.9±0.22^{abc}	3.4±0.58^{e}	7.8±0.48 ^{h}	70.0±0.03^{ab}	0.73±0.12^{abcd}	0.07±0.03^{bcd}
mixture gum 1%**	27.1±0.56^{bcd}	72.9±0.56^{abc}	4.2±0.38^{de}	4.0±0.74^{efgh}	76.0±0.07^{a}	0.62±0.30^{abcd}	0.08±0.03^{bcd}

Each observation is a mean of 3 replicate experiments.

Mean with the same letter in each column are not significantly different at 95% level.

**Mixture gum 0.5% means mixture of pectin 0.5% and CMC 0.5%.

**Mixture gum 1% means mixture of pectin 1% and CMC 1%.

moisture loss of coated samples during frying and therefore, lower oil uptake.

Our results revealed that samples coated with xanthan, guar and CMC gums required a lower amount of force for cutting (Table 2). Studied by Rovedo et al. (1999), Olewnick and Kulp (1993) have shown that final texture of a fried product is slightly dependent on its composition. In fact, interaction between protein and starch (amylose and amylopectin) is important for the quality and texture of final product. Hence, pectin and mixture of pectin and CMC can react with the cell wall constituents (calcium) of potato and lead to a harder texture which requires a higher force for cutting ($p<0.05$).

Regarding color, the highest L value was observed in coated samples with 0.5% CMC and mixture of 0.5% CMC and 0.5% pectin while the lowest L value was related to coated samples with 0.5% pectin which significantly different with uncoated sample ($p<0.05$%). Other gums didn't have a significantly different L value compared with uncoated samples

Table 2 Effect of single coating layer with hydrocolloids on color and texture of potato French fries

Treatment	Maximum shearing force	Value L	Value a	Value b	ΔE
blank	12.2±0.14^{a}	66.2±2.11^{ab}	−0.98±0.01^{a}	15.6±0.61^{b}	68.0±2.11^{ab}
pectin 0.5%	9.4±0.11^{d}	60.0±1.21^{b}	1.43±0.11^{a}	20.2±1.01^{ab}	63.3±1.41^{b}
pectin 1%	10.2±0.17^{c}	63.4±0.18^{ab}	0.38±0.08^{a}	19.2±0.19^{ab}	66.2±1.61^{ab}
guar 0.3%	8.1±0.08^{i}	68.0±0.34^{a}	0.04±0.02^{a}	18.5±2.10^{ab}	70. 6±2.01^{ab}
guar 0.5%	8.8±0.12^{e}	69.1±2.32^{a}	0.66±0.14^{a}	20.4±1.76^{ab}	72.0±1.01^{a}
guar 1%	10.3±0.05^{b}	64.8±1.54^{ab}	0.29±0.06^{a}	19.1±1.41^{ab}	67.6±0.84^{ab}
CMC 0.5%	8.4±0.21^{g}	69.1±0.90^{a}	0.58±0.04^{a}	21.7±0.61^{ab}	72.5±0.61^{a}
CMC 1%	8.6±0.23^{f}	66.4±2.56^{ab}	1.77±0.21^{a}	23.2±1.78^{a}	70.5±1.34^{ab}
xanthan 0.5%	6.2±0.13^{l}	64.9±0.78^{ab}	−0.17±0.01^{a}	19.8±2.05^{ab}	67.8±1.09^{ab}
xanthan 1%	6.4±0.28^{j}	68.6±3.03^{a}	−0.62±0.11^{a}	17.2±1.21^{ab}	70.7±1.39^{ab}
xanthan 1.5%	8.2±0.16^{h}	63.7±0.38^{ab}	0.27±0.15^{a}	19.8±2.51^{ab}	66.7±1.82^{ab}
mixture gum 0.5%**	10.2±0.21^{c}	68. 3±1.48^{a}	0.04±0.01^{a}	20.0±1.23^{ab}	71.2±2.08^{a}
mixture gum 1%**	15.2±0.25^{a}	66.0±1.68^{ab}	1.37±0.23^{a}	21.4±2.16^{ab}	69.5±1.71^{ab}

Each observation is a mean of 3 replicate experiments.

Mean with the same letter in each column are not significantly different at 95% level.

**Mixture gum 0.5% means mixture of pectin 0.5% and CMC 0.5%.

**Mixture gum 1% means mixture of pectin 1% and CMC 1%.

Table 3 Effect of double coating layer with hydrocolloids on quality attribute of potato French frie

Coating	Blank	G+X	G+G
Dry matter content (% w.b)	44.4±1.17[a]	27.2±5.40[b]	30.7±1.61[b]
Moisture content (%w.b)	55.6±1.17[b]	72.9±5.40[a]	69.3±1.61[a]
Fat Content (% w.b)	14.1±0.18[a]	5.8±0.72[b]	3.8±0.71[b]
Coating pick up (% w.b)	-	11.3±3.08[a]	10.0±1.26[a]
Decrease in fat uptake due to coating (% w.b)	-	59.0±0.05[a]	73.9±0.05[a]
Decrease in water loss due to coating (% w.b)	-	0.72±0.21[a]	0.57±0.08[a]
Water loss during frying (% w.b)	0.30±0.02[a]	0.08±0.07[b]	0.13±0.02[b]
Maximum shearing force	12.2±0.28[a]	6.7±0.13[c]	7.7±0.12[b]
value L	66.2±1.18[ab]	62.1±0.58[a]	67.1±2.11[a]
value a	−0.98±0.08[a]	0.60±0.18[a]	0.16±0.02[a]
value b	15.6±0.68[b]	19.6±1.71[a]	20.3±1.18[a]
ΔE	68.0±2.08[ab]	65.1±1.13[a]	70.9±2.11[a]

Each observation is a mean of 3 replicate experiments.

Mean with the same letter in each column are not significantly different at 95% level.

G+X mean double layer coating with mixture gum 1% + xanthan 1%.

G+G mean double layer coating with mixture gum 1% + guar gum 1%.

**Mixture gum 1% means mixture of pectin 1% and CMC 1%.

($p>0.05$%) which was in agreement with the results of Daraei Garmakhany et al. (2008) and Khalil (1999). Both concentrations of CMC had a high a value which was increased with increase of CMC concentration. For pectin coated samples, by increasing pectin concentration, the a value was decreased. The highest and lowest a value was observed respectively for 1% CMC and uncoated samples which was similar to b value. Finally for ΔE value, there was a difference in samples coated with various gums, although in many cases the difference was not significant ($p>0.05$%). The highest and lowest ΔE values were observed respectively for 1% CMC and 0.5% pectin coated samples (Table 2). Since there is no significant difference between coated and uncoated samples in terms of color values in most of the cases, it can be concluded that single-layer coating with mentioned gums is favorable for commercial production of French fries, but the final selection of

Table 4 Effect of triple coating layer with hydrocolloids on quality attribute of potato French fries

Coating	Blank	G+X+C	G+G+C.
Dry matter content (% w.b)	44.4±1.17[a]	27.0±6.12[b]	24.5±3.54[b]
Moisture content (%w.b)	55.6±1.17[b]	73.6±6.12[a]	75.5±3.54[a]
Fat Content (% w.b)	14.1±0.18[a]	5.0±1.71[b]	4.4±1.86[b]
Coating pick up (% w.b)	-	13.3±3.08[a]	12.5±1.26[a]
Decrease in fat uptake due to coating (% w.b)	-	64.4±0.12[a]	68.5±0.14[a]
Decrease in water loss due to coating (% w.b)	-	0.72±0.26[a]	0.83±0.15[a]
Water loss during frying (% w.b)	0.30±0.02[a]	0.36±0.04[a]	0.31±0.13[a]
Maximum shearing force	12.2±0.28[a]	10.5±1.07[b]	10.6±1.28[b]
value L	66.2±1.18[ab]	66.9±1.21[a]	62.2±1.08[a]
value a	−0.98±0.08[a]	−0.16±0.01[a]	1.07±0.11[a]
value b	15.6±0.68[b]	17.2±0.91[a]	20.6±1.07[a]
ΔE	68.0±2.08[ab]	69.1±1.47[a]	65.8±1.82[a]

Each observation is a mean of 3 replicate experiments.

Mean with the same letter in each column are not significantly different at 95% level.

**G+X+C mean triple layers coating with mixture gum 1% + xanthan 1% + CMC 1%.

G+G+C mean triple layers coating with mixture gum 1% + guar 1% + CMC 1%.

Mixture gum 1% means mixture of pectin 1% and CMC 1%

coating agent must be done according to the influence of coating gums on oil uptake, texture and other quality attributes of French fries in addition to color.

Influence of double-layer coating

Our results (Table 3) revealed that double-layer coating with guar gum reduced the oil uptake of final products more than xanthan gum, but the difference is not statistically significant ($p>0.05$). The other result was reduction of moisture loss during frying with double-layer coating ($p<0.05$) which in this regard, xanthan was more effective than guar, i.e., French fries coated with xanthan had a higher moisture content ($p<0.05$). During frying water content of potato strips changed to vapor and this vapor create a suction presser in fried strips. Hence the potato strips removed from the fryer this suction pressure led to penetration of oil instead evaporated water. According to this fact each factor that prevents water loss during frying led to decrease in oil uptake. This could be the reason of higher oil uptake of xanthan coated products, since the moisture is replaced by oil during frying.

As it is shown in Table 3, the cutting force for double-layer guar coated samples was significantly higher than their xanthan counterparts ($p<0.05$). The highest cutting force (12.2 N) was related to uncoated samples and the lowest for xanthan coated samples. The lower cutting force of double-layer coated products could be explained by the higher moisture loss of uncoated samples which causes surface shrinkage and a compressed texture in these samples, thereby, requiring more cutting force. Moisture content in coated French fries is higher and so their texture becomes tenderer during frying that needs a lower cutting force.

In terms of color, double-layer coated products with guar gum had the highest L value and the lowest L value was belonging to xanthan coated samples (Table 3). On the other hand, xanthan coated products had the highest a value and the lowest a value was related to uncoated samples. The other results of color values were presented in Table 3. As it can be seen (Table 3), considering total evaluation (ΔE), the highest ΔE value was related to guar coated product which was significantly different and higher than xanthan coated samples ($p<0.05$).

Influence of triple-layer coating

We found that triple-layer coated products with guar gum had higher moisture content than their xanthan gum counterparts (Table 4) which in both was significantly different ($p<0.05$) and higher than uncoated samples. In terms of oil uptake, guar coating led to a lower oil uptake compared with xanthan and generally, triple-layer coating caused a significantly lower oil uptake than uncoated samples ($p<0.05$). This could be explained by the role of moisture removal during frying which was described before.

In terms of texture evaluation, triple-layer coating caused a lower cutting force (Table 4). When comparing two different gums, guar coated French fries required a higher cutting force than xanthan coated products.

Considering color evaluation, the highest and lowest L values were related to xanthan and guar coated samples respectively, but the difference was not statistically significant ($p>0.05$). Generally, triple-layer coated products had higher a, b and c values compared with uncoated samples (Table 4).

Conclusion

Our results showed that coating of French fries with different layers of hydrocolloids reduced the moisture loss of products during frying because of their barrier properties. Since moisture removal during frying is a key factor for oil uptake of fried products, coated samples have significantly lower oil uptake than uncoated ones. For single-layer coating, 0.5% CMC, the mixture of CMC and pectin (0.5 and 1%), guar 0.3% and xanthan (in all concentration) produced fried products with the lowest oil uptake. From these gums, CMC and the mixture of CMC and pectin is recommended for single-layer coating and the other gums, particularly xanthan, are not favorable because their solution have a high viscosity and can not coat the products uniformly. Considering double and triple-layer coating, although they can reduce the oil uptake, but they not recommended for some of fried products such as chips and French fries neither which are expected to have a tender structure, because these coated products have high moisture content nor a tender texture. Double and triple-layer coating can be used for the production of low fat products.

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