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Quality of french fried potatoes as influenced by coating with hydrocolloids

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Abstract

Potato french fries were coated with a combination of calcium chloride and either pectin or sodium alginate at different levels. The best treatment was selected for the second coating with different hydrocolloids. Qualities of single- and double-coated french fries were evaluated. Potato french fries coated with sodium alginate as a first coating had less oil reduction and less quality than those coated with pectin. Single-coated french fries with a combination of 0.5% calcium chloride and 5% pectin had the highest reduction of oil content as well as the highest moisture content. Also, coated french fries at these levels exhibited higher red and yellow colours and were firmer than the control. Coated french fries with 0.5% calcium chloride and 5% pectin had higher sensory scores for all attributes compared to the control. French fries coated with carboxy methyl cellulose (CMC) as a second layer were more effective than those coated with pectin or sodium alginate in reducing the oil content. The incorporation of CMC at 1.5% level as a second layer reduced the oil content by 54%; however, the single coating with 0.5% calcium chloride and 5% pectin reduced the oil content by 40%. Double-coated french fries had higher moisture contents and firmer structures than the single coated french fries. Increasing the level of the hydrocolloid forming the second coating up to 1.5% resulted in non-significant differences in the sensory scores for all attributes. Scanning electron microscope photographs indicated that the single- or double-coating process was effective in protecting the cellular structure of potato tissues from the damage produced during deep-fat frying.

1. Introduction

Fat and oils are important sources of certain nutrients and food energy and also provide unique properties for fried food, such as flavour and mouthfeel, improve overall food palatability and provides heat transfer medium during cooking (Pearson, Gray, & Tatum, 1981; Schneeman, 1987). During the past 10 years, the American Heart Association and other health organizations have encouraged reduction of fat from food to less than 30% of calories for most people (USDA, 1990; USDA & USDHHS, 1990).

Deep-fat frying is a complex and important operation, widely used by the food industry and consumers (Varela, 1988). Oil uptake during deep-fat frying of products is affected by many factors, including oil quality, frying temperature and duration, its composition (e.g. moisture, solids, fat, protein) porosity and pre-frying treatment such as drying and blanching (Pinthus, Weinberg, & Saguy, 1995; Selman & Hopkins, 1989; Stier & Blumenthal, 1990). French fried potatoes represent one of the major items in the food market either as a processed product or as a frozen par-fried. It has been reported that french fried potatoes absorb about 15% oil during frying (Toma, Leung, Augustin, & Iritani, 1986). To make such products more acceptable to health-conscious consumers, the fat should be reduced. Many attempts have been made to reduce oil uptake during deep-fat frying. Batter coating and breading can influence oil absorption, but the reported results have been inconsistent (Duxbury, 1989; Makinson, Greenfield, Wong, & Willis, 1987). Incorporation of long-fibre cellulose into batters or donut mixes reduces oil uptake reasonably (Ang, Miller, & Dunham, 1990). Increasing gel strength of restricted potato products reduces oil uptake during deep-fat frying (Pinthus, Weinberg, & Saguy, 1992).

This paper addresses the reduction in oil retention of potato french fries by forming a dry double coating with different hydrocolloid gel-forming compounds prior to frying. The first coating includes cross linking polyvalent agents (calcium ions) and either alginate or pectin

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hydrocolloid gel-forming compounds. The second coating is applied only by using different hydrocolloids. Alginate and pectin are widely used in food systems as a stabilizer and to modify the rheology of food sols. One of their more useful properties is gelation. Alginate and pectin are different from other gel-forming hydrocolloids because they form chemically- rather than thermally-induced gels. Alginate and pectin gels are formed by intermolecular association with polyvalent cations (Clarke, Sofos, & Schmidt, 1988; Hudson and Buescher, 1986; Means, Clarke, Sofos, & Schmidt, 1987; Sapers, Cooke, Heidel, Martin, & Millir, 1997). Calcium ions are superior to other polyvalent cations in their interaction with alginate and pectin and are also the most commonly used cations in food systems (Chang, Tsai, & Chang, 1993; Cottrell & Kovacs, 1980; Sanderson, 1981). The Food Safety and Inspection Service of the United States Department of Agriculture (USDA; FSIS, 1986) allows the use of pectin, alginate and calcium as binders.

The objectives of this study were to evaluate the effect of a single coating with various levels of a combination of calcium chloride and pectin or sodium alginate on oil reduction, water content, colour, texture and sensory properties of potato french fries. The effect of a second coating with different hydrocolloids (pectin, alginate and carboxy methyl cellulose), for the best single coating treatment, was also evaluated.

2. Material and methods

2.1. Materials

King Edward potatoes (*Solanum Tuberosum* L,) used in the study were obtained from the Vegetable Research Farm at Shibin El-Kom, Menofiya University, Egypt. The hydrocolloids used in the investigation and their sources were: (1)- pectin (Sigma Chemical Company, St Louis, MO, USA). (2)- alginic acid, sodium salt (Aldrich Chemical Company, Milwaukee, WI, USA). (3)- carboxy methyl cellulose, high viscosity (Sigma Chemical Company, St-Louis, MO, USA).

2.2. Preparation of potato french fries

The potatoes were hand-peeled, cut into strips (1.0×1.0×6.0 cm) with a french fry cutter (Matric 15 type GHEF, Italy) and washed with cold water. The strips were divided into five portions. The first portion was blanched by heating at 85°C for 6 min in water (without calcium chloride), while the other four portions were blanched in an aqueous solution of calcium chloride of different concentrations (0.1, 0.3, 0.5 and 0.7%). These strips were then dried in a convection oven (VEB MLW Medizinische, Gerate, Berlin, Germany) at 150°C for 10 min. The first coating with hydrocolloid was achieved by soaking the strips of each portion, in an aqueous solution of either pectin or sodium alginate at different concentrations 1, 2, 3, 4, 5 and 6%), at 37°C for 5 min. Samples from each portion were saved without hydrocolloid treatment as a control. The strips were then dried at 150°C for 10 min and fried at 170°C for 3 min in sunflower seed oil using a deep-fat fryer (CICA model type GLE No. 18651, Italy). All fried samples were drained for 1.5 min and cooled to room temperature before analysis.

The best treatment for potato strips (calcium chloride 0.5%, pectin 5%), which had the least oil content without altering the organoleptic properties of the final product, was selected for the application of the second coating. The second coating was applied by dipping the strips, for 5 min, in different concentrations (0.5, 1.0 1.5, 2.0 and 2.5%) of aqueous solutions of pectin, sodium alginate and carboxy methyl cellulose and then drying for an additional 10 min at 150°C. Strips were then fried as previously described.

2.3. Analytical methods

Moisture and fat contents were determined according to the method of AOAC (1990). Colour of the french fries was determined using a Lovibond Tintometer (The Tintometer LTD, Salisbury, England).

The Ottawa Texture Measuring System (Canners Machinery LTD., Ontario, Canada) was used for evaluating the Kramer shear force, (kg force/20 g sample).

For the scanning electron microscope photographs, samples were fixed in 2.5% glutaraldehyde buffer with 0.1 M phosphate buffer at pH 7.4. Samples were fixed cold (4°C) in the same buffer for 1–2 h, then rinsed three times for 30 min and dehydrated in ethanol. Samples were dried with CO_2 under vacuum using Samdri-PVT-3B Tousimis apparatus (Tousimis Research Corporation, Rockville, MD, USA). Samples were coated with gold using a JEOL, JFC-1100E, ion sputtering device and examined by a JEOL, TSM-5300 scanning microscope.

Sensory evaluation of french fries was conducted by eight trained panellists who were graduate students and staff members in the Department of Food Science and Technology, Menofiya University. Randomly coded samples were served to panellists individually. Five sensory attributes were evaluated (appearance, colour, taste, texture, and overall palatability) using an 8-point hedonic scale for each trait where 8 = excellent and 1 = extremely poor.

Data were recorded as means of triplicate measurements and were analyzed using a 5 (calcium chloride concentration)×13 (treatment)×3 (replication), for the first coating, and a 5 (hydrocolloid concentration)×3 (hydrocolloid type)×3 (replication), for the second coating, completely randomized factorial design (Montgomery, 1984).

An analysis of variance (SAS, 1988) was conducted. When a significant main effect was detected, the means were separated with the Student-Newman-Keuls test. Differences between treatments at the 5% ($p \leq 0.05$) level were considered significant.

3. Results and discussion

The oil content of single coated potato french fries was significantly ($p \leq 0.05$) affected by calcium chloride level and hydrocolloid treatment (Table 1). Data indicated that samples blanched with only calcium chloride at different levels had a slight reduction in oil content compared to control (1.8—14% reduction). These results might indicate that calcium alone is able, to some extent, to stabilize the tissue structure against the violence of the frying process. Firming the cell wall induced by calcium has been attributed to the formation of Ca-pectates that increase middle lamella-cell wall rigidity (Grant, Morris, Rees, Smith, & Thom, 1973) and resistance to degradation by the frying process.

On the other hand, samples treated with a combined pectin or sodium alginate and calcium chloride solution appeared to be significantly lower in oil content than control (6–40% reduction). These results indicate that coating with calcium chloride/pectin or sodium alginate interaction might form a rigid crosslinked network which helps to cement the cell walls and enclose the outer surface of the tissue and consequently prevent the oil penetration into the potato tissue. The lowest oil content was obtained by coating the potato french fries with 0.5% calcium chloride and 5% pectin.

The effect of coating with different levels of calcium chloride and pectin or sodium alginate on moisture content of french fries is shown in Table 2. The basic physical effect of deep-fat frying is water replacement by oil (Gamble, Rice, & Selman, 1987; Pinthus, Weinberg, & Saguy, 1993). Coating with pectin or sodium alginate gel-forming compounds and calcium chloride as cross-linking agent may alter the water-holding capacity and consequently affect oil uptake. Data indicated that french fries coated with either pectin or sodium alginate and calcium chloride had higher ($p \leq 0.05$) moisture contents than control. French fries coated with 0.5% calcium chloride and 5% pectin had the highest ($p \leq 0.05$) moisture content among all coated samples. It has been established that the deep-fat frying process causes damage to the cellular structure in plant tissues which may allow more water to evaporate (Toma et al., 1986). A linear relationship between oil uptake and water removal has been reported (Gamble et al., 1987). Therefore, in the present study, more oil was absorbed in the control samples than the coated samples with a combination of pectin or sodium alginate and calcium chloride.

The scanning electron microscope photographs of fried potato tissue (Fig. 1) might explain the results of the oil and moisture contents. The control sample showed extensive cell delamination, ruptured cells,

Table 1
Effect of single coating with combinations of various levels of calcium chloride and pectin or sodium alginate on oil content (g/100 g sample) of potato french fries[1]

Treatment		Calcium chloride concentration (%)					
		0	0.1	0.3	0.5	0.7	Mean[2]
Control		16.8	16.5	15.2	14.4	14.4	15.46^{h}
Pectin	1%	16.6	15.6	11.5	10.8	10.7	13.04^{ef}
	2%	16.1	15.2	11.2	10.7	10.8	12.80^{e}
	3%	15.6	14.9	10.7	10.4	10.5	12.42^{cd}
	4%	14.7	14.1	10.6	10.3	10.3	12.0^{b}
	5%	14.2	13.7	10.4	10.1	10.1	11.70^{a}
	6%	14.0	13.7	10.3	10.1	10.2	11.66^{a}
Sodium alginate	1%	16.6	15.8	11.9	11.5	11.5	13.46^{g}
	2%	16.4	15.4	11.7	11.3	11.3	13.22^{fg}
	3%	15.9	15.1	11.5	11.1	11.2	12.96^{e}
	4%	15.1	14.4	11.3	10.9	10.9	12.52^{d}
	5%	14.7	14.0	11.0	10.7	10.6	12.20^{bc}
	6%	14.4	14.1	11.1	10.7	10.8	12.21^{bc}
Mean[3]		15.5^{d}	14.8^{c}	11.4^{b}	11.0^{a}	11.0^{a}	

[1] Each value in the table is the mean of three replicates and two determinations were conducted for each replicate.
[2] Means in the same column with different letters are significantly different ($p \leq 0.05$), LSD = 0.24.
[3] Means in the same row with different letters are significantly different ($p \leq 0.05$), LSD = 0.39.

Table 2
Effect of single coating with combinations of various levels of calcium chloride and pectin or sodium alginate on moisture content (%) of potato french fries[1]

Treatment		Calcium chloride concentration					
		0	0.1	0.3	0.5	0.7	Mean[2]
Control		17.78	18.23	20.17	21.6	21.50	19.83^{a}
Pectin	1%	17.93	18.45	31.50	33.70	33.65	27.05^{d}
	2%	18.51	18.91	32.17	33.88	33.85	27.46^{e}
	3%	19.63	20.36	33.85	34.10	34.12	28.41^{g}
	4%	20.75	21.92	34.01	34.19	34.16	29.01^{h}
	5%	21.37	23.48	34.15	34.31	34.30	29.52^{i}
	6%	21.52	23.42	34.15	34.25	34.28	29.52^{i}
Sodium alginate	1%	17.95	18.18	30.75	31.55	31.58	26.0^{b}
	2%	18.21	18.51	30.91	31.89	31.89	26.30^{c}
	3%	18.91	20.01	32.55	32.70	32.71	27.18^{d}
	4%	19.63	21.43	31.92	33.15	33.14	27.95^{f}
	5%	20.18	23.02	32.90	33.80	33.77	28.73^{h}
	6%	20.96	23.09	32.88	33.78	33.77	28.90^{h}
Mean[3]		19.49^{a}	20.73^{b}	31.61^{c}	32.52^{d}	32.52^{d}	

[1] Each value in the table is the mean of three replicates and two determinations were conducted for each replicate.
[2] Means in the same column with different letters are significantly different ($p \leq 0.05$), LSD = 0.18.
[3] Means in the same row with different letters are significantly different ($p \leq 0.05$), LSD = 0.24.

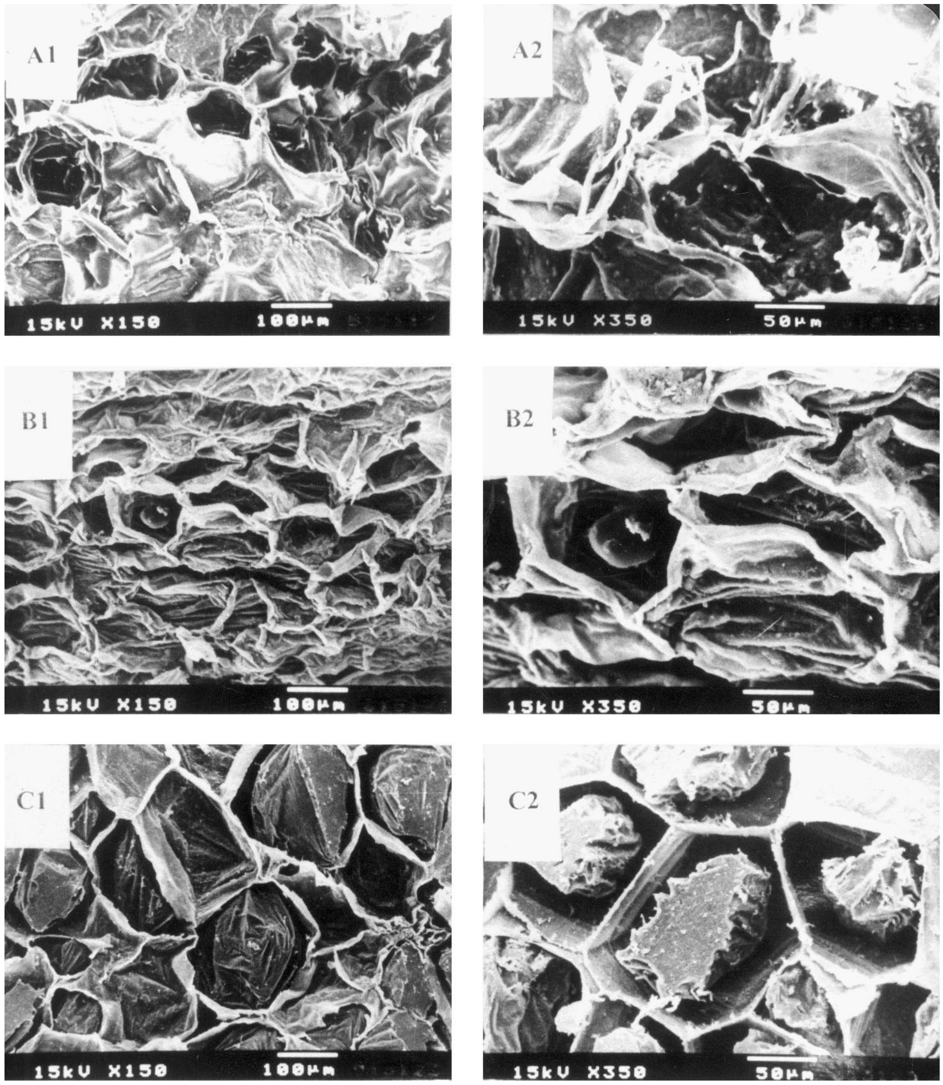

Fig. 1. Electron microscope photograph of uncoated (A1, 2); single-coated (B1, 2) and double-coated (C1, 2) potato french fries.

marked reduction in cytoplasmic contents due to migration of water, and large void spaces (A1). Also, middle lamella and cell wall damage in control samples were clearly observed (A2). In contrast, samples treated with a single coating of 0.5% calcium chloride and 5% pectin showed slight reduction in cell size and improved cellular integrity with slight shrinkage in the cell membrane (B1). Also, there were no disruption of cell walls or delamination of the middle lamella (B2).

The shear force data (Table 3) indicated that french fries coated with pectin or sodium alginate and calcium chloride were firmer ($p \leq 0.05$) than the control. It is well known that the texture of potato depends on the presence of pectic substances, which are part of the intercellular material (Badui, 1993). The weak structure (softness) of control samples could be attributed to the degradation of pectic substances during cooking, weakening the structure of the middle lamella matrix and concomitant loss of intercellular adhesion as well as weakening of cell walls which may play an important role in the rupturing of cells during the processing of potato fries [see Fig. 1 (A1 and A2)]. On the other hand, the increase of firmness in coated samples with either pectin or sodium alginate and calcium chloride could be due to the formation of a rigid crosslinked network that increases middle lamella-cell wall rigidity [see Fig. 1 (B1 and B2)], and forms a resistant film on the surface of the potato to protect the cell structure during the frying process.

French fries coated with pectin or sodium alginate exhibited higher ($p \leq 0.05$) red and yellow colours than the control (Table 4). The visual density values of single coated samples increased ($p \leq 0.05$) as the level of calcium chloride increased. The high visual density values of coated potato fries show a tendency toward a darker colour than the control. The brightness of the single coated samples followed a trend opposite that for visual density.

The saturation values of coated french fries increased ($p \leq 0.05$) as the level of calcium chloride increased. The increase in the saturation values indicates more intense colour. Increasing the level of pectin up to 5% resulted in a significant ($p \leq 0.05$) increase in saturation.

The sensory scores for all attributes were increased ($p \leq 0.05$) as the level of calcium chloride increased up to 0.5% concentration (Table 5). French fries coated with pectin at 3, 4 and 5% levels had higher ($p \leq 0.05$) sensory scores than the control for all the sensory attributes. On the other hand, french fries coated with sodium alginate at all tested levels were similar or lower in sensory scores than the control for all sensory attributes, except for the appearance and texture at 4 and 5% levels. It is interesting to note that panellists gave the low sensory scores for the single coated french fries at the lowest calcium chloride levels (0 and 0.1%) and at the highest pectin or sodium alginate level (6%). These results might indicate that the excess of pectin or sodium alginate, which has not yet reacted with calcium ions was responsible for lowering the sensory scores. Similar findings were observed by Means and Schmidt (1986).

The above results indicate that french fries coated with a single layer composed of 0.5% calcium chloride and 5% pectin had the lowest oil content, the highest moisture content and the best sensory characteristics. Therefore, this treatment was selected to be coated with another layer of hydrocolloid.

The effect of a second coating with different types and levels of hydrocolloids on oil content, moisture content and shear force of potato french fries is presented in Table 6. Data indicate that carboxy methyl cellulose (CMC) as a second layer was more effective ($p \leq 0.05$) than pectin or sodium alginate in reducing the oil content. It is notable that the first coating (combination between 0.5% calcium chloride and 5% pectin) reduced the oil content by 40%, while the incorporation of CMC as a second coating reduced the oil content by 54%.

The moisture content of double-coated french fries followed an opposite trend to the oil content.

Double-coated french fries, with CMC, were softer ($p \leq 0.05$) than those with pectin or sodium alginate. Generally, the double-coated french fries had firmer structures than the single-coated french fries.

The scanning electron microscope photographs of double-coated french fries [Fig. 1, (C1 and C2)] explain the results of oil and moisture contents as well as the structures of the potato fries. The photographs indicate that there were no rupture of potato tissue cells or reductions in cell size (C1). Also, the middle lamella-cell

Table 3
Effect of single coating with combinations of various levels of calcium chloride and pectin or sodium alginate on shear force (kg/20 g sample) of potato french fries[1]

Treatment		Calcium chloride concentration (%)					
		0	0.1	0.3	0.5	0.7	Mean[2]
Control		36.1	37.3	41.7	43.6	44.4	40.60^{a}
Pectin	1%	37.3	38.5	42.0	44.8	45.9	41.70^{b}
	2%	38.4	39.7	44.3	44.3	45.9	42.52^{c}
	3%	40.2	41.6	46.2	47.1	48.3	44.68^{e}
	4%	41.7	42.8	47.8	48.5	50.1	46.18^{f}
	5%	42.0	44.2	49.3	50.0	51.5	47.42^{h}
	6%	43.5	47.1	53.1	53.3	54.8	50.36^{k}
Sodium alginate	1%	38.8	39.1	45.2	46.2	47.4	43.34^{d}
	2%	39.9	40.6	6.5	47.8	48.6	44.68^{e}
	3%	41.4	42.8	48.4	49.3	51.8	46.74^{g}
	4%	42.8	44.1	49.3	50.7	52.4	47.86^{i}
	5%	43.1	46.4	50.1	51.8	53.3	48.94^{j}
	6%	44.3	49.2	53.9	55.2	56.9	51.90^{l}
Mean[3]		40.7^{a}	42.6^{b}	47.5^{c}	48.8^{d}	50.4^{e}	

[1] Each value in the table is the mean of three replicates and two determinations were conducted for each replicate.
[2] Means in the same column with different letters are significantly different ($p \leq 0.05$), LSD = 0.24.
[3] Means in the same row with different letters are significantly different ($p \leq 0.05$), LSD = 0.39.

Table 4
Colour attributes of single-coated french fries as influenced by calcium chloride level and hydrocolloid type and level[1]

Colour trait	Effect of calcium chloride concentration (%)					LSD	Effect of treatment													LSD
								Pectin concentration (%)						Alginate concentration (%)						
	0	0.1	0.3	0.5	0.7		Control	1	2	3	4	5	6	1	2	3	4	5	6	
Red[2]	0.33^{a}	0.53^{b}	0.72^{c}	1.29^{d}	1.68^{e}	0.07	0.60^{a}	0.84^{b}	0.74^{b}	1.0^{c}	1.30^{d}	1.42^{d}	1.30^{d}	0.74^{b}	0.74^{b}	0.80^{b}	0.76^{b}	0.80^{b}	0.82^{b}	0.10
Yellow[2]	1.08^{a}	1.62^{b}	2.28^{c}	2.59^{d}	3.34^{e}	0.07	1.48^{a}	2.47^{e}	2.31^{d}	2.48^{e}	2.96^{f}	2.96^{f}	3.03^{f}	2.04^{c}	2.02^{c}	1.66^{b}	1.64^{b}	1.64^{b}	1.64^{b}	0.11
Visual[2] density	0.02^{a}	0.03^{b}	0.05^{c}	0.07^{d}	0.09^{e}	0.004	0.03^{a}	0.06^{b}	0.06^{b}	0.07^{c}	0.08^{d}	0.09^{e}	0.09^{e}	0.03^{a}	0.03^{a}	0.03^{a}	0.03^{a}	0.03^{a}	0.03^{a}	0.007
Brightness[2] (%)	93.7^{e}	91.6^{d}	87.3^{c}	84.4^{b}	80.6^{a}	0.14	91.5^{f}	86.3^{e}	84.9^{d}	84.1^{c}	82.1^{b}	79.2^{a}	79.0^{a}	91.5^{g}	91.5^{f}	91.5^{f}	91.5^{f}	91.5^{f}	91.5^{f}	0.23
Saturation[2] (%)	15.8^{a}	21.7^{b}	30.9^{c}	28.8^{d}	39.7^{e}	0.16	20.6^{a}	30.9^{c}	31.2^{d}	32.0^{e}	35.9^{f}	36.9^{g}	37.1^{g}	21.5^{b}	21.5^{b}	21.6^{b}	21.5^{b}	21.4^{b}	21.6^{b}	0.26

[1] Each value in the table is the mean of three replicates and two determinations were conducted for each replicate.
[2] Means in the same row with different letters are significantly different ($p \leq 0.05$).

wall rigidity is clearly observable (C2). These findings indicate that double coating was more effective than single coating in protecting the potato tissue cells against the violence of the deep-fat frying process.

The colour attributes of double-coated french fries were affected ($p \leq 0.05$) by the level of the hydrocolloid forming the second coating (Table 7). Increasing the level of the hydrocolloid resulted in significant ($p \leq 0.05$)

Table 5
Sensory scores of single-coated french fries as influenced by calcium chloride level and hydrocolloid type and level[1]

Sensory trait	Effect of calcium chloride concentration (%)					LSD	Effect of treatment													LSD
								Pectin concentration (%)						Alginate concentration (%)						
	0	0.1	0.3	0.5	0.7		Control	1	2	3	4	5	6	1	2	3	4	5	6	
Appearance[2]	3.9^{a}	4.5^{b}	5.4^{c}	6.5^{d}	5.3^{c}	0.44	4.4^{a}	4.6^{a}	4.8^{a}	5.6^{bc}	5.6^{bc}	6.0^{c}	5.0^{ab}	4.6^{a}	4.8^{a}	5.0^{ab}	5.6^{bc}	5.8^{c}	4.8^{a}	0.72
Colour[2]	3.2^{a}	3.8^{b}	4.8^{c}	5.9^{d}	5.1^{c}	0.44	4.4^{a}	4.4^{a}	4.4^{a}	5.4^{b}	5.4^{b}	5.4^{b}	4.4^{a}	4.2^{a}	4.2^{a}	4.2^{a}	4.2^{a}	4.4^{a}	4.2^{a}	0.72
Texture[2]	3.5^{a}	43^{b}	5.5^{d}	6.8^{e}	5.0^{c}	0.44	4.6^{ab}	4.6^{ab}	4.6^{ab}	5.6^{c}	5.6^{c}	5.6^{c}	4.8^{ab}	4.4^{a}	4.8^{ab}	5.2^{bc}	5.6^{c}	5.8^{c}	4.8^{ab}	0.71
Taste[2]	5.5^{b}	5.6^{b}	6.5^{c}	6.8^{c}	5.0^{a}	0.43	6.4^{c}	6.6^{cd}	6.6^{cd}	7.2^{d}	7.2^{d}	7.2^{d}	6.4^{c}	4.0^{a}	4.4^{a}	4.6^{a}	5.4^{b}	5.6^{b}	4.6^{a}	0.69
Overall[2] acceptability	4.0^{a}	4.6^{b}	5.1^{bc}	6.6^{d}	5.2^{c}	0.51	4.8^{ab}	5.1^{abc}	5.1^{abc}	5.7^{cd}	5.9^{cd}	6.1^{d}	5.2^{bc}	4.3^{a}	4.6^{ab}	4.8^{ab}	5.2^{bc}	5.4^{bcd}	4.6^{ab}	0.81

[1] Each value in the table is the mean of three replicates and two determinations were conducted for each replicate.
[2] Means in the same row with different letters are significantly different ($p \leq 0.05$). Means based on an 8 point scale where 1 = extremely poor and 8 = excellent.

Table 6
Effect of second coating with various levels of pectin, sodium alginate and CMC[1] on oil content (g/100 g sample), moisture content (%) and shear force (kg/20 g sample) of potato french fries

Concentration (%)		Treatment											
		Pectin	Sodium alginate	CMC	Mean[2]	Pectin	Sodium alginate	CMC	Mean[2]	Pectin	Sodium alginate	CMC	Mean[2]
		Oil (%)				Moisture (%)				Shear force			
Control	0	10.1	10.1	10.1	10.1^{c}	34.31	34.31	34.31	34.31^{a}	50.0	50.0	50.0	50.0^{a}
	0.5	9.2	9.1	8.9	9.04^{b}	35.10	35.43	36.52	35.68^{b}	51.7	52.6	50.2	51.5^{b}
	1	8.7	8.6	8.4	8.57^{b}	36.72	37.04	37.34	37.03^{c}	52.4	54.3	50.2	53.2^{c}
	1.5	8.5	8.4	7.7	8.16^{a}	37.11	37.22	40.15	38.16^{d}	54.6	56.2	50.3	53.7^{d}
	2	8.6	8.5	7.5	8.20^{a}	37.09	37.0	40.63	38.25^{d}	57.8	59.9	50.3	56.0^{e}
	2.5	8.5	8.4	7.5	8.13^{a}	37.10	37.22	40.62	38.32^{d}	60.3	62.3	50.3	57.63^{f}
Mean[3]		8.93^{b}	8.83^{b}	8.34^{a}		36.24^{a}	36.38^{a}	38.26^{b}		54.47^{b}	55.88^{c}	50.22^{a}	

[1] Carboxymethyl cellulose. Each value in the table is the mean of three replicates and two determinations were conducted for each replicate.
[2] Means in the same column with different letters are significantly different ($p \leq 0.05$), LSD for oil = 0.34, LSD for moisture = 0.24, LSD for shear force = 0.43.
[3] Means in the same row with different letters are significantly different ($p \leq 0.05$), LSD for oil = 0.48, LSD for moisture = 0.34, LSD for shear force = 0.60.

Table 7
Colour attributes of double-coated french fries as influenced by hydrocolloid level and type[1]

Colour trait	Effect of concentration (%)						LSD	Effect of treatment			LSD
	0	0.5	1	1.5	2	2.5		Pectin	SA[3]	CMC[4]	
Red[2]	0.70^{a}	0.81^{b}	0.93^{b}	0.97^{b}	0.97^{c}	1.27^{c}	0.10	1.23^{c}	0.83^{b}	0.75^{a}	0.07
Yellow[2]	2.50^{a}	2.97^{c}	2.71^{b}	2.77^{bc}	2.80^{bc}	2.93^{c}	0.20	2.85^{a}	2.78^{a}	2.70^{a}	0.20
Visual density[2]	0.06^{a}	0.07^{b}	0.07^{b}	0.07^{b}	0.07^{b}	0.09^{c}	0.009	0.09^{c}	0.07^{b}	0.06^{a}	0.007
Brightness (%)[2]	86.1^{e}	84.2^{d}	83.5^{c}	83.5^{c}	82.9^{b}	80.5^{a}	0.22	80.4^{a}	84.2^{b}	85.8^{c}	0.15
Saturation (%)[2]	37.0^{a}	39.7^{b}	39.9^{b}	37.3^{a}	39.6^{b}	39.1^{b}	0.65	38.7^{a}	38.9^{a}	38.6^{a}	0.46

[1] Each value in the table is the mean of three replicates and two determinations were conducted for each replicate.
[2] Means in the same row with different letters are significantly different ($p \leq 0.05$).
[3] Sodium alginate.
[4] Carboxymethyl cellulose.

Table 8
Sensory scores of double-coated french fries as influenced by hydrocolloid level and type[1]

Sensory trait	Effect of concentration (%)						LSD	Effect of treatment			LSD
	0	0.5	1	1.5	2	2.5		Pectin	SA[3]	CMC[4]	
Appearance[2]	7.7[b]	7.0[b]	7.0[b]	7.0[b]	6.0[a]	6.0[a]	0.87	6.8[a]	6.8[a]	6.8[a]	0.62
Colour[2]	8.0[b]	8.0[b]	7.7[ab]	7.7[ab]	7.7[ab]	7.3[a]	0.50	7.3[a]	7.6[a]	8.0[b]	0.36
Texture[2]	8.0[b]	7.7[b]	7.7[b]	7.3[ab]	6.7[a]	6.7[a]	0.71	7.4[a]	6.8[a]	7.9[b]	0.50
Taste[2]	8.0[b]	8.0[b]	8.0[b]	7.0[b]	7.0[a]	7.0[a]	0.60	7.5[a]	7.7[a]	7.7[a]	0.42
Overall acceptability[2]	8.0[b]	8.0[b]	7.7[ab]	7.6[ab]	7.1[a]	7.0[a]	0.73	7.4[a]	7.5[a]	7.7[a]	0.52

[1] Each value in the table is the mean of three replicates and two determinations were conducted for each replicate.
[2] Means in the same row with different letters are significantly different ($p \leq 0.05$).
[3] Sodium alginate.
[4] Carboxymethyl cellulose.

increases in the red and yellow colours as well as the visual densities. Coated fries, with CMC as a second layer, were lighter ($p \leq 0.05$) in colour (less red and lower visual density) than those coated with pectin or sodium alginate.

The sensory scores of double-coated french fries for all attributes were affected ($p \leq 0.05$) by the levels of the hydrocolloids forming the second coating (Table 8). Increasing the level of the hydrocolloid up to 1.5% resulted in non-significant ($p > 0.05$) differences in the sensory scores for all attributes. However, at 2 and 2.5% levels, there were significant ($p \leq 0.05$) reductions in sensory scores compared to the control (0% level), except for colour at the 2% level which gave a similar score. Appearance, taste and overall acceptability were not affected ($p > 0.05$) by the type of the hydrocolloid forming the second coating. However, CMC had higher ($p \leq 0.05$) texture and colour scores than sodium alginate and pectin.

From the above results, it could be concluded that coating of potato tissue with hydrocolloid gel-forming compounds and a calcium cross-linking agent, as a first coating, followed by an additional hydrocolloid as a second coating, was effective in protecting the potato tissue from the violence of deep-fat frying and reducing the oil content of the final product by 55%. Also, coating prevented the water from evaporation during deep-fat frying and improved the sensory characteristics of the potato french fries.

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