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Research Article
Application of Hydrocolloids as Coating Films to Reduce Oil Absorption in Fried Potato Chip-Based Pellets

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Abstract
Background and Objective: Fat frying is a popular method used in food processing. Potato chip-based pellets (PCBPs) are the most commonly consumed fried food item manufactured globally. Due to increased consumer awareness surrounding the health problems associated with consumption of high-fat fried foods, preferences have shifted to fried food that is lower in fat. The present study aimed to investigate the effects of using carrageenan and xanthan thin coating films to reduce oil absorption in fried potato chip-based pellets and to evaluate the chemical, physical and sensory properties of the resulting products. **Materials and Methods:** In the present study, two selected hydrocolloids of different concentrations, carrageenan (1, 2, 3 and 4%) and xanthan (0.1, 0.2, 0.3 and 0.4%), were used to coat potato chip-based pellets to evaluate their effect on moisture retention, oil absorption reduction and sensory characteristics. **Results:** Carrageenan and xanthan significantly reduced oil absorption across all concentrations, ranging from 24-46.9% and 25.6-57.4%, respectively. The most effective level of fat reduction was found using 4% carrageenan and 0.3% xanthan coatings. Overall sensory acceptability was improved across concentrations. **Conclusion:** Application of edible coatings to reduce oil content can be used to produce products that meet the health and quality preferences of consumers.

Key words: Potato chip-based pellets, coating film, oil absorption, sensory quality, fried food

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Frying plays an important role in food preparation and is considered one of the most popular cooking methods to enhance the taste, flavor, aroma, texture of food and provide a unique influence on sensory characteristics of food items[1,2]. Fried products have great importance in the food industry due to their popularity among consumers and large quantities of fried food are produced at both industrial and commercial levels.

A high amount of oil is absorbed during the frying process, reaching in some cases up to more than 40% of the total food product weight[3,4]. Gadiraju *et al.*[2] reported that consumption of fried foods is associated with a higher risk of chronic coronary diseases. Ziaiifar *et al.*[5] reported that fat content is a nutritional critical point in deep-fat frying, in addition, lipid oxidation during frying generates different oxidation byproducts, some of which are also associated with premature aging, cell membrane damage, heart disease and cancer[6]. Therefore, consumption of fried food has become a significant health concern.

A strong proposal has been developed to reduce oil content in fried foods, thus prompting studies on the development of food products with reduced fat and cholesterol levels. There is a need for a better understanding of how oil is absorbed by deep-fried food and how processing conditions influence the quantities that are absorbed. Coating food can be an effective method to reduce oil uptake. Hydrocolloids are the most promising method since they act as good barriers to fats. Commonly used hydrocolloids include isolated proteins, cellulose derivatives and alginates, which can be applied by immersion or spraying[7-11].

The global snack pellet market in 2014 was dominated by potato-based snack pellets, however, snack pellets of broadly consumed fried products are projected to grow at a compound annual growth rate of 6.0%, which would exceed USD 7 billion by 2020. This growth is likely due to the flourishing snack food sector across the globe and rising demands for healthy and light snack food for on-the-go consumption[12]. Li and Fan[13] recommended a method for frying food with low oil content and sensorial acceptability that has considerable market potential, although the natural and functional polysaccharides must be identified to produce better oil barriers and water permeability as coating surface materials for reducing oil absorption[13].

The present study aimed to evaluate the effects of using different concentrations of carrageenan and xanthan coating thin films to reduce oil absorption in fried potato chip-based pellets (PCBPs) and to study the chemical, physical and sensory properties of these products.

MATERIALS AND METHODS

Materials: Potato chip-based pellets (PCBPs) ingredients are as follows: Potato granules, potato starch, edible salt and potato flakes. These ingredients were purchased from a local market (JOPELLETS, Amman, Jordan). Commercial carrageenan (CA) (CARRA GEL PWJ 5304, Gelymar, Spain) and xanthan gum (Aldrich Chemical Company, USA) were used as coating materials.

Preparation of coating solutions: Coating solutions were prepared for each coating material. Four solutions with the concentrations of 1, 2, 3 and 4% carrageenan and 0.1, 0.2, 0.3 and 0.4% xanthan were prepared at room temperature. Glycerol was added at 3% w/v to these solutions as a plasticizer. The PCBPs were dipped for 10 sec in the coating solutions followed by air drying with an air blower. Dipping and drying procedures were repeated to ensure uniform coating of the film on the products. PCBPs without coatings were used as control[14].

The coated and uncoated samples [control (C)] were fried in an electrical deep-fat fryer (Emjoi power, Model UEDL-206, China) with corn oil (Yara oil, Kafak Trading Company, Jordan) at 180$\pm$2°C for 10 sec (controlled temperature and time). In each batch, twenty PCBPs were placed inside the frying basket. The frying basket was immersed in oil. Samples were fried until a golden color surface was observed and the temperature of frying oil was monitored by a digital thermocouple (K-type, APPA-51, Taiwan). The oil was drained by shaking the fryer basket and the fried products were blotted with tissue paper to remove excess oil[15]. The oil was changed every four frying batches.

The samples were then allowed to stabilize at room temperature, weighed and drawn for subsequent tests. One part of the freshly fried samples was taken immediately for sensory evaluation, while the other parts were placed in plastic bags until the other chemical and physical analysis were performed.

Moisture and oil content: The moisture content (MC) of the PCBPs was measured using an oven-drying method (Memmert, 854, Schwapach, Germany) and the oil content (OC) was determined using the Soxhlet apparatus[16].

The percentage of oil reduction (OR) capacity of the edible coating relative to control (uncoated samples) were estimated as the percent of oil content difference between uncoated and coated samples as shown in the following equation:

$$OR\ (\%) = \frac{OC(\text{after coating}) - OC(\text{before coating})}{OC(\text{before coating})} \times 100$$

The percentage of moisture retention (MR) was calculated using the moisture content (MC) of the sample before coating (control) and the moisture content of the sample after coating as shown in the following equation:

$$MR\ (\%) = \frac{MC(\text{after coating}) - MC(\text{before coating})}{MC(\text{before coating})} \times 100$$

Free fatty acid percent (as oleic acid) and peroxide values were analyzed at each frying batch according to AOAC[16]. The acidity and peroxide value for the frying oil ranged from 0.22-0.25 and 9.9-9.96, respectively, taking care to maintain these values within corn oil specification[17].

Physical methods: The specific volume of each sample was determined by immersion in a graduated cylinder filled with paraffin oil. Specific volumes were calculated by dividing the sample weight by the volume of paraffin oil displaced[18].

Sensory analysis: Samples from each treatment were evaluated for sensory evaluation by an 11 member trained panel of people aged 18-50 years of both genders from the Nutrition and Food Processing Department at Al-Balqa Applied University.

Before evaluating the samples, panelists were familiarized with the test procedure and scoring system.

Each sample was evaluated for general appearance, color, flavor, taste, crispiness and overall acceptability using a descriptive nine-point hedonic scale, in which 9 represented "like extremely" and 1 represented "dislike extremely." Small amount of bread and water was provided between samples to neutralize any lingering taste from the previous sample. All treatments were evaluated induplicate on separate occasions.

Statistical analysis: Statistical analysis was carried out using the statistical analysis system package (SAS Institute Inc., N.C. USA). The data obtained were analyzed using a completely randomized design (CRD) to study the effect of treatments on the fat %, moisture %, oil reduction %, moisture retention %, specific volume and sensory scores. The significant difference of the mean was determined using the least significant difference (LSD) method. Correlations were calculated between the fat and moisture content, oil reduction and sensory attributes of the PCBPs.

RESULTS AND DISCUSSION

Fat and moisture content: Figure 1 shows the fat and moisture content of the PCBPs. Increasing concentrations of carrageenan as a coating thin film was effective in reducing fat percentage compared to the uncoated sample (C). In addition, 4% carrageenan significantly ($p\leq 0.05$) reduced fat to 21%, whereas 1% carrageenan resulted in a significantly ($p\leq 0.05$) higher fat content of 30% compared to the other coated samples, the fat content of the uncoated samples (C) was 39.5%.

The moisture percentage across different levels of carrageenan ranged from 0.84-1.16%. The fat content of the fried PCBP samples decreased when the moisture content was increased, this result was predicted, as oil absorption occurs when the moisture is removed from food during the frying process. Manjunatha *et al.*[19] reported that the oil content of products is affected by initial moisture content and particle size distribution. Higher initial moisture content and small particle size resulted in higher residual oil content, in addition, the ratio of residual oil content to water removed was independent of frying oil temperature. These results are consistent with that of Angor *et al.*[14].

The results of fat and moisture content of the coated samples of PCBP with different levels of xanthan and uncoated samples are shown in Fig. 2. Uncoated PCBP samples had significantly ($p\leq 0.01$) higher fat content (39.5%) compared to the coated samples. The samples coated with 0.3% xanthan had the lowest fat content (16.8%), while the samples coated with 0.1% xanthan had the highest fat content (29.4%). These results are consistent with the findings of Garmakhany *et al.*[11], who reported that xanthan concentrations lower fat content of French fries.

The moisture content of the fried PCBPs at different levels of xanthan ranged from 0.84-1.16%. Usawakesmanee *et al.*[20] and Ali *et al.*[21] also found that using edible coating for frying potato strips increased moisture content of the products. Increased moisture content due to coating maybe a result of the barrier of coating properties that prevent moisture loss during frying[22].

Oil reduction and moisture retention: Oil and moisture retention percentages of control and coated samples are shown in Fig. 3 and 4, respectively. Oil reduction occurred across different concentrations of carrageenan and xanthan proportionate with the decrease in the amount of oil reduction in the final products.

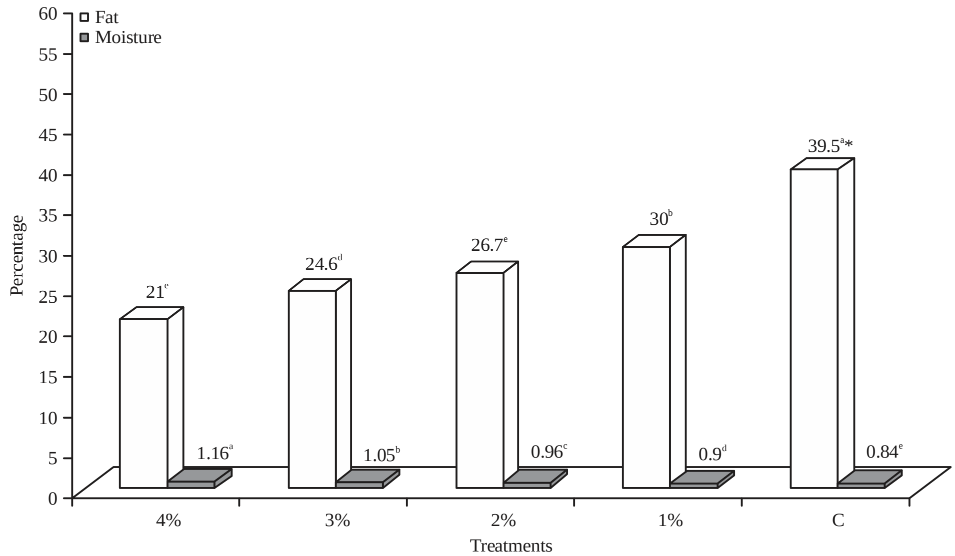

Fig. 1: Fat and moisture content of fried potato chips-based pellet at different concentration levels of carrageenan as coating films
*Different superscript letters are significantly (p = 0.05) different according to LSD

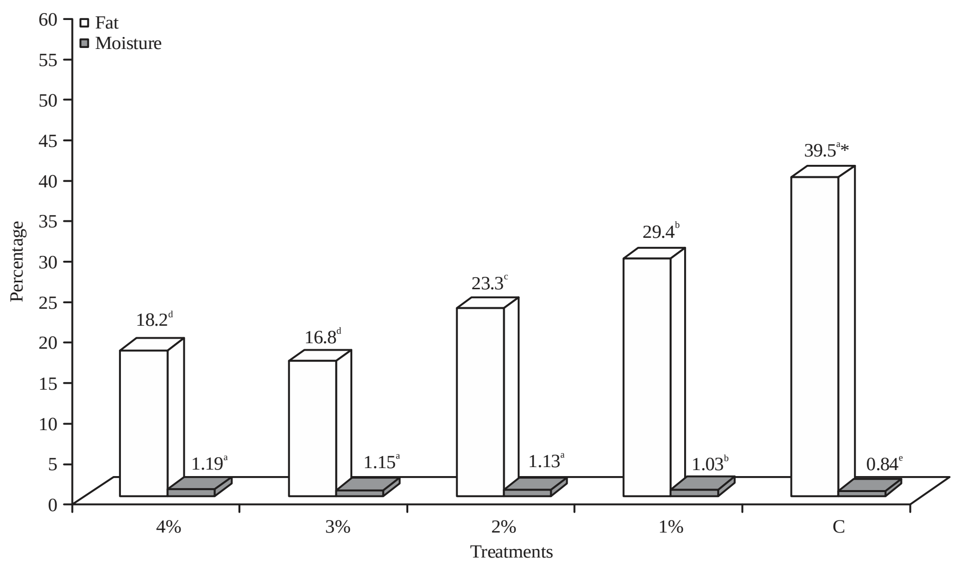

Fig. 2: Fat and moisture content of fried potato chip-based pellet at different concentration levels of xanthan coating films
*Different superscript letters are significantly (p = 0.05) different according to LSD

Carrageenan (4%) and xanthan (0.3%) coatings resulted in the highest oil reductions of 46.9 and 57.4%, respectively, while the lowest oil reduction was observed in the 1% carrageenan and 0.1% xanthan coatings (24 and 25.6%, respectively) compared to the uncoated samples (C). In addition, all coated treatment samples had significantly higher oil reductions compared to uncoated samples. These results are consistent with the study of Garmakhany *et al.*[22], who reported that xanthan gum coating reduced oil in French fries products. In addition, Kim *et al.*[23] reported that hydrocolloid coating reduced the oil content up to 41% in potato strips compared to control.

Figure 3 and 4 shows the moisture percentage retained in fried PCBPs sample coated with different concentrations of carrageenan and xanthan. Increased concentrations of coating materials increased moisture retention, 4% carrageenan and 0.4% xanthan obtained the highest level of moisture retained, which is consistent with the findings of Akdeniz *et al.*[18], who

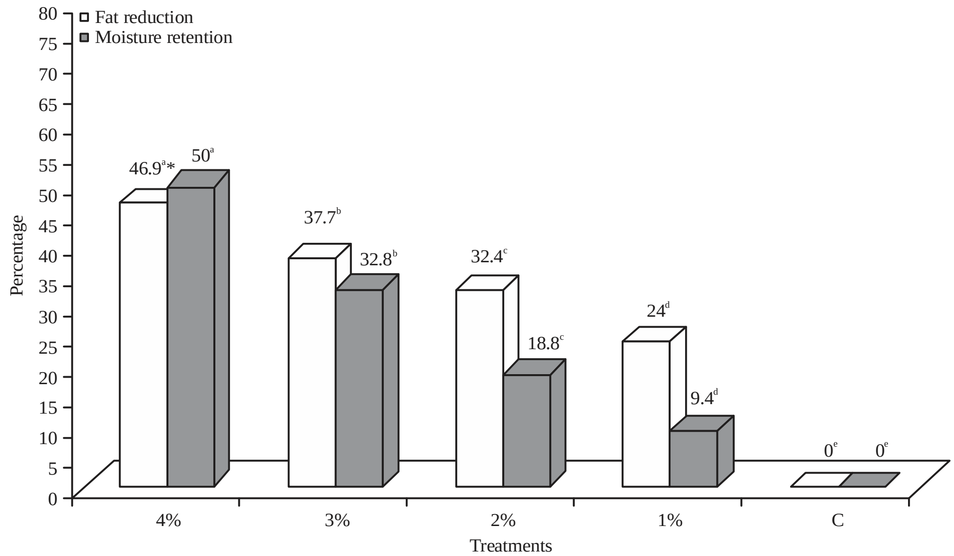

Fig. 3: Oil reduction and moisture retention of different levels of carrageenan as coating films for fried potato chips- based pellets
*Different superscript letters are significantly (p = 0.05) different according to LSD

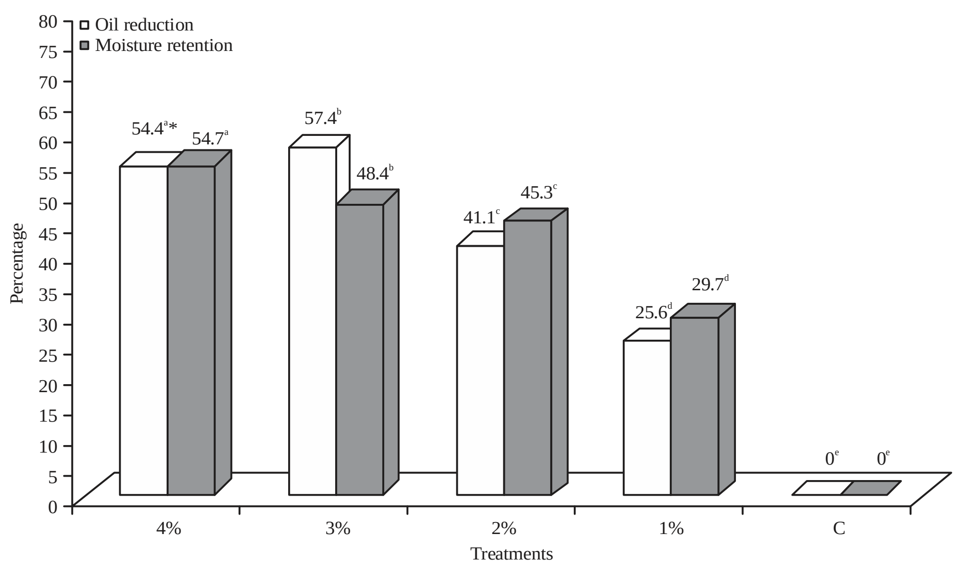

Fig. 4: Oil reduction and moisture retention of fried potato based pellets at different concentration levels of xanthan as coating films
*Different superscript letters are significantly (p = 0.05) different according to LSD

reported that slices of fried carrot coated with hydroxypropyl methylcellulose, guar gum and xanthan gum increased moisture compared to (C) samples. Edible coatings act as a moisture and fat barriers to reduce fat content in fried products[10]. Kurek *et al*.[24] reported that 0.5% (w/v) xanthan coatings reduced oil uptake of potato chips by 24.8%.

Purwar and Pawar[25] reported that higher oil reduction and moisture retention in French fries is due to pretreatment and the addition of hydrocolloids. The film-forming characteristics of hydrocolloids, which include carrageenan and xanthan, prevent the absorption of oil while enabling the retention of the natural moisture of food[25]. Martinez *et al*.[26] concluded that the use of edible coating-based guar gum, xanthan and carboxymethyl cellulose is feasible for fried products to produce lower oil content and generate moisture retention by immobilizing water, which is a feature of hydrocolloids. When a coated food product is fried, the film hinders oil absorption, resulting in a reduction of fat absorption, calories and an improvement in the nutritional qualities of the final product[27]. The specific volume of all samples ranged from 2.3-2.5 g mL^{-1}. There were no significant (p>0.05) differences in the specific volume of the fried PCBPs among samples, indicating that coated films did not affect the specific volume of the treatments. These results confirm the report of Angor *et al.*[14], who found that there were no significant differences among fried potato pellet chips coated with different coating films (starch and bread crumbs), indicating a lack of a coating effect on product-specific volume[14].

Sensory quality attributes are important aspects of overall acceptability of food products. Fat frying is widely used in the industrial production of food because consumers prefer the taste, appearance and texture. Mean hedonic scores for appearance, color, flavor, taste, crispiness and overall acceptability of the fried PCBPs coated with different levels of carrageenan and xanthan are presented in Table 1 and 2, respectively. There were no differences in the overall acceptability rating scores for all treatments coated with different concentrations of carrageenan and xanthan. However, Maity *et al.*[28] reported that 0.3% xanthan pre-treatment provided the best sensory results.

Carrageenan and xanthan improved sensory preferences of appearance, flavor, taste, crispiness and overall acceptability. Increases in xanthan and carrageenan significantly increased (p<0.05) overall acceptability. Among coated PCBP samples, overall acceptability scores ranged from 7.3-8.3, with attributes corresponding respectively to "like moderately" and "like very much." The highest scores of overall acceptability were 8.0 and 8.3, respectively, for carrageenan (4%) and xanthan (0.3%), the score of the control sample (6.9) corresponded to "like slightly" (p<0.05). Ghavidel *et al.*[29] reported only a slight improvement on sensory attributes from the use of edible films on fried potato strips compared to the control sample. Bourlieu *et al.*[30] reported that carrageenan and other coatings produce a stable food with a crisp exterior and a soft, tender interior. Albert and Mittal[31] also reported that coating banana slices with xanthan reduced oil uptake by 17.2% without affecting crispiness, color, flavor or overall quality.

Correlation coefficients matrix of fat and moisture content, oil reduction and sensory attributes of fried potato-based pellets: The correlation coefficients of fat and moisture content, oil reduction and sensory attributes are shown in Table 3. Fat content was significantly negatively ($p \leq 0.01$) correlated with oil reduction (r = -0.99) and moisture content

Table 1: Mean sensory evaluation scores of different levels of carrageenan coating films for deep fried potato-chip based pellet*

Treatment (%)	Appearance	Color	Flavor	Taste	Crispy	Overall acceptability
1	7.9^{ab**}	8.0^{ab}	7.1^{a}	6.9^{bc}	8.0^{a}	7.3^{ab}
2	8.4^{a}	8.2^{a}	7.2^{a}	7.0^{bc}	8.0^{a}	7.6^{a}
3	7.9^{ab}	7.6^{ab}	7.2^{a}	7.4^{ab}	8.3^{a}	7.8^{a}
4	8.2^{a}	8.3^{a}	7.5^{a}	8.0^{a}	8.5^{a}	8.0^{a}
Control	7.2^{b}	7.4^{b}	6.7^{a}	6.5^{c}	6.7^{b}	6.9^{b}

*Each mean represents is the average of 11 readings, where 9 refers to “like extremely” and 1 refers to “dislike extremely", **Values within the same column followed by different letters are significantly ($p \leq 0.05$) different according to LSD

Table 2: Mean sensory evaluation scores of different levels of xanthan coating films for deep fried potato-chip based pellet*

Treatment (%)	Appearance	Color	Flavor	Taste	Crispy	Overall acceptability
0.1	7.5^{ab**}	7.9^{ab}	7.2^{b}	7.2^{ab}	7.6^{a}	7.5^{bc}
0.2	8.1^{a}	8.2^{a}	7.2^{b}	7.3^{ab}	8.1^{a}	7.9^{ab}
0.3	8.2^{a}	8.3^{a}	8.0^{a}	7.9^{a}	8.2^{a}	8.2^{a}
0.4%	8.1^{a}	8.3^{a}	7.8^{a}	7.8^{a}	8.0^{a}	8.3^{a}
Control	7.1^{b}	7.4^{b}	6.7^{b}	6.5^{b}	6.7^{b}	6.9^{c}

*Each mean represents the average of 11 readings, where 9 refers to “like extremely” and 1 refers to “dislike extremely”, **Values within the same column followed by different letters are significantly ($p \leq 0.05$) different according to LSD

Table 3: Pearson correlation coefficient matrix of fat and moisture content, oil reduction and sensory attributes of fried potato chip-based pellet

	Fat content	Oil reduction	Moisture content	Appearance	Color	Flavor	Taste	Crispy	Overall acceptability
Fat (%)	1.00								
Oil reduction	-0.99**	1.00							
Moisture (%)	-0.91**	0.91**	1.00						
Appearance	-0.92**	0.92**	0.88**	1.00					
Color	-0.80 *	0.78*	0.73*	0.64	1.00				
Flavor	-0.78 *	0.91**	0.86**	0.63	0.79*	1.00			
Taste	-0.92**	0.78*	0.78*	0.78*	0.83*	0.78*	1.00		
Crispy	-0.90**	0.89**	0.73*	0.77*	0.92**	0.66	0.91**	1.00	
Overall acceptability	-0.86**	0.84**	0.90**	0.86**	0.81*	0.87**	0.78*	0.76*	1.00

*$p \leq 0.05$, **$p \leq 0.01$

(r = -0.91). This result is in agreement with Sahin *et al.*[32], who reported that oil uptake was negatively correlated with moisture content.

Moisture content and oil reduction were highly significantly positively correlated (r = 0.91) ($p \leq 0.01$). Kaur *et al.*[33] showed that higher moisture retention is associated with higher oil reduction in PCBPs during frying and Salvador[34] concluded that the oil uptake was correlated with moisture loss within coated and non-coated samples ($r^2 \geq 0.93$). In addition, Kassama and Ngadi[35] also reported a strong linear relationship between oil uptake and moisture loss during deep-fat frying of chicken breast.

We found a significant positive correlation between oil reduction and all sensory attributes, indicating that consumers prefer low-fat fried foods. Aida *et al.*[36] suggested that oil uptake during frying should be considered as the fat content of a product affects its flavor, odor and general organoleptic properties.In addition, Kurek *et al.*[24] reported that hydrocolloid coatings are invisible and have no negative influence on the sensory attributes of fried food.

CONCLUSION

Carrageenan and xanthan films reduced 46.9 and 57.4% of oil absorption, respectively and increased moisture retention during the frying process. Among the different concentrations of coating materials, 4% carrageenan and 0.3% xanthan provided the best results and were most effective at reducing oil absorption. These coatings also significantly improved the overall acceptability of the PCBPs.

The edible films did not affect the sensory characteristics of the PCBPs or the acceptance of the products. Thus, the application of edible coatings to reduce oil content of PCBPs can be applied to other products to meet both the health and quality preferences of consumers.

SIGNIFICANCE STATEMENTS

This study revealed the potential for using carrageenan and xanthan as coating films to reduce oil absorption of fried potato chip-based pellets. This study help the researchers to determine how to reduce fat in fried foods to meet the requirements of healthy nutrition.

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