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Original Article

Juiciness improvement of frozen battered shrimp burger using modified tapioca starch, sodium alginate, and iota-carrageenan

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Abstract

A battered shrimp burger, as a new value-added shrimp product, was developed by increasing the juiciness of a frozen battered shrimp burger using a mixture of hydrocolloids. The formulations of hydrocolloid mixtures containing modified tapioca starch (MTS), sodium alginate (AL), and iota-carrageenan (CA) were optimized. Juiciness measurements were defined and analyzed by 13 trained panelists. Texture Profile Analysis (TPA) as well as moisture and fat contents of the products were analyzed. The mixture of MTS and AL had an impact on moisture content and juiciness scores, while CA influenced the hardness. The product made using the optimized formulation (0.3% MTS + 0.7% AL) had a higher moisture content and juiciness scores ($p<0.05$), but no significant difference was found in fat content compared to the control burger ($p>0.05$). However, higher springiness and gumminess were found in the control burger ($p<0.05$), compared to that produced using optimized formulation. The hardness, fracturability, adhesiveness, and chewiness were not different ($p>0.05$).

Keywords: modified tapioca starch, sodium alginate, iota-carrageenan, juiciness, burger

1. Introduction

Shrimps and shrimp products are one of the most economically important products of Thailand. In the year 2006 (January-August), Thailand exported 192,141 tons of shrimp products with a value of 1,360 million US dollars. This was an increase of 14.76% when compared to the year 2005 over the same period (Research Department of Siam City Bank Public Company Limited, 2006). To increase the variety of shrimp products, value added products should be considered. However, the use of small shrimps or broken shrimp meat for new products is still limited. Nowadays, burgers and battered products are very common, and are well-liked products in almost every country, especially European countries (Llorca *et al.*, 2003). Therefore, the development of frozen battered shrimp burger should be a promising alternative to feature in the export market.

Freezing processes and frozen storage are commonly used to preserve battered products. However, the deleterious changes, which can significantly reduce product quality, generally take place during frozen storage. Brewer (1989) showed that long term frozen storage decreased moisture content, water holding capacity, and the juiciness of ground pork. However, thiobarbituric acid (TBA) value, thaw loss, drip loss, and total loss increased. Upon thawing of frozen meat, exudates are produced, thereby affecting consumer acceptability.

Carbohydrates such as starches and hydrocolloids have been tested in an attempt to improve cooking yield, to increase moisture retention, and to modify product texture

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(Keeton, 1994). Modified starch has been used as binders to maintain juiciness and tenderness in low-fat meat products (Giese, 1992). Berry and Wergin (1993) found that the inclusion of modified pregelatinized potato starch in both low- and high-fat beef burgers could improve tenderness and cooking yields. This was due to the ability of the potato starch to bind water and hold it during cooking. Other starches such as tapioca, potato, and modified starch from waxy maize have shown similar results, with increasing water retention and cook yield (Troutt *et al.*, 1992; Bullock *et al.*, 1995).

Carrageenans are another group of ingredients, which have gained approval for improving stability and texture of comminuted meat products (Trius *et al.*, 1994) and used as water-binding agents in low-fat beef burgers (Desmond *et al.*, 1998). Foegeding and Ramsey (1986) found that kappa-carrageenans were able to hold moisture and increase the hardness of cooked low-fat frankfurter. Iota-carrageenan has the greatest capacity to retain moisture in a meat system and has very good freeze/thaw stability compared to kappa- and lamda-carrageenans (Egbert *et al.*, 1991). Bloukas *et al.* (1997) showed that kappa-carageenan and a mixture of kappa and iota-carrageenan have a better water binding capacity for low-fat fankfurter than iota-carrageenan. However, iota-carrageenan contributed to a softer product with a higher overall acceptability.

Alginate, another strong water-binding polysaccharide, has inconsistently performed as a gelling agent in fresh, restructured beef steaks and pork chops (Means and Schmidt, 1986; Trout *et al.*, 1990). The synergistic effects of hydrocolloids combinations have been examined in meat patties. The combinations of sodium alginate and modified tapioca starch improved juiciness of low-fat beef patties as reported by Berry (1997). Lin and Keeton (1998) showed that ground beef patties containing carrageenan and sodium alginate have a higher moisture content than those containing alginate or carrageenan alone.

The purpose of this study was to formulate a mixture of three hydrocolloids, including modified tapioca starch (MTS), sodium alginate (AL), and iota-carrageenan (CA), in order to improve the juiciness of frozen battered shrimp burgers.

2. Materials and Methods

2.1 Materials

2.1.1 Shrimp preparation

White shrimps (*Litopenaeus vannamei*) with a size of 90 shrimps/kg were obtained from shrimp farms in Songkhla Province, 24-36 hours after they were collected. Within an hour the shrimps were placed in ice with an ice/shrimp ratio of 2:1 (W/W) and transported to the Department of Food Technology, Prince of Songkla University (PSU), Hat Yai, Songkhla. Upon arrival, the shrimps were washed with clean water, deheaded, peeled and ground with a grinder (Moulinex Masterchef-350, La Defense, France) for 10 seconds. The ground shrimps were packed in polyethylene bags and kept in ice until used. The ground shrimps were stored not longer than 12 hours.

2.1.2 Coating materials

Two coating materials were used. These were: wheat flour (Thai flour mill Industry, Co. Ltd., Samutprakarn, Thailand) and corn flour (Ocean, Ocean Food (Thailand) Ltd., Bangkok, Thailand), and Japanese style bread crumbs (Farmhouse, President Bakery Public Co. Ltd., Bangkok Thailand)

2.1.3 Seasoning

The seasoning used was pepper powder (Nguan Soon Hand No.1, Bangkok, Thailand), classic yellow mustard (French's®, Reckitt Benckiser Inc., Springfield, MS, USA), grated parmesan cheese (Kraft, Kraft Food Ltd., Fishermansbend, VIC, Australia), and Krusto bread crumbs (Lobo, Globo Food Ltd., Supanburi, Thailand).

2.1.4 Hydrocolloids

The hydrocolloids used were sodium alginate (Union Chemical 1986 Co., Ltd., Bangkok, Thailand), iota-carrageenan (Sigma-Aldrich Inc., St. Louis, MO, USA), and modified tapioca starch (National 7, National Starch and Chemical Co., Ltd, Bangkok, Thailand).

2.1.5 Palm oil

Palm olein oil was obtained from Morakot, Morakot Industry Co. Ltd., Samutprakarn, Thailand.

All the coating, seasoning, hydrocolloids, and palm oil were kept in a dry place at 28-29°C for not longer than 6 months.

2.2 Methods

2.2.1 Preparation of batter

To prepare batter, wheat flour, corn flour, and salt (88.5%, 6.0% and 5.5%, respectively) were mixed. Thereafter, water was gradually added with a solid to water ratio of 1:2 for 3 min by using a food processor (King model - 05, Tokyo, Japan).

2.2.2 Preparation of battered shrimp burger

The formulation of the burger modified from Sawatdiwat (2000) is shown in Table 1. All ingredients were mixed for 5 min using a food processor (King model - 05, Tokyo, Japan). Fifty grams of mixture were weighed and formed with hamburger mould with a diameter of 8 cm and a thickness of 1 cm, followed by pre-dusting with wheat flour

Table 1. Ingredients of shrimp burger

Ingredients	Content (%)
Ground shrimp	60
Egg	6.5
Bread crumb	6.5
Salt	0.5
Pepper powder	0.5
Onion	14
Mustard	2
Cheese	4
Water	5
MTS	* } 1
AL	*
CA	*

Source: Modified from Sawatdiwat (2000)
* The hydrocolloid proportions shown in Table 2

(1.5±0.5% picked up) and immersed in the batter (20±2% picked up). The samples were breaded with bread crumbs (3.5±1% picked up) and deep-fat fried in palm oil at 180°C for 3.5 min (with core temperature ~75°C). The burger samples were packed in Nylon laminated linear low density polyethylene (Nylon/LLDPE) bags and kept at -20°C for 24-72 hours before analyzed. The frozen burgers were thawed at 4°C for 2 hours, and then baked in an oven at 230°C for 15 minutes.

2.2.3 The experimental design

The augmented simplex-centroid design was used for studying the blending of three hydrocolloids, modified tapioca starch (MTS), sodium alginate (AL), and iota-carrageenan, (CA). The design contained 10 points of treatment with 4 points replicated (a replication of 4 treatments) in order to calculate the experimental error, as shown in Table 2. The maximum level of each variable was 1% (related to total formulation). All samples were subjected to analysis as follows.

2.2.4 Chemical analysis

Moisture and fat content of the battered shrimp burger samples were determined according to the method of AOAC (1999). The values were expressed in % (wet weight basis).

2.2.5 Texture measurement

The Texture Profile Analysis (TPA) of the battered shrimp burger samples was performed using a texture analyzer (model TA-XT2i, Stable Micro System, Surrey, UK) equipped with a 25Kg-load cell. The burger sample was cut into 8 pieces and placed under a cylindrical 50 mm-diameter probe that moved downwards at a constant speed of 3.0 mms^{-1} (pre-test), 1.0 mms^{-1} (test), and 3.0 mms^{-1} (post-test). Hardness, fracturability, cohesiveness, adhesiveness, springiness, gumminess, and chewiness were calculated according

Table 2. Experimental design of modified tapioca starch, sodium alginate, and iota carrageenan mixtures on juiciness improvement of frozen battered shrimp burger.

Treatment	Component proportion (%)		
	Modified tapioca starch (MTS)	Sodium alginate (AL)	Iota - carrageenan (CA)
H1	0.5	0.5	-
H2	1	-	-
H3	-	1	-
H4	0.33	0.33	0.33
*H5	-	1	-
H6	-	0.5	0.5
H7	0.17	0.67	0.17
H8	0.67	0.17	0.17
H9	-	-	1
*H10	-	-	1
H11	0.5	-	0.5
*H12	-	0.5	0.5
*H13	1	-	-
H14	0.17	0.17	0.67

Note: * H5, H10, H12 and H13 were the replicated design points of H3, H9, H6, and H2, respectively.

to the method of Dreeling *et al.* (2000).

2.2.6 Sensory evaluation by trained panelists

The human subjective training method used was based on International Standard ISO 8586-1 (1993). Members of the panel were recruited from M.Sc. students of Food Science and Technology Program at PSU. Thirteen panelists were selected, based on interest, availability, verbal expression, and the liking for burger. The panelists were trained 20 times for 1 hour each. A brief background to sensory evaluation was discussed by the researchers and panelists. The discussion included term and definition of each key sensory attribute in battered shrimp burgers. The capability of the trainees in recognizing and distinguishing the product texture was assessed by conducting taste exercises providing samples with various levels of moistness and juiciness. The trainees were ready to evaluate the intensity of the juiciness in formulated burgers when they could identify the intensity of the attribute.

The method of evaluating the description of the juiciness and its intensity was generated by the panelists. The thirteen panelists had discussion sessions after tasting the shrimp patties (59.51% moisture content) and compared them with battered shrimp burgers (49.99% moisture content, research sample). The thirteen trained panelists clearly understood the definition of 'juiciness'. They knew what they were looking at in the 3-step evaluation of the intensity of the attribute - by first bite, while chewing, and after swallowing.

The 14 experimental samples were evaluated over 3 sessions of 4 or 5 products each using a multi-sample difference test (Meilgaard *et al.*, 1999). The samples were served according to the serving plan designed to balance first-order carry-over effects (MacFie *et al.*, 1989). The intensity scale of juiciness was agreed on a 15 cm line scale (anchored at 1 cm and 14 cm as "low" and "high", respectively).

2.2.7 Optimization of hydrocolloid mixtures

The models adopted for juiciness and moisture content were used to optimize the hydrocolloid proportion using the software Design Expert version 7.0.3 (Stat-Ease, Inc., Minneapolis, MN, USA). The optimized formula was then produced and compared by testing with the control (without hydrocolloid). All samples were subjected to analysis by objective and subjective methods as stated above.

2.2.8 Statistical analysis

Completely Randomized Design (CRD) was used for the statistical analysis. Data were subjected to analysis of variance (ANOVA) and mean comparisons were carried out by Duncan's multiple range test. To compare the mean of the control and optimized product, a t-test was performed. Correlations between TPA parameters and juiciness score were also determined using an SPSS package (SPSS 10.0) for Windows (SPSS. Inc., Chicago, IL, USA). Analysis of variance for regression and the mathematical model were analyzed using the software Design Expert version 7.0.3 (Stat-Ease, Inc., Minneapolis, MN, USA). The significance of the differences was defined at $p<0.05$.

3. Results and Discussions

3.1 Moisture content and textural properties of battered shrimp burger added with different hydrocolloid mixtures

The effect of hydrocolloids on the moisture content and texture of battered shrimp burger is shown in Table 3. The lowest moisture content was found in the battered shrimp burgers with only MTS added (H2, H13) ($p<0.05$). This result was contrary to Ruusunen *et al.* (2003) who found that MTS improved the water binding capacity of low fat frankfurters. This may be due to the denaturation of the shrimp meat proteins beginning before starch gelatinization starts in the meat/starch system (García-García and Totosaus, 2008). Gelatinization of MTS occurred around 55ºC (manufacturer's information) and white shrimp myosin formed the gel matrix at around 50.78ºC (Tammatinna *et al.*, 2004). Those phenomena most likely affected the water binding and textural properties (García-García and Totosaus, 2008).

The battered shrimp burger added with AL (HM3, HM5) or CA (HM9, HM10) alone had a higher moisture content, when compared with those where MTS was added ($p<0.05$). The functional properties of hydrocolloid are related in part to the ability to imbibe and retain large amounts of water. Alginates are made up of β-D mannuronic acid and α-L-guluronic acid. The carboxyl groups present on each sugar unit of chain are able to bind water and to promote strong electrostatic repulsion between the chains, leading to the rapid hydration (Sánchez *et al.*, 1995). Iota-carrageenan is a hydrocolloid consisting of two sulfate groups per repeat unit of disaccharide. It can improve moisture retention in meat products on the basis of its ability to form complexes with water and protein (Cofrades *et al.*, 2000; Yuguchi *et al.*, 2003).

TPA data showed that using MTS or AL (H3 and H5) alone appeared to decrease hardness. The burger containing the combined MTS and AL (H1) had the highest adhesiveness and the lowest hardness, adhesiveness, springiness, cohesiveness, gumminess, and chewiness ($p<0.05$), while those containing CA had the highest hardness ($p<0.05$). The results were in agreement with Berry (1997) who found that sodium alginate in combination with MTS improved the tenderness, juiciness, and cooking yields. This is possibly due to the considerable swelling (moisture uptake) of starch granules during cooking. In such a case, alginate would be concentrated in the decreasing spaces between the starch granules. Improvements in tenderness have also been noted in low-fat patty formulation in which alginate, locust bean

Table 3. Moisture content and TPA values of battered shrimp burgers with various hydrocolloid mixtures.

Treatment	Moisture Content** (%)	Texture Profile Analysis (TPA)***					
		Hardness(g)	Adhesiveness(s)	Springiness	Cohesiveness	Gumminess	Chewiness
HM1	52.82 ± 0.77^{ab}	$8,212.81\pm315.71^{h}$	-104.76 ± 11.45^{d}	0.44 ± 0.03^{g}	0.28 ± 0.02^{b}	$2,281.79\pm227.61^{f}$	$1,005.23\pm162.43^{f}$
HM2	50.34 ± 1.47^{bc}	$9,914.49\pm565.32^{ef}$	-59.11 ± 30.39^{c}	0.50 ± 0.04^{ef}	0.30 ± 0.02^{ab}	$2,990.74\pm377.03^{de}$	$1,496.64\pm278.55^{ef}$
HM3	53.88 ± 0.44^{a}	$9,336.16\pm645.29^{g}$	-9.44 ± 3.15^{ab}	0.45 ± 0.03^{g}	0.29 ± 0.04^{ab}	$2,723.90\pm477.25^{de}$	$1,216.60\pm193.60^{ef}$
HM4	54.29 ± 1.36^{a}	$10,046.59\pm363.19^{ef}$	-1.49 ± 0.56^{ab}	0.51 ± 0.05^{def}	0.30 ± 0.02^{ab}	$3,009.49\pm277.75^{de}$	$1,518.40\pm153.93^{def}$
*HM5	52.50 ± 1.66^{ab}	$9,095.43\pm391.46^{g}$	-24.78 ± 8.09^{b}	0.47 ± 0.04^{fg}	0.28 ± 0.01^{ab}	$2,584.92\pm170.81^{ef}$	$1,226.54\pm114.18^{ef}$
HM6	53.53 ± 1.53^{a}	$11,277.08\pm459.43^{d}$	-19.04 ± 11.03^{ab}	0.59 ± 0.05^{c}	0.31 ± 0.01^{a}	$3,506.17\pm219.74^{c}$	$2,096.44\pm307.71^{bcd}$
HM7	54.00 ± 0.42^{a}	$10,177.50\pm470.49^{e}$	-17.43 ± 6.21^{ab}	0.55 ± 0.04^{cde}	0.30 ± 0.02^{ab}	$3,088.02\pm267.68^{d}$	$1,691.99\pm218.23^{cde}$
HM8	53.93 ± 0.31^{a}	$12,593.89\pm847.26^{bc}$	-1.37 ± 0.86^{ab}	0.57 ± 0.03^{c}	0.30 ± 0.02^{ab}	$3,817.90\pm150.84^{abc}$	$2,166.21\pm137.04^{bc}$
HM9	52.70 ± 2.12^{ab}	$13,655.45\pm904.11^{a}$	-0.78 ± 0.13^{a}	0.70 ± 0.05^{a}	0.30 ± 0.02^{ab}	$4,151.20\pm519.34^{a}$	$2,924.97\pm406.03^{a}$
*HM10	52.83 ± 0.39^{ab}	$13,509.51\pm860.34^{a}$	-1.42 ± 0.36^{ab}	0.69 ± 0.05^{ab}	0.31 ± 0.02^{a}	$4,210.46\pm461.09^{a}$	$2,335.23\pm1,127.91^{ab}$
HM11	52.22 ± 1.16^{ab}	$12,353.23\pm949.10^{c}$	-3.39 ± 1.49^{ab}	0.55 ± 0.03^{cd}	0.29 ± 0.02^{ab}	$3,630.75\pm450.16^{bc}$	$2,435.05\pm880.63^{ab}$
*HM12	52.55 ± 2.16^{ab}	$13,675.61\pm617.19^{a}$	-3.28 ± 2.50^{ab}	0.57 ± 0.06^{c}	0.30 ± 0.03^{ab}	$4,187.14\pm492.85^{a}$	$1,704.77\pm500.72^{cde}$
*HM13	49.59 ± 1.75^{c}	$9,792.97\pm971.65^{efg}$	-51.04 ± 38.43^{c}	0.55 ± 0.03^{cde}	0.30 ± 0.02^{ab}	$2,955.52\pm410.30^{de}$	$2,461.38\pm791.98^{ab}$
HM14	54.58 ± 0.68^{a}	$13,258.30\pm758.80^{ab}$	-3.24 ± 1.01^{ab}	0.65 ± 0.05^{bc}	0.30 ± 0.02^{ab}	$4,038.70\pm407.68^{ab}$	$2,617.85\pm389.35^{ab}$

Note: * H5, H10, H12 and H13 were the replicated design points of H3, H9, H6 and H2, respectively. ** Mean ± SD from triplicate determinations, *** Mean ± SD from seven determinations. Different superscripts in the same column indicate significant differences ($p<0.05$).

gum or modified starch was used separately compared to patties added with pea flour, a blend of xanthan and locust bean gums or iota- and kappa-carrageenan (Bullock *et al.*, 1995). Bloukas *et al.* (1997) and Foegeding and Ramsey (1986) also found that the addition of carrageenans increased the firmness or resistance to compression of low-fat frankfurter. The addition of 0.5% kappa-carrageenan and iota-carrageenan increased the hardness of pork sausage (De Freitas *et al.*, 1997). This may be due to the Ca^{2+} cation forming bridges between two sulfate groups of two different double helixes of carrageenan, thus forming inter-macromolecular bonds and resulted in an increase in the breaking force of the gel (Linden and Lorient, 1999). In addition, Gómez-Guillén and Montero (1996) suggested that iota-carrageenan form a fine three-dimensional network with some points of connection with the protein matrix.

Significant correlations were observed between TPA parameters and juiciness scores. Hardness, springiness, gumminess, and chewiness were highly negative correlated with sensory juiciness, which evaluated the intensity of moisture released from the sample ($R = -0.71$ to -0.77, $p<0.05$).

3.2 Juiciness of battered shrimp burger added with different hydrocolloids

The description of juiciness was generated by 13 panelists using fried shrimp patties (Todd Mon Kung) and a battered shrimp burger sample. Overall, most of the panelists had a mastication frequency of 6-7, 8, and 13 times across the sample set. Most of the panel members of the 10 panelists evaluated juiciness when they felt moistness or wetness in the samples while chewing. In other words, juiciness evaluation was based on the amount of water released from the sample during mastication. The panel had reached consensus about evaluating the intensity of juiciness involving the three steps, which resemble the way people eat foods. The determination of juiciness in the first step was to measure the softness of each sample at the first bite. The second was to evaluate the intensity of moisture released from the sample during 6-8 chews. The last step was to evaluate the smoothness left in the panelists' mouth and throat during swallowing.

The juiciness results as evaluated by 13 trained panelists are shown in Table 4. The addition of MTS (H2 and H13) or CA (H9 and H10) alone in the burger formulations yielded the burger with a low juiciness score ($p<0.05$), while using a high AL level such as H1, H3, and H5 throughout the three evaluation steps increased the juiciness score ($p<0.05$). This result can be explained by human sensitivity (the trained panelists) being more sensitive to detect this product characteristic. Furthermore, juiciness is also perceived from a combination of various sources - not only the moisture content in the product. An increase in juiciness affected by AL may be due to the formation of heat stable gel. In addition, calcium bridges would maximize the interaction between negatively charged molecules and this might improve gel firmness and stability (Desmond *et al.*, 1998). The results were in line with those of Berry (1994), who found that pork nuggets with added AL retained more moisture content compared to the pork control sample (without hydrocolloids). Huffman *et al.* (1992) reported that CA had no influence on juiciness of low fat pork patties.

3.3 Formulation optimization of hydrocolloids in battered shrimp burger

The predicted equations, coefficients of determina-

Table 4. Juiciness scores of battered shrimp burgers with various hydrocolloid mixtures.

Treatment	Juiciness score**		
	1st step	2nd step	3rd step
HM1	7.37 ± 0.90^{ab}	8.36 ± 1.12^{a}	8.39 ± 1.14^{a}
HM2	6.11 ± 1.34^{cde}	7.16 ± 1.45^{bcd}	7.42 ± 1.45^{ab}
HM3	7.44 ± 1.07^{ab}	8.31 ± 1.44^{ab}	8.58 ± 1.46^{a}
HM4	6.26 ± 1.19^{bcde}	7.18 ± 1.10^{bcd}	7.35 ± 1.26^{abc}
*HM5	7.02 ± 1.42^{abc}	8.04 ± 1.43^{ab}	8.22 ± 1.45^{a}
HM6	6.41 ± 1.26^{abcde}	7.18 ± 1.06^{bcd}	7.31 ± 1.21^{abc}
HM7	6.43 ± 1.47^{abcde}	7.31 ± 1.41^{abc}	7.31 ± 1.43^{abc}
HM8	7.61 ± 1.96^{a}	8.27 ± 1.97^{ab}	8.45 ± 2.04^{a}
HM9	5.18 ± 1.08^{e}	5.92 ± 1.00^{d}	6.03 ± 1.15^{c}
*HM10	5.81 ± 1.61^{de}	6.38 ± 1.60^{cd}	6.51 ± 1.57^{c}
HM11	6.11 ± 1.82^{cde}	6.50 ± 1.30^{cd}	6.71 ± 1.49^{bc}
*HM12	5.73 ± 1.40^{de}	6.63 ± 1.38^{cd}	6.86 ± 1.48^{bc}
*HM13	6.50 ± 1.46^{abcd}	7.17 ± 1.42^{abcd}	7.32 ± 1.54^{abc}
HM14	6.36 ± 1.66^{bcde}	7.05 ± 1.62^{abc}	7.31 ± 1.81^{abc}

Note: * H5, H10, H12 and H13 were the replicated design points of H3, H9, H6 and H2, respectively. ** Scale = 15 (1 = low intensity, 14 = high intensity). 1st step is the softness of sample at first bite, 2nd step is the feeling of moist of sample or moist released from sample during 6-8 chews, and 3rd step is the smoothness during swallowing. Mean ± SD from thirteen trained panelists. Different superscripts in the same column indicate significant differences ($p<0.05$).

Table 5. Predictive regression models and goodness-of-fit for moisture content and juiciness scores of battered shrimp burgers added with various hydrocolloid mixtures.

Parameter	Regression models	R^2	Probability of model	Lack of fit (p)
Moisture content				
	Y = 50.02MTS + 52.93AL + 52.78CA + 8.65 MTS x AL + 7.56 MTS x CA + 2.25 AL x CA	0.7590	0.0221	0.2656
Juiciness score				
1st step	Y = 6.88MTS + 7.28AL + 5.65CA	0.6375	0.0038	0.2578
2nd step	Y = 7.42MTS + 8.23AL + 6.44CA + 3.04 MTS x AL + 0.40 MTS x CA – 1.87AL x CA	0.9007	0.0008	0.4407
3rd step	Y = 7.83MTS + 8.43AL + 6.46CA	0.7713	0.0003	0.1986

Note: MTS; Modified tapioca starch, AL; Sodium alginate, CA; Iota carrageenan, p; probability level.

tion (R^2), probability of models, and lack of fit of models obtained for moisture content and juiciness are shown in Table 5. The models were linear and quadratic equations. The predicted regression models with statistical significance, no lack of fit, and $R^2>0.7$ were used to generate the mixture response surface contour plot (Figure 1). For juiciness at the first step, it was not possible to apply a predicted model due to lower R^2 ($R^2<0.7$). This indicates that the factors found are correct, but there are other unidentified sources of variation. Therefore, the model does not explain enough of the

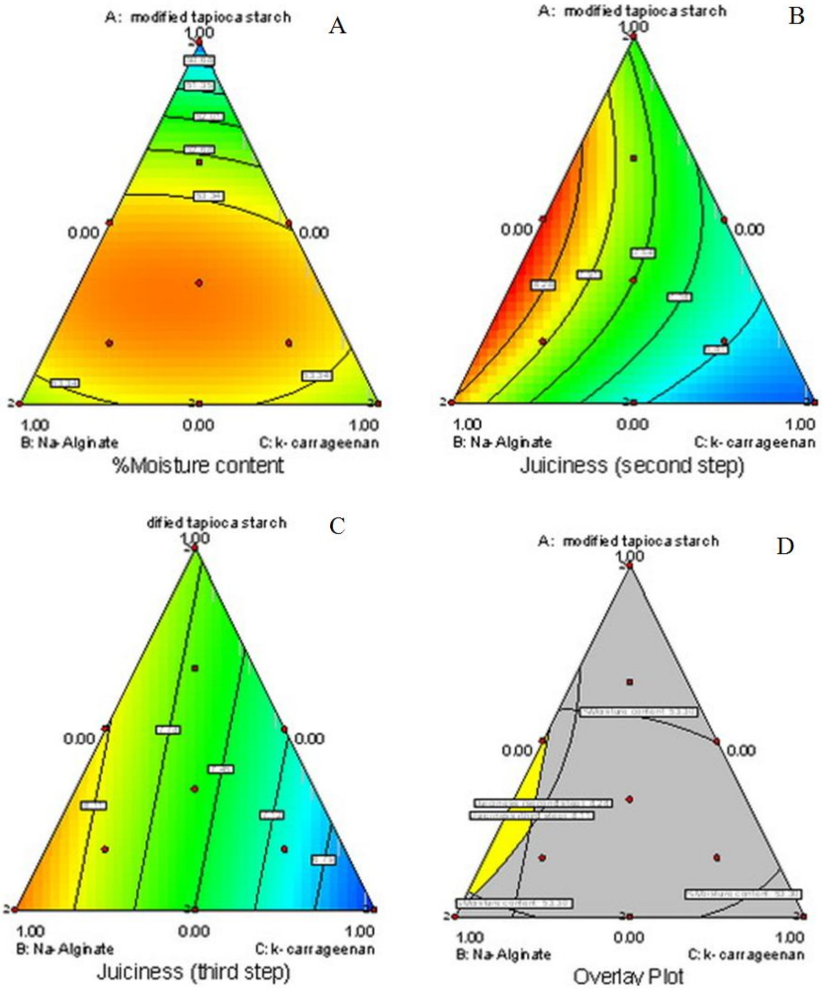

Figure 1. Mixture response surface contour plots displaying the combined effect of modified tapioca starch (MTS), sodium alginate (AL), and κ-carrageenan (CA) on moisture content (A), juiciness score at the second step (B), juiciness score at the third step (C) of battered shrimp burgers, and optimum region (yellow shade) that obtained high moisture content (>53.3%), the 2nd and 3rd step juiciness score level (>8.28 and >8.11, respectively).

direction of the response (juiciness at the first step). AL was the most important variable determining moisture content and juiciness scores in all three evaluating steps as shown by the highest coefficient in Table 5. The negative coefficient corresponding to the combinations between AL x CA that resulted in lower juiciness scores at the second step. However, the blending of MTS and AL increased juiciness scores. This outcome is similar to those previously reported by Berry (1997), who found that the mixture of MTS and AL provided an improvement of juiciness in low fat beef patties due to the considerable moisture uptake of starch granules during cooking. In addition, alginate would be concentrated in decreasing spaces between starch granules.

To obtain the optimum region, a contour plot with predicted juiciness scores (second and third step) and moisture content of at least 8.11, 8.28, and 53.3% respectively (close to maximum values), were selected to derive a predicted optimum formulation range. The optimum region (shaded area in Figure 1) consists of 0.46-0.93% AL, 0.07-0.54% MST, and 0.00-0.09% CA. The optimized formulation with highest desirability (0.83) obtained from software calculation was composed of 0.3% MTS and 0.7% AL. To verify the predicted model, the predicted and observed values for juiciness (2nd and 3rd step) scores and moisture content of the optimized formulation were compared. The experimental errors for all values ranged from 0.08 to 0.13%.

3.4 Properties of the battered shrimp burger added with optimized hydrocolloid formulation

From Table 6 and 7, the model formulated burger with the optimized hydrocolloid mixtures had higher juiciness scores and a higher moisture content, compared to the control ($p<0.05$). Control formulation contained higher fat in the coating and in the burger (Table 6) ($p<0.05$). During deep-fat frying, water in the sample was evaporated and moved out. The vapor left voids for fat to enter later. Thus fat uptake is largely determined by the moisture content

Table 6. Moisture and fat content of the control (without hydrocolloids) and optimized formula of battered shrimp burgers.

Treatment	% Moisture Content		% Fat Content	
	Coating	Burger	Coating	Burger
Control(without hydrocolloids)	30.43 ± 0.90^{a}	63.50 ± 0.22^{b}	9.80 ± 0.69^{a}	10.88 ± 0.12^{a}
Optimized Formula	27.34 ± 1.59^{b}	65.18 ± 0.27^{a}	7.82 ± 0.19^{b}	9.53 ± 0.06^{b}

Note: Mean ± SD from triplicate determinations. Different superscripts in the same column indicate significant differences ($p<0.05$).

Table 7. TPA values and juiciness scores of the control (without hydrocolloids) and optimized formula of battered shrimp burgers.

Texture Profile Analysis* (TPA)	Control (without hydrocolloids)	Optimized Formula
Hardness (g)	$7,756.04\pm272.78^{a}$	$7,446.43\pm675.01^{a}$
Fracturability (g*s)	14.81 ± 4.37^{a}	18.47 ± 2.36^{a}
Adhesiveness (s)	-4.18 ± 3.24^{a}	-5.63 ± 2.62^{a}
Springiness	0.46 ± 0.03^{a}	0.39 ± 0.02^{b}
Cohesiveness	0.24 ± 0.02^{b}	0.28 ± 0.02^{a}
Gumminess	$1,823.56\pm158.87^{b}$	$2,116.32\pm198.16^{a}$
Chewiness	841.82 ± 109.07^{a}	829.13 ± 93.90^{b}
Juiciness score**		
1st step	6.97 ± 1.32^{b}	8.23 ± 1.45^{a}
2nd step	7.72 ± 1.46^{b}	9.17 ± 1.64^{a}
3rd step	7.72 ± 1.55^{b}	8.98 ± 1.64^{a}

Note: *Mean ± SD from seven determinations. ** Scale = 15, (1 = low intensity, 14 = high intensity). 1st step is the softness of sample at first bite, 2nd step is the feeling of moist of sample or moist released from sample during 6-8 chews, and 3rd step is the smoothness during swallowing. Mean ± SD from thirteen trained panelists. Different superscripts in the same column indicate significant differences ($p<0.05$).

(Mellema, 2003). The higher fat content of control battered shrimp burger may be due, in part, to more moisture loss during frying (as shown by the lower moisture content), while the burger with optimized hydrocolloid was able to imbibe water and therefore had the improved moisture retention.

TPA results as shown in Table 7 indicated that the higher gumminess and cohesiveness were found in the optimized formulation than in the control burger ($p<0.05$). No differences in other textural attributes such as hardness, fracturability, adhesiveness, and chewiness between both samples were observed ($p>0.05$).

4. Conclusions

The addition of MTS or CA alone in the burger formulation seemed to decrease the product's moisture content and juiciness scores, while AL or combinations of MTS and AL increased the juiciness score. TPA data showed that when combinations of MTS and AL were applied in the battered shrimp burger had a decreased hardness, springiness, cohesiveness, gumminess, and chewiness, whereas CA enhanced hardness.

The optimized formula, predicted the highest moisture content and the 3-step juiciness scores by the models, was composed of 0.3% MTS and 0.7% AL. The product produced with the optimized formula appeared to possess the improved moisture content and juiciness scores, but had no changes in texture, such as hardness, adhesiveness, and chewiness.

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