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Chemical composition and physical properties of extruded snacks containing crab-processing by-product†

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Abstract: The crab-processing industries generate millions of pounds of by-product annually, which results in a loss of edible product and presents a considerable waste disposal problem. The purpose of this research was to investigate the use of crab-processing by-product (CB) in the development of a calcium-rich expanded snack. The specific objectives were to examine the effects of type of CB (wet or dry), feed composition and screw speed (150 or 250 rpm) on selected properties of extruded snacks. Product formulations consisting of 0–400 g kg^{-1} CB combined with corn meal and potato flakes were processed in a twin-screw extruder. The resulting extrudates were analysed for proximate and mineral (calcium, sodium) composition, pH, water activity (a_w), total plate count, bulk density, expansion ratio and colour. Both CB type and level of incorporation had significant effects ($P < 0.05$) on the calcium content, expansion ratio, bulk density and pH of the extrudates. Increasing the CB level resulted in increased calcium content (from 5.1 to 52.4 mg g^{-1}) and pH (from 6.1 to 8.8). Screw speed had no significant effects ($P > 0.05$) on expansion ratio and bulk density. A high processing temperature (157 °C) and low a_w resulted in undetectable microbial growth on the extrudates. This research demonstrates that ground crab-processing by-product can be successfully incorporated into an expanded snack product. Further research will evaluate consumer response to this novel value-added product.

Keywords: extrusion; by-product utilisation; snack food; crab processing

INTRODUCTION

More than 300 million pounds of crab, having a value of over $260 million, are landed annually in the USA (Fisheries Statistics and Economics Division, National Marine Fisheries Service, personal communication, 2000). These commercial landings generate an estimated 270 million pounds of postprocessing waste each year. Assuming an average picked meat yield of 100 g kg^{-1},[1] the blue crab (*Callinectes sapidus*) fisheries alone produced approximately 160 million pounds of postprocessing waste in 2000. Crustacean-processing waste, or by-product, has traditionally been disposed of in landfills, composted, or incorporated into animal feeds. However, the by-product, which contains pigments, flavour components, calcium and other minerals, and high-quality protein, can also be used to create value-added products.[2] Commercial food items already produced using crustacean by-products include flavoured cooking oils, soup and sauce bases, chitinous biopolymers for nutraceutical and food-processing uses, minced meat for seafood stuffings, and natural pigments for shellfish analogue products.

Extrusion processing is another potential method of adding value to crustacean-processing by-product. One of the primary benefits of extrusion is that it can transform a highly perishable initial product into a shelf-stable food. A number of finfish species, including carp,[3] sardine,[4] Atlantic cod,[5,6] pink salmon[7,8] and channel catfish,[9,10] have been minced and successfully co-extruded with cereals to produce a variety of snack food products. That research was mainly conducted to develop uses for underutilised sources of fish muscle and to enhance the protein content of traditionally nutrient-poor snacks. The fish mince was either previously dried and added as a flour,[6–8] partially dried,[11,12] or added as is,[3–5,9]

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saving the costs associated with drying. There are no reports in the literature on the utilisation of crustacean-processing by-products in extruded snacks. The overall objective of this research was to investigate the use of wet and dry crab-processing by-product (CB) in the development of a seafood-flavoured, calcium-rich expanded snack. The specific objectives were to examine the effects of type of CB (wet or dry), feed composition and screw speed on selected properties of extruded snacks.

MATERIALS AND METHODS

Ingredients

Yellow corn meal was purchased from ConAgra Corn Processing (Atchison, KS, USA). Potato flakes were obtained from McCains (Presque Isle, ME, USA). A commercial spice mixture was provided by Georgia Spice Co (Atlanta, GA, USA). The raw material for the crab-processing by-product was obtained from a local crab processor (Boyton's, Lamoine, ME, USA). It consisted of Atlantic rock crab (*Cancer irradians*) discards that had been coarsely chopped (Chipper/Shredder, Troy-Bilt, Port Washington, WI, USA), then stored in sealed plastic buckets at −18 °C prior to further processing. The discards were the portions of the boiled crab legs remaining after the handpicking operations, and included meat and shell. The chopped crab by-product mixture was partially thawed, then reduced in particle size by multiple passes through a Hobart grinder (Model 84141, Hobart Mfg Co, Troy, OH, USA) using progressively smaller dies (from 0.25 to 0.0625 inch). Butylated hydroxytoluene (Aceto Corp, Lake Success, NY, USA) was added to the CB after the first grind, at a level of 20 mg kg^{-1}, to help control lipid oxidation. A portion (∼25 kg) of the CB was spread on stainless steel drying trays and oven dried at 120 °C for 12 h until a final moisture content of ∼100 g kg^{-1} was reached. The dried CB was ground in a laboratory mill (Thomas-Wiley, Arthur H Thomas Co, Philadelphia, PA, USA) and passed through a 2 mm mesh screen.

Batches of wet or dry CB, corn meal, potato flakes and spice mix were prepared according to the formulations in Table 1. Experimental levels of wet CB were set at 100, 180 and 250 g kg^{-1}, and levels of dry CB were 100, 200 and 400 g kg^{-1}. The ratio of corn meal to potato flakes was maintained at 2:1 for all batches. A control mixture contained only corn meal, potato flakes and the spice mix. All ingredients were mixed in 10 kg batches for 10 min using a Hobart mixer (Model H-600-D, Troy Manufacturing, Troy, OH, USA), and the moisture content of each batch was determined prior to extrusion. Each batch was extruded in duplicate.

Table 1. Formulation of extrusion mixes (g kg^{-1})

Treatment	Wet CB	Dry CB	Corn meal	Potato flakes	Spice mix
WC-10	100	0	593	297	10
WC-18	180	0	540	270	10
WC-25	250	0	493	247	10
DC-10	0	100	593	297	10
DC-20	0	200	527	263	10
DC-40	0	400	393	197	10
Control	0	0	660	330	10

Extrusion conditions

A laboratory-scale co-rotating twin-screw extruder (Model ZSK 30, Werner & Pfleiderer, Ramsey, NY, USA) with a screw length of 963 mm and a screw diameter of 30 mm was used for extrusion. The extruder was equipped with a 4 mm diameter cylindrical die and a single-blade cutter which was kept at a constant speed of 555 rpm. The high-shear screw configuration used consisted of a total of 504 mm of 42° forward conveying elements, 56 mm of 28° conveying elements, 14 mm of 28° narrow pitch conveying elements, 260 mm of 20° conveying elements, 7 mm of 41° Igel, 14 mm of 45/5 kneading block elements at 671 mm, 20 mm of 45/5 kneading block elements at 739, 813 and 883 mm, 14 mm of 45/5 left-handed kneading block elements at 685 and 759 mm, and 20 mm of 20° reverse elements. The temperatures of the six barrel sections were set at 60, 90, 97, 115, 135 and 157 °C. Screw speeds used were 150 and 250 rpm (Table 2). The formulations were fed into the extruder using an Accu-Rate hopper (Moksnes Manufacturing Inc, Whitewater, WI, USA) at a rate of 13.5 kg h^{-1}. Tap water was pumped into the first barrel section using a piston metering pump (American Lewa, Holliston, MA, USA) to provide a feed moisture content of 210–230 g kg^{-1}. The sample mixtures were continuously extruded in random order, and each mixture was extruded in duplicate (replicates A and B). A minimum of 4 min running time was allotted between treatments to ensure equilibration before representative samples were taken. Extrudate samples (∼1500 g per replicate) were collected on a wire mesh screen and dried at 175 °C for 7 min in a Hobart single-rack gas convection oven (Hobart Co, Troy, OH, USA). The dried samples were placed in tri-laminate bags (Cadillac Products, Paris, IL, USA),

Table 2. Extrusion treatments

Code	Level of CB incorporation (g kg^{-1})	Screw speed (rpm)
Control	0	150
WC-10-150	100 wet	150
WC-18-150	180 wet	150
WC-25-150	250 wet	150
DC-10-150	100 dry	150
DC-10-250	100 dry	250
DC-20-150	200 dry	150
DC-20-250	200 dry	250
DC-40-150	400 dry	150
DC-40-250	400 dry	250

heat sealed and stored at room temperature (∼25 °C) until physical, chemical and microbial analyses were performed.

Expansion ratio (ER)

Expansion ratio was calculated as the diameter of the extrudate divided by the diameter of the die. The diameter was measured at the centre of each piece of extrudate using a vernier caliper accurate to 0.05 mm. Ten measurements were performed for each replication.

Bulk density (BD)

Bulk density of the extrudates was determined in duplicate. A 250 ml beaker was filled with extrudate to the 150 ml mark while tapping gently, and the weight of the extrudate was recorded. Bulk density was calculated as mass/volume of extrudate ($g\,cm^{-3}$).

Colour measurement

Approximately 15 g of extrudate was finely ground using a household-type coffee grinder (Braun, Mississauga, Ontario, Canada), and 3 g aliquots were analysed in duplicate for each sample. Instrumental colour of the ground extrudates was measured using a spectrocolorimeter (LabScan II Model 5300, Hunterlab Associates Laboratory, Inc, Reston, VA, USA) to record L, a and b values. Readings were recorded and averaged from three rotations per sample.

Proximate and mineral composition

Moisture content was determined by heating 3 g of ground extrudate in a 105 °C oven for 14 h, then measuring the weight loss. Crude lipids and Kjeldahl nitrogen were determined according to AOAC[13] procedures 945.14 and 988.05 respectively, and ash content according to AOAC procedure 938.08. Calcium and sodium were determined by dissolving the ash residue in 2 ml of concentrated acid (HCl/HNO_3 1:1 v/v), adjusting the volume to 100 ml and analysing for calcium and sodium content on an ICP spectrophotometer (Jarrel-Ash AtomComp, Waltham, MA, USA). All chemical analyses were performed in duplicate.

Water activity and pH

Water activity of the ground extrudates was measured using an Aqualabs CX2 water activity meter (Decagon Devices, Inc, Pullman, WA, USA). Measurements of pH were performed on 2 g of ground extrudate mixed with 20 ml of distilled water and shaken mechanically for 5 min. Both water activity and pH were determined in duplicate for each sample.

Microbial analyses

Aerobic plate counts were performed on the raw ground by-product and on the extrudates using standard AOAC[14] techniques. Samples (25 g) were weighed aseptically into sterile stomacher bags and stomached with 225 ml of bactopeptone (Difco Laboratories, Detroit, MI, USA) for 2 min in a Stomacher Lab-Blender (Tekmar Company, Cincinnati, OH, USA). Samples were serially diluted, plated on standard plate count agar (Difco Laboratories) and allowed to incubate at ∼25 °C for 48 hours. All samples were homogenised and plated in duplicate.

Statistical analyses

Statistical differences among the 10 treatments were evaluated on SYSTAT 8.0 (SSI, Richmond, CA, USA) using one-way analysis of variance. Significant ($P < 0.05$) differences between means were determined by Tukey's *post hoc* test.[15] Regression analyses were performed to observe linear relationships between product characteristics.

RESULTS AND DISCUSSION

Both the wet and the dry CB were successfully incorporated into expanded snack products. Formulations containing up to 250 $g\,kg^{-1}$ wet CB and up to 400 $g\,kg^{-1}$ dry CB were processed without extruder failure. Both CB type (wet or dry) and level of incorporation had significant effects on the dependent variables measured.

Physical analyses

Within each CB type (wet or dry), as the CB content increased, the expansion ratio of the extrudates decreased (Fig 1) and the bulk density increased (Table 3). Similar results have been observed by other investigators,[6–8,12] who found that, as fish muscle replaced starch in the feed, gelatinisation and expansion of the extrudates decreased. It was proposed that the protein enclosed available starch, thereby limiting its expansion.[6] The lower expansion observed with high CB concentrations was also likely influenced by the high ash levels in those extrudates (see Table 4). It was reported[16] that, as eggshell (composed primarily of calcium carbonate) supplementation of corn starch extrudates increased from 0 to 100 $g\,kg^{-1}$, the expansion ratio of the extrudates decreased by approximately 30%. Although lipids are also known to

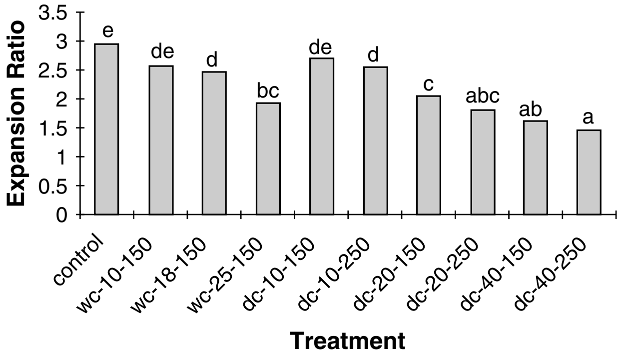

Figure 1. Effect of treatment on expansion ratio of extrudates. Expansion ratio values were determined on a dry weight basis. Different letters above columns indicate significant differences.

interfere with gelatinisation of starch,[17] the uniformly low lipid content of our extrudates indicates that fat content was not a factor influencing expansion.

Screw speed had no significant effects ($P > 0.05$) on the physical properties of the extrudates (Table 3). Other researchers[10] reported that, as the screw speed increased from 100 to 250 rpm, the bulk density of tapioca/fish extrudates decreased; this decrease was more significant in their study possibly owing to the lower barrel temperatures used (90–100 °C). Under those conditions the increase in shear due to increased screw speed would have a more pronounced effect on the total energy input to the system and on the physical properties of the extrudates. However, it has also been reported[6,7] that, amongst the common independent variables typically examined in extrusion studies (temperature, feed composition, screw speed, moisture content), screw speed appears to have the least effect on any of the dependent variables measured.

The colour of the extrudates as measured by Hunter L, a and b values was not significantly ($P > 0.05$) affected by treatment variables. However, within each product type, as the level of CB increased, there was a strong trend for both L (lightness) and b (yellowness) values to decrease. These slight colour differences among treatments were anticipated owing to differences in feed composition and the intrinsic colours of the yellow corn meal and the light brown CB.

Table 3. Expansion ratio, bulk density and Hunter *L*, *a* and *b* values of extrudates[a]

Treatment code	Expansion ratio	Bulk density ($g\,cm^{-3}$)	L	a	b
Control	2.9e	0.08ab	70.9b	5.8ab	36.6a
WC-10-150	2.5de	0.15abc	68.4ab	6.1ab	26.6a
WC-18-150	2.5d	0.16bc	66.1ab	7.1b	25.6a
WC-25-150	1.9bc	0.28d	65.9ab	5.5ab	22.8a
DC-10-150	2.7de	0.11abc	70.2ab	4.9ab	25.2a
DC-10-250	2.5d	0.07a	68.4ab	4.8ab	24.0a
DC-20-150	2.0c	0.16bc	67.2ab	4.5ab	23.4a
DC-20-250	1.8abc	0.13abc	67.7ab	4.1a	22.8a
DC-40-150	1.6ab	0.17c	63.6a	4.0a	19.7a
DC-40-250	1.4a	0.11abc	64.7ab	3.9a	18.9a

[a] Each value is the average of two replications, each analysed in duplicate. Different letters within each column indicate significant differences ($P < 0.05$) among treatments, based on one-way analysis of variance followed by Tukey's *post hoc* test.

Chemical analyses

There were few significant ($P > 0.05$) differences in crude protein content among extrudate treatments based on analysis of variance (Table 4). However, there was a significant positive correlation ($r^2 = 0.898$, $P = 0.038$) between crude protein content and CB incorporation in the extrudates. The highest level of CB incorporation, $400\,g\,kg^{-1}$, resulted in an average crude protein level of $125\,g\,kg^{-1}$ in the extrudates, a 70% increase over the control extrudates. Other researchers have reported enhanced protein concentrations in rice flour-based extrudates with the addition of minced carp.[3] They were able to increase the crude protein content from 83 to $109\,g\,kg^{-1}$ when $200\,g\,kg^{-1}$ raw carp mince was incorporated into the feed mixture. When $350\,g\,kg^{-1}$ minced cooked carp was added, the resultant protein content of the extrudate increased to $154\,g\,kg^{-1}$. These values are slightly higher than those obtained in our study, since CB contains a significant amount of ash in addition to minced muscle.

The most significant effects of feed composition were observed in the ash and calcium contents of the extrudates (Table 4). As expected, ash content increased with increasing level of CB incorporation. Extrudates containing dry CB had significantly higher ash contents than those from the wet CB treatments and the control. Because crab shell ash consists primarily of calcium, the calcium concentration of the extrudates was significantly effected by the level of CB incorporation. Linear regression analysis of calcium content and level of CB incorporation resulted in $r^2 = 0.88$, $P = 0.08$. Calcium concentrations of the extrudates ranged from a low of $5.1\,mg\,g^{-1}$ to a high of $52.4\,mg\,g^{-1}$. To be considered 'high in calcium',

Table 4. Proximate composition, calcium and sodium concentrations and pH of extrudates[a]

Treatment code	Moisture ($g\,kg^{-1}$)	Ash ($g\,kg^{-1}$)	Lipid ($g\,kg^{-1}$)	Protein ($g\,kg^{-1}$)	Calcium ($mg\,g^{-1}$)	Sodium ($mg\,g^{-1}$)	pH
Control	11a	13a	0.2a	74a	5.1a	0.5a	6.13a
WC-10-150	41b	31ab	0.8ab	79a	5.4a	0.7ab	7.03b
WC-18-150	10a	44bc	0.3a	86ab	10.9ab	1.3abc	7.35bc
WC-25-150	27ab	62cd	1.1ab	94ab	11.3ab	1.3abc	7.84c
DC-10-150	36ab	84de	0.2a	92ab	11.9ab	1.5abc	7.27bc
DC-10-250	25ab	87e	0.8ab	115ab	20.6abc	2.2abc	7.26bc
DC-20-150	36ab	162f	1.0ab	101ab	22.1abc	1.7abc	7.92c
DC-20-250	14ab	160f	1.0ab	107ab	29.4bc	2.3bc	7.84c
DC-40-150	28ab	305g	1.5b	123ab	41.2cd	2.8c	8.66d
DC-40-250	34ab	308g	1.8b	128b	52.4d	2.9c	8.75d

[a] Each value is the average of two replications, each analysed in duplicate. Different letters within each column indicate significant differences ($P < 0.05$) among treatments, based on one-way analysis of variance followed by Tukey's *post hoc* test.

a food product must contain more than one-fifth of the US Recommended Daily Allowance (RDA) of 1200 mg. All the extrudates formulated with dry CB, and those formulated with $180\,g\,kg^{-1}$ or more of wet CB, contained more than 240 mg calcium per 28 g (1 oz, serving). Crab shell calcium is primarily in the form of calcium carbonate, which, while poorly soluble, has a fractional absorption slightly higher than that of calcium citrate[18] and was shown to be as well utilised as dairy calcium in an animal study.[19] Increases in extrudate calcium concentrations were mirrored by increased pH of the extrudates owing to the presence of carbonate. The pH values in the extrudates ranged from 6.1 in the control treatment to an average of 8.7 in the treatment with $400\,g\,kg^{-1}$ dry CB.

Microbial analyses

Although aerobic plate counts of the wet CB resulted in an average of $156 \times 10^5\,cfu\,g^{-1}$, no microbial growth was detected in any of the extrudate treatments up to 3 months postprocessing. The high processing temperature (157 °C) appeared sufficient to inactivate the high number of micro-organisms present in the raw product. In addition, the water activity of the extrudates ranged from 0.03 to 0.11, well below the range for microbial growth.

CONCLUSIONS

A mildly flavoured expanded snack was produced from a blend of crab-processing by-product, corn meal and potato flakes. The ground CB was successfully utilised in both wet and dry forms and resulted in a calcium-rich product with negligible microbial counts after 3 months of room-temperature storage. Both CB type (wet or dry) and level of incorporation had significant effects on the dependent variables measured. Further research should focus on the use of wet CB in order to save the costs associated with drying, and should include sensory evaluation to determine consumer response to this novel value-added product.

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