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From waste to a new sustainable ingredient in the kitchen: Red king crab abdominal flap (*Paralithodes camtschaticus*)

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ABSTRACT

Paralithodes camtschaticus (red king crab) is an introduced species in the Barents Sea. Nowadays it is considered invasive, representing a potential threat to the ecosystems. In Norway, the red king crab catch has increased from 50 tons to 1906 tons from 2004 to 2011. As it is almost exclusively the legs of the red king crab that are commercially used, around 32% of the crab is discarded. This means 351 tons of waste during this eight-year period, an amount that will only increase in the next few years. Taking this environmental problem into consideration, the king crab abdominal flap, a common waste product in the king crab industry, has been used as an example to analyze the nutritional value and heavy metal content. The results show that the content of lead (<0.01 mg/kg), cadmium (0.0986 mg/kg) and mercury (0.0163 mg/kg) is below the concentrations established by EFSA (0.5 mg/kg). Also, the concentration of macronutrients was compared to standard king crab legs where the protein accounts for 14.6 g per 100g, fat for 0.5 g and carbohydrates for 0.6 g. Mineral compounds such as potassium, phosphorus, and sodium have been found in high concentrations in comparison to king crab leg samples. According to a sensory analysis, there are significant differences between the abdominal flap and leg, but the abdominal flap has been accepted by consumers averaging 6 points on the hedonic scale. In addition, male testers appreciated the flavor more than female testers in all the samples, but without any preferences between samples (variances were the same). Finally, when comparing cooking methods, pan searing has been concluded to be the best method to cook the abdominal flap, as it enhances the texture, aroma, and flavor, followed by cooking it sous-vide and pan seared and lastly just sous vide. The differences in flavor are due to the compounds generated during each process. Our culinary application study shows that this product is completely acceptable as a new ingredient, even for fine dining restaurants.

1. Introduction

One of the largest commercially caught arthropods in the world, the *Paralithodes camtschaticus* (red king crab), it's an invasive species in the Barents Sea and along the coast of Norway (Jørgensen, 2013), Alaska and Russia (Dvoretsky and Dvoretsky, 2015). In Russian waters, the red king crab commercial stock reached 21 million crabs in 2016 (Dvoretsky and Dvoretsky, 2018). The populations of red king crab in Norway have skyrocketed, with an estimated 12 million crabs living in the Barents Sea alone (WWF-Norge, 2002). Since it is an introduced species, the red king crab represents a potential threat to the ecosystems in the Barents Sea, due to their predatory behavior and ability to travel great distances with their long legs (Christiansen et al., 2015). Red king crabs are also a growing concern for fishermen, particularly in gillnet industries, as they destroy nets when they are by-caught (Jørgensen, 2013). Red king crab is a very expensive delicacy, above all, because of its legs. However, the rest of the animal is commonly not used in gastronomy. The by-product represents 32% of the crustacean. It is, therefore, highly relevant to reconsider this "waste" in order to use the whole product (Andreassen, 2014).

According to a report by the Nofima Laboratory about red king crab in Northern Europe, the catch of red king crab increased from 50 tons to 1906 tons from 2004 to 2011 (Stenberg et al., 2012). According to this study, 351 tons of waste was produced during this 8-year period. With this in mind, it is important to manage this waste in a sustainable way. It will become a major environmental issue due to the high concentration

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of different metabolites from proteins in landfills or ocean waters.

In addition, these wasted by-products contain a large amount of protein and essential amino acids, such as valine, leucin, arginine, lysin and threonine. The total amounts are 25% of free amino acids as well as 21% other proteins (Stenberg et al., 2012). Another finding in the Nofima Lab study in Norway was that the content of heavy metals in the waste was below the maximum limits permitted in the Commissions Regulations (EU) Nº 1881/2006 of December 19, 2006, setting maximum levels for certain contaminants in food stuffs (Stenberg et al., 2012). The established limit is 0.5 mg/kg wet weight of mercury and lead (The Commision of the European Communities, 2006).

The adult male king crab abdominal flap (Fig. 1) as an interesting new part of the crab to use, due to around 50 tons are wasted per year by fishery producer (Stenberg et al., 2012). The king crab abdominal flaps used in this study were sourced from Norway, from the MS Donna company. MS Donna focuses on responsible fishing and has a zero-waste philosophy (rethink, reuse and reduce). MS Donna has highlighted some of the offcuts of the king crab, such as the abdominal flap and roe, by offering them to restaurants and challenging them to find ways to use them in their menus.

The king crab abdominal flap has been used in different traditional recipes, for example in Norway and Alaska, where they are pickled. More recently, king crab abdominal flap appeared on the menu of different fine dining restaurants in the Nordic region, where the goal is to turn food waste into a fine dining experience (MS Donna, 2010).

The objective of this research is highlighting the importance of the king crab abdominal flap as a new product and resource in gastronomy.

2. Materials and method

The nutritional value of flap was analysed to carry first part of this studio. To study the acceptance of the flap, a sensory analysis was performed by comparing of leg and flap samples. Additionally, three cooked methods were studied by another sensory analysis to analyze the appropriated cooked method for the flap.

2.1. Nutritional value

ALS Laboratory Group Norway AS were responsible for the nutritional analysis of the king crab abdominal flap. The analysis was performed using raw frozen King crab flaps. Four different samples were analysed per triplicate, with an average of 112 g per samples.

2.1.1. Water content

The water content was measured with a gravimetry standard AOAC method, feeding stuff sampling & analysis regulations 2000 (AOAC International, 1995) whose established detection limit is 0.1 g/100 g with a measurement error of ±1.1%.

2.1.2. Ash

The ash content was measured with a gravimetry method according to BS 4401 Part1 1998 Commission Regulation (EC) 152/2009 (The Commision of the European Communities, 2006), with the detection limit 0.1 g/100 g and a measurement error of ±6.5%.

2.1.3. Energy

The measurement of energy (kcal/KJ) of king crab abdominal flap was carried out under the Council directive 90/496/ECC, with the detection limit 12 kcal/100 g; 50 KJ/100 g (European Council, 1990).

2.1.4. Fat

Fat content was performed by an internal method (data not shown) from ALS Laboratory Group Norway AS, under the principle of a pulsed NMR method (Gribnau, 1992), with the detection limit 0.1 g/100 g and a measurement error of ±2%.

2.1.5. Carbohydrate

According to the rule of council directive 90/496/ECC (European Council, 1990), carbohydrate concentration was analysed under the next equations: Total carbohydrate = 100 – (water content + protein + fat + ash) with the detection limit 0.1 g/100 g, and a measurement error of ±2%.

2.1.6. Protein

Dumas-Method was used for N-total (Mæhre et al., 2018), total protein concentration was quantified by intern method from ALS Laboratory Group Norway AS, according to equation 6.25*N-total, with the detection limit 0.1 g/100 g and a measurement error of ±2%.

2.1.7. Metals

The analysis was made according to UNE-EN 13805:2014, Foodstuffs - Determination of trace elements - Pressure digestion and EPA-Method 200.8 by ICP-SFMS (Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma - Mass Spectrometry) (ICP-MS) (Manecki et al., 2018).

2.2. Sensory analysis

2.2.1. Raw materials

Paralithodes camtschaticus (red king crab) abdominal flap samples were supplied by MS Donna in Drengsrudhagen 6, 1383 Asker, Norway. The king crabs were caught in the FAO27 fishing area. The abdominal flaps had an average weight of 20 g with a size ranging from 10 to 12 cm. The average weight of the legs was 30 g, with a size of approximately 12

Fig. 1. Brined and pan seared king crab flap and raw king crab abdominal flap.

cm. The king crab abdominal flaps were received frozen at −18 °C. 120 flaps and 25 legs were used in this study.

2.2.2. Sample preparation

The samples were received frozen and kept in the freezer with an average temperature of −18 ± 2 °C until cleaning. Both the abdominal flaps and legs were thawed at 4 ± 2 °C for 24 h. After cleaning (Video 1), samples were brined (in a proportion of 1:2 wt of the clean flaps to brine respectively), with “seaweed fish brine” for 12 h. A “seaweed fish brine” was made with 5% (w/v) salt, 4% (w/v) sugar, 0.5% (w/v) toasted coriander seeds, 1% (w/v) kombu seaweed and 0.3% (w/v) lemon zest (Myhrvold, 2011).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.ijgfs.2021.100455

Leg and flap were sous-vide cooked at 50 ± 2 °C for 15min (Myhrvold, 2011) to carry out the first part of the sensory analysis. For the second part of the sensory analysis, three different cooking techniques were chosen to analyze the best method to cook the flap. These techniques were *sous-vide* at 50 ± 2 °C, *sous-vide* and pan seared and just pan seared for 3 min at 180 ± 2 °C (Fig. 1).

2.2.3. Consumer test

The analysis was carried out with a panel of 80 students from Copenhagen Hospitality College (HRS) and chefs from the Alchemist restaurant, both located in Copenhagen, Denmark, from September to December 2020. All of them were adults in a wide age range (from 18 to 46 years old; averaging 29 years). The gender ratio was 51% female and 49% male. The room temperature was kept at 25 °C. Students were briefed prior to the evaluation to ensure the reliability of the results. The nine-point hedonic scale (1 = “dislike extremely”, 9 = “like extremely”) was used to evaluate the participant’s level of liking and three different characteristics, aroma, texture, and taste. (Pimentel et al., 2015).

5 g of sample (pieces of 2 × 2.5 cm) was serviced at 50 °C and randomly coded.

First part of the consumer test was done by comparation of flap and leg sample. Second part was studied for flap sample by three different cooked methods, explained in section 2.2.2.

2.2.4. Data analysis

Data from the first experiment (leg vs flap) were analysed using a two-way ANOVA with interaction, with the independent factors of type of sample (legs vs flaps) and consumer gender (males vs females). A Tukey’s test at $p < 0.05$ level was carried to detect differences between means. For the second experiment (cooking method) data were analysed by a two-way ANOVA, considering two independent factors and their interaction: cooking method (sous-vide vs sous-vide plus pan seared vs pan-seared) and consumer gender (male vs female). A Tukey’s test at $p < 0.05$ level was carried to detect differences between means (Haynes, 2013). XLSTAT Version 2020.4.1 was used to conduct the statistical analyses (Addinsoft, 2021).

3. Results

3.1. Nutritional analysis

Table 1 shows the obtained results for the nutritional composition and heavy metal content of King crab abdominal flaps. The values per 100 g of sample were found: 2.1 g ash, 82.2 g water, 14.6 g protein, 0.5 g fat, 0.6 g carbohydrate and 277 kcal. Per kilogram of sample, the king crab abdominal flap contained 3.67 mg of iron, 1470 mg of phosphorus, 4050 mg of sodium, and 2520 mg of potassium.

King crab abdominal flap showed a low concentration of heavy metals: <0.01 mg/kg of lead, 0.0986 mg/kg of cadmium or 0.0163 mg/kg of mercury.

Table 1
Heavy metals and nutritional content.

Element	Concentration [mg/kg]
Lead (Pb)	<0.01
Chromium (Cr)	<0.2
Manganese (Mn)	0.189
Zinc (Zn)	60.2
Arsenic (As)	9.74
Cadmium (Cd)	0.0986
Copper (Cu)	1.13
Nickel (Ni)	<0.02
Cobalt (Co)	0.00887
Mercury (Hg)	0.0163
Molybdenum (Mo)	0.0164
Iron (Fe)	3.67
Selenium (Se)	0.333
Aluminum (Al)	3.03
Potassium (K)	2520
Magnesium (Mg)	420
Sodium (Na)	4050
Sulfur (S)	3140
Phosphorus (P)	1470
Vanadium (V)	0.0316
Element	**g/100g**
Ash (g)	2.1
Moisture (g)	82.2
Protein (g)	14.6
Fat (g)	0.5
Carbohydrate (g)	0.6
Energy (Kcal)	277

3.2. Sensory analysis

3.2.1. Comparison between king crab leg and abdominal flap

As Table 2 shows the ANOVA for *p* value between the interactions have differences.

Tukey test shows how leg and flap have not significant differences in taste for male, however female perceived differences. The taste perception between gender differed.

In this trial, the aroma and texture perception of the samples differed between legs and flaps. By contrast, there are not significant differences for flap texture between gender (Table 2).

3.2.2. Comparison between three different cooking methods

For this comparison, three different cooking methods were used. As a result of the second experiment, it was concluded that the variances are different, which interceptions are below the $\alpha < 0.05$. The null hypothesis has been declined (Table 3).

The sous vide method delivered a different result compared to the other cooking methods for texture and taste, however aroma differed between gender. As pan seared as sous vide seared pan do not have differences for female either for male for any attributes studied (Table 3).

4. Discussion and conclusion

The flaps have similar nutritional qualities to leg meat and are well below the thresholds for nasty chemicals. The results of the study showed that the amount of heavy metals in king crab abdominal flap samples are below the maximum concentration established by the European Food Safety Authority (EFSA). The concentration must not be over 0.5 mg/kg (The Commision of the European Communities, 2006, 2016), thus the king crab abdominal flap sample did not exceed the maximum limit of lead, mercury and cadmium. In addition, the results showed that the sample contains 12.7 mg/kg of arsenic. The most present arsenic in seafood is arsenobetaine, a type of organic arsenic that does not readily enter the cell and is excreted, unchanged, in the urine (International Agency for Research on Cancer (IARC), 2012).

The nutritional quality of flap red king crab, compared to other

Table 2
Results of two way-ANOVA and post-hoc analysis (Tukey HSD) of the attributes taste, aroma and texture depending on gender and leg or flap; means, standard deviation and p-value are showed.

	Male				Female				p^{Gender}	$p^{Leg\text{-}flap}$	$p^{intercept}$
	Leg		Flap		Leg		Flap				
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD			
Taste	7.3[a]	2.8	6.9[a]	2.8	6.1[ab]	2.8	5.6[b]	2.8	**0.004**	**0.023**	**<0.0001**
Aroma	6.7[a]	2.6	6.4[ab]	2.6	6.0[ab]	2.6	5.4[b]	2.6	**0.018**	0.125	**<0.0001**
Texture	7.3[a]	3.1	6.0[b]	3.1	6.2[ab]	3.0	5.5[b]	3.0	0.323	0.146	**<0.0001**

Legend: samples within the same row followed by different letters were significant different ($p < 0.05$).

Table 3
Results of two way-ANOVA and post-hoc analysis (Tukey HSD) of the attributes taste, aroma and texture depending on gender and each cooked method (pan seared, sous vide and pan seared-sous vide) for flap; means, standard deviation are p-value are showed.

	Male						Female						p^{Gender}	p^{Method}	$p^{intercept}$
	Pan seared		Sous vide-pan seared		Sous vide		Pan seared		Sous vide-pan seared		Sous vide				
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD			
Taste	7.6[a]	3.0	7.2[ab]	3.5	6.1[b]	3.1	7.1[ab]	3.0	6.8[ab]	3.0	6.0[b]	3.0	0.256	**0.015**	**<0.0001**
Aroma	7.4[a]	3.0	7.0[ab]	3.0	6.0[b]	3.0	6.4[ab]	2.9	6.3[ab]	2.9	5.6[ab]	2.9	**0.037**	0.079	**<0.0001**
Texture	6.7[a]	3.3	6.6[a]	3.3	5.2[ab]	3.3	6.6[a]	3.2	6.4[a]	3.2	5.0[b]	3.2	0.877	**0.001**	**<0.0001**

Legend: samples within the same row followed by different letters were significant different ($p < 0.05$).

seafood with the same characteristics, they have similar qualities (Risso and Carelli, 2012). These results provide interesting information to promote the consumption of king crab abdominal flaps instead of king crab legs.

Although the flaps have differences in appearance, the sensory qualities are comparable with those of leg meat. Generally, males liked the samples more than females in both cases, due to the fact that women may detect odors at lower concentration thresholds, as they have a greater sensitivity of aroma and taste (Koubaa and Eleuch, 2020). On the other hand, according to another investigation, males were more likely to be "high sweet likers" (Yang et al., 2020).

On the other hand, there is no published literature about this product, and the culinary methods used were chosen according to experience and the potential of reproduction in a normal kitchen. The samples "pan seared" and "sous vide and pan seared" were perceived to be without differences, although the first sample got the highest score on the hedonic scale, especially for taste. Sous vide is a great cooking method for meat, fish and vegetables, with good texture and nutritional value (Zavadlav et al., 2020), keeping moisture and tenderizing collagen. Due to the thermal process, meat proteins experience denaturation. These attributes contribute to organoleptic features, such as juiciness (Baldwin, 2012; Hwang et al., 2019). Nevertheless, the "sous vide" sample got a low result, especially in regards to texture, thus, the juicy attribute was not accepted for crustaceans. These changes in textures are reflected in the fact that the males ranked the "sous vide" method about one point higher than females. In contrary, the trend for "pan seared" is the same for both genders. The juiciness decreases when increasing the cooking temperature, hence the texture change.

Therefore, "pan seared" and "sous vide and pan seared" had different variances compared to "sous vide". These differences are attributed to the roasting, where numerous aromas are generated through the Maillard reaction. High temperatures speed up the chemical reactions and accelerates the evaporation of water. Hydrolyzing the proteins in amino acids may be responsible for the umami taste (Zhang et al., 2019). In addition, the reaction produced between one amino acid and one sugar will produce hundreds of volatile compounds. These molecules are generally heterocyclic compounds, of which the structure depends on the heteroatoms present in the amino acids (N, O or S) (Wong et al., 2008). All these volatile compounds are not generated during the sous vide process, thus producing less umami flavor. This might be the reason why the "pan seared" samples were the most appreciated by the participants. Also, the optimization of the cooking method leads to a high-quality dish, due to the fact that the change in texture is very important for the experience of consuming flap, especially between genders.

In conclusion, the flap has been accepted by consumers, being higher that acceptability for the male than the female. In addition, taste, texture, and aroma were improved by the cooking technique, being the best on the pan seared. The consumption of this by-product will reduce the large amount of waste generated during the harvest (approximately 30% of the total red king crab catch). It will also reduce environmental problems, as flaps are discarded and dumped into the sea or close to the shore (Lorentzen et al., 2018). Thus, using these by-products can lead to an added product-value and can reduce the pressure in the environment.

Finally, the product is currently on the menu at Alchemist restaurant. Consequently, it might be accepted in fine dining restaurants. The king crab abdominal flap might be a potential new ingredient to consume instead of king crab leg.

Future lines of research might be to analyze the aroma compounds in different cooking methods as well as studying other culinary techniques for cooking and presenting king crab abdominal flap. Also, during this research, king crab roe was also found to be a very interesting waste product that will be valuable in further research.

5. Culinary application

According to the results from the sensory analysis, a king crab abdominal flap recipe was developed in the Alchemist restaurant test kitchen. The king crab abdominal flap was first brined in a seaweed brine (as explained in section two) for 24 h at 4 °C and then cooked at 52 °C for 15 min. Following the results obtained in the sensory analysis, the abdominal flap was brined, cooked sous vide and pan seared (3 min at 180 °C), a thin slice of bread was placed underneath the flap before it was pan seared. When cooked like this, the bread becomes toasted and crispy, while preserving the delicate texture of the king crab abdominal flap (Fig. 2).

Authors contributions

NR carried out all sensory analysis and drafted the manuscript. DP carried out all gastronomic applications and experiments and adapt the manuscript. RR carried out gastronomic applications test and sensory

Fig. 2. Culinary application. Sous vide and pan-fried king crab abdominal flap, fermented pumpkin and orange sauce and king crab roe by Alchemist restaurant. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

analysis samples. KO supplied all material samples and data on king crab and sustainability fishing inputs. RM founded and check all manuscript. All authors read and approved the final manuscript.

Implications for gastronomy

The research article "From waste to a new sustainable ingredient in the kitchen: red king crab abdominal flap (*Paralithodes camtschaticus*)", is relevant for gastronomy because it highlights an unused part of the king crab that has typically been disregarded and directly discarded for years. The research demonstrates the abdominal flap's gastronomical value through data analysis, including nutritional value, water content, ash, energy, fat, carbohydrates, and proteins. It also proves its safety with data on metals. Most importantly, it demonstrates the abdominal flap's relevance in gastronomy, and potential to create a new market and business opportunities for something that was previously discarded and potentially polluting the ocean. This is reinforced by the results of consumer tests on different samples comparing the leg and abdominal flap.

The article documents culinary techniques and applications, including three different cooking methods on the king crab abdominal flap. The methods prove the product's viability and consumer liking, in addition to showing its culinary application in a fine dining restaurant context, Alchemist (2 Michelin stars) in Copenhagen.

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