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The effect of furcellaran or κ-carrageenan addition on the rheological and mechanical vibration damping properties of restructured chicken breast ham

--Manuscript Draft--

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Abstract:	The aim of the study was to investigate the dependence of selected textural, rheological and mechanical vibration damping properties of restructured chicken breast ham (RCBH) on the concentration of applied furcellaran (FRC1 or FRC2) or κ-carrageenan (KC) [0.0 g/100 g (CS; control sample), 0.25 g/100 g, 0.50 g/100 g, 0.75 g/100 g, 1.00 g/100 g] during a 14-day storage period (at 4±2 °C). The textural, rheological and also mechanical vibration damping properties of the tested samples were affected by the type and concentration of applied polysaccharide and the storage period. Furthermore, the samples prepared with KC and FRC1 at a concentration of 1.00 % (w/w) presented the highest values of hardness, G′, G′′ and G*. Furthermore, the values of G* and δ (in all tested frequency ranges) indicated for all RCBH samples a solid-like behavior over the whole experiment. The results obtained from the above-mentioned methods were confirmed by the non-destructive vibration damping method. In particular, it was found that the first resonance frequency peak position increased with an increase in the RCBH stiffness leading to lower vibration damping properties of the samples.

Cover letter for manuscript LWT-D-20-04395

Ursula Gonzales-Barron, Ph.D.

Editor

LWT - Food Science & Technology

Dear prof. Gonzales-Barron,

Subject: Submission of revised paper "*The effect of furcellaran or κ-carrageenan addition on the rheological and mechanical vibration damping properties of restructured chicken breast ham*" (LWT-D-20-04395).

Thank you very much for reviewing our manuscript. We also greatly appreciate the interest that the editors and reviewers have taken in our manuscript and the constructive criticism they have given. We believe that the comments have identified important areas which required improvement. The manuscript has certainly benefited from these insightful revision suggestions and comments in the overall presentation and clarity.

We have carefully reviewed the comments and have revised the manuscript accordingly. More specifically, as suggested by one reviewer we have adjusted the title of the manuscript to "*The effect of furcellaran or κ-carrageenan addition on the textural, rheological and mechanical vibration damping properties of restructured chicken breast ham*". Moreover, the manuscript text was modified and English language was revised. Furthermore, corrections in the "Materials and methods", "Results and discussion" were performed as it was suggested by the reviewers. New tables (2 and 3) depicting the chemical analysis and pH values development were also added. Moreover, the "Conclusion" part, "References" and "Highlights" were corrected accordingly.

Our responses are given in a point-by-point manner below. Original reviewer comments are shown in italics and responses are in regular typeface. The changes to the text and figure captions are shown yellow.

The revision has been developed in consultation with all coauthors, and each author has given approval to the final form of this version. We hope that you find the revised version appropriated and worth publishing in *LWT - Food Science & Technology*.

Sincerely,

Ing. Richardos Nikolaos Salek, Ph.D.,

Department of Food Technology,

Faculty of Technology

Tomas Bata University in Zlín

Response to the Reviewers and the Editor

Manuscript ID: LWT-D-20-04395

Title: The effect of furcellaran or κ-carrageenan addition on the rheological and mechanical vibration damping properties of restructured chicken breast ham.

Reviewer 1:

The manuscript is original in the sense that it addresses the use of two algal polysaccharides as gelling and stabilizing agents in the RCBH system. However, the manuscript is too wordy to read, and should definitely be shortened. Information on the tables and figures are repetitive in the text and does not conform to the manuscript style. These sentences were marked on the manuscript body and a note "delete" was attached. Also, the sentences are full of tautologies which have also been marked as delete. The use of English language is poor and the text should be checked by a native speaker. The manuscript is on the use of furcerellan and carrageenan as stabilizers in RCBH, however no conclusive results have been mentioned anywhere in the manuscript including the "Conclusions". "Results and Discussion" is repetitive because it has been organized according to the procedural steps used in the "Materials and Methods". "Results and Discussion" should be organized to describe the effects of these polysaccharides on the rheological properties in total without subtitling. Subtitles is the rheological and mechanical properties part in the "Results and Discussion" if needed could be "the effect of the type of polysaccharide on the mechanical and rheological properties" and "the effect of polysaccharide concentration on the mechanical and rheological properties". Also, carrageenan and furcerellan have been addresses as polysaccharides, biopolymers, polymers in different parts of the text. The authors should decide which one they prefer and address them as they may choose, but should not address them with different names all over the text. Also, referencing has been exaggerated. Sentences have been used instead of addressing the information in parenthesis. Specifically;

1. Lines 142, 183, 269 exaggerated reverencing

2. Lines 191-192 The sentence should be organized so as to make it understandable

3. Lines 230-247 Chemical composition and changes in the chemical composition including pH seems to be an important factor affecting the rheological and mechanical properties initially and during 14-days storage. So these data should be given in tabular form and the section should be discussed accordingly

The manuscript cannot be published as-is. Major revisions should be undertaken. Download file.

Authors comment: Thank you for your thoughtful and thorough review of our manuscript. It has been carefully checked and corrections have been made according to your recommendations.

Response to Reviewer 1:

1. *Lines 142, 183, 269 exaggerated reverencing.*

   Response: Corrected.

2. *Lines 191-192 The sentence should be organized so as to make it understandable.*

   Response: Corrected, and we are sorry (**Lines 193-194**).

3. *Lines 230-247 Chemical composition and changes in the chemical composition including pH seems to be an important factor affecting the rheological and mechanical properties initially and during 14-days storage. So these data should be given in tabular form and the section should be discussed accordingly.*

   Response: We agree with the reviewers comment. New tables (Table 2 and 3) were added, providing information about the chemical attributes of the RCBH samples during storage. In addition, these results were discussed accordingly and compared to results existing in the literature (**Lines 237-251**).

Reviewer 2:

The manuscript evaluates the effect of furcellaram or k-carrageenan addition on the properties of restructured chicken breast ham. The addition of the polysaccharides affected textural and rheological characteristics of the samples. The work is interesting, but some questions should be addressed.

Specific comments:

- Title should include textural (mechanical) properties.

- Abstract: p.4, line 32-35: Please consider rewriting these sentences. The word "furthermore" is repetitive.

- p.7, line 99-102: This sentence needs revision.

- p.7, line 108 and 115: The treatments are 3 polysaccharides, 4 concentrations, + 1 control sample, in triplicate, right? So, the total would be 13 x 3 = 39, not 45. Please revise.

- p.8, line 132: please include the information about sample storage (temperature 4°C, 14 days). Why 14 days?

- p.8, line 135-137: please cite the reference for those methods. "Fat or lipid content" instead of "lipid level".

- p.9, line 150: why were the samples heated up to 70°C? In the cooking process, samples would not reach higher temperatures?

- p.14, line 266-268: the sentences are repetitive. Consider revising.

- p.16, line 312-315: is this a good result? Is there an ideal range for hardness and other textural properties?

- p.16, line 314: ($p < 0.05$).

- Authors did not discuss the practical relevance of the addition of polysaccharides for product characteristics. Which treatment (which polysaccharide, at which concentration) would be the most appropriate?

- Table 1: why the water amounts are different in the brine formulations?

Authors comment: Thank you for your review of our paper. We have answered each of your points below.

<u>Response to Reviewer 2:</u>

1. *Title should include textural (mechanical) properties.*

   Response: The title was corrected as it was suggested.

2. *Abstract: p.4, line 32-35: Please consider rewriting these sentences. The word "furthermore" is repetitive.*

   Response: Corrected.

3. *p.7, line 99-102: This sentence needs revision.*

   Response: The sentence was revised. We are sorry for this inaccuracy and thank you for mentioning this.

4. *p.7, line 108 and 115: The treatments are 3 polysaccharides, 4 concentrations, + 1 control sample, in triplicate, right? So, the total would be 13 x 3 = 39, not 45. Please revise.*

   Response: We agree. It was corrected **(Lines 119-121)**

5. *p.8, line 132: please include the information about sample storage (temperature 4°C, 14 days). Why 14 days?*

   Response: Information about samples storage we added to the text (**Line 135**). Based on results from previously performed pilot-experiments (unpublished data) in similar products we could report that the storage time of 14 days is a time period during which the samples retain their sensory properties and are microbiologically “stable/safe”.

6. *p.8, line 135-137: please cite the reference for those methods. "Fat or lipid content" instead of "lipid level".*

   Response: Thank you for mentioning this, the appropriate references were added (**Lines 389-390**). The term “fat content” was used.

7. *p.9, line 150: why were the samples heated up to 70°C? In the cooking process, samples would not reach higher temperatures?*

   Response: According to *Toldrá et al. (2010)* and *Pancrazio et al. (2015),* during cooking (also considered as pasteurization) the internal temperature of the RCBH samples (or similar products) reaches values between 69 and 72 °C for a period of 30 to 60 min. So higher temperatures were not expected during the thermal treatment of the samples.

8. *p.14, line 266-268: the sentences are repetitive. Consider revising.*

   Response: We are sorry for this. The sentences were corrected.

9. *p.16, line 312-315: is this a good result? Is there an ideal range for hardness and other textural properties?*

   Response: Thank you very much for a very interesting question. We are afraid that it is not possible to answer unambiguously. The appropriate range for hardness and other textural properties depends on many factors, such as geographical region, legislative conditions, consumer habits etc. Our goal was not to find out the ideal range of the tested properties. Our aim was to compare products with different algae polysaccharides and concentrations during storage.

10. *p.16, line 314: ($p < 0.05$).*

    Response: Corrected.

11. *Authors did not discuss the practical relevance of the addition of polysaccharides for product characteristics. Which treatment (which polysaccharide, at which concentration) would be the most appropriate?*

    Response: Thank you for your comment. However, to provide a clear answer for this issue is a little bit difficult. Hence, consumers among different parts of the world have different preferences about organoleptic attributes of ham or similar products. Nevertheless, with respect to our results we could state that concentrations of KC and

FRC1 higher than 0.75 g/100 g might be appropriate for the production of RCBH samples presenting a more solid-like character with better water holding and mechanical vibrations damping properties. In general, our findings could be useful for both members of the research community and industrial producers, indicating that furcellaran is a promising alternative to κ-carrageenan for obtaining RCBH of desirable functional and organoleptic properties (**Lines 375-380**).

12. *Table 1: why the water amounts are different in the brine formulations?*

Response: We would like to thank the reviewer for mentioning this. Moreover, we would like to apologize for further inaccuracies that were presented in Table 1. The current table was corrected. Furthermore, during the design of the experiment we decided to maintain the RCBH samples dry matter content constant. Thus, this is the main reason for the increasing amount of water (within the brine formulation) together with the increasing amount of polysaccharide used.

Reviewer 3:

This paper (LWT-D-20-04395) deals with investigating the effect of furcellaran or κ-carrageenan addition on the rheological and mechanical vibration damping properties of restructured chicken breast ham. In my opinion, this paper can be published in LWT - Food Science and Technology after minor revision.

Specific comments:

1. The Highlights need to be improved. The second Highlight is too general, and the fourth and fifth ones are not a highlight.

2. Line 90: the statement is not true, because there are several publications about the application of k-carrageenan in meat product.

3. A separated paragraph is needed to describe the purity and supplier of all the chemicals and reagents used in this work, rather than mentioning this information in Methods.

4. Line 152: the authors should explain why a gap of 2.0 mm was used, because it is too large for dynamic oscillatory test.

5. It is not clear what the final conclusion is. The addition of hydrocolloids affected the properties of the samples, but is it desirable or not? What are the conclusion and suggestion after this investigation?

6. Table 1 and Figure 3: the authors should indicate the standard deviation and if there is any significant difference among the results.

Authors comment: Thank you for your review of our paper, we also deeply appreciate your time and suggestions for improvement. We have answered each of your points below.

Response to Reviewer 3:

1. *The Highlights need to be improved. The second Highlight is too general, and the fourth and fifth ones are not a highlight.*

   Response: We are sorry for this mistake. Highlights were modified.

2. *Line 90: the statement is not true, because there are several publications about the application of k-carrageenan in meat product.*

   Response: We agree with the reviewers comment and we apologize. We have modified the sentence to "Furthermore, application of furcellaran in meat/poultry products is rare and no information on its application in RCBH production is available" (**Lines 88-90**).

3. *A separated paragraph is needed to describe the purity and supplier of all the chemicals and reagents used in this work, rather than mentioning this information in Methods.*

   Response: Corrected (**Lines 96-108**).

4. *Line 152: the authors should explain why a gap of 2.0 mm was used, because it is too large for dynamic oscillatory test.*

   Response: The Malvern Kinexus pro+ rheometer (Malvern Instruments Ltd., United Kingdom) was used for the performance of the rheological analysis. The gap of 2.00 mm was selected according to the manufacturer's recommendation for this kind of samples. Additionally, we have performed also a preliminary study with gaps between 1 – 2 mm and the results and trends were very similar (unpublished data).

5. *It is not clear what the final conclusion is. The addition of hydrocolloids affected the properties of the samples, but is it desirable or not? What are the conclusion and suggestion after this investigation?*

   Response: Please see response to reviewer's 2 comment 11. Thank you for your comment. However, to provide a clear answer for this issue is a little bit difficult. Hence, consumers among different parts of the world have different preferences about organoleptic attributes of ham or similar products. Nevertheless, with respect to our results we could state that concentrations of KC and FRC1 higher than 0.75 g/100 g might be appropriate for the production of RCBH samples presenting a more solid-like character with better water holding and mechanical vibrations damping properties. In general, our findings could be useful for both members of the research community and industrial producers, indicating that furcellaran is a promising alternative to κ-carrageenan for obtaining RCBH of desirable functional and organoleptic properties (**Lines 375-380**). Conclusions were revised.

6. *Table 1 and Figure 3: the authors should indicate the standard deviation and if there is any significant difference among the results.*

   Response: In Figure 3 error bars are presented, the scales are very small. Table 1 is showing the formulation of the RCBH samples and we worked very precisely

<u>Reviewer 4:</u>

It is a very interesting paper about the role of three different polysaccharides on the rheological and textural properties of chicken breast meat. This paper is well-written and well-structured, is clear and concise, and I recommend its publication after answering these questions (minor revision):

1.- The paper is plenty of brackets (square brackets) and they are not usually used in scientific literature. I recommend rewriting the sentences where they are included to avoid their use.

2.- Line 65-66.

Too many references to support the role of the carrageenan in the food industry.

3.- Table 1.

Why are the variations of water between the brine formulations produced?

4.- Section 3.2.1 and 3.2.2

Is there any difference between the effect of carrageenan and furcellaran on the rheological properties of the processed chicken breast meat? If there is not any difference, it has to be stated in the main document.

5.- Line 298-305.

This paragraph is about the meaning of the complex modulus and the phase angle. If for a better understanding the authors want to clarify the meaning of these parameters, they have to be introduced the first time they are mentioned in the results section.

6.- Conclusion section.

Authors have to remark the differences of behaviour found between the polysaccharides used in this work when they are used in a meat product. The conclusion and abstract sections are not the same thing, in the conclusion section a more in-depth analysis of the results obtained is required.

7.- Highlights.

The highlights have to remark the novelty and key findings of this work. The current highlights are already well known by the research community.

Authors comment: Thank you for your review of our paper, we also deeply appreciate your time and suggestions for improvement. We have answered each of your points below.

Response to Reviewer 4:

1. *The paper is plenty of brackets (square brackets) and they are not usually used in scientific literature. I recommend rewriting the sentences where they are included to avoid their use.*

   Response: Corrected.

2. *Line 65-66. Too many references to support the role of the carrageenan in the food industry.*

   Response: Corrected.

3. *Table 1. Why are the variations of water between the brine formulations produced?*

   Response: Please see response to reviewer's 2 comment 12. We would like to apologize for further inaccuracies that were presented in Table 1. The current table was corrected. Furthermore, during the design of the experiment we decided to maintain the RCBH samples dry matter content constant. Thus, this is the main reason for the increasing amount of water (within the brine formulation) together with the increasing amount of polysaccharide used.

4. *Section 3.2.1 and 3.2.2. Is there any difference between the effect of carrageenan and furcellaran on the rheological properties of the processed chicken breast meat? If there is not any difference, it has to be stated in the main document.*

   Response: The highest values of hardness were reported for samples containing 1.00 g/100 g of KC, whilst the lowest were for the CS, in the order KC>FRC1>FRC2 regardless of the polysaccharide concentration. The results of the shear force were analogous to those of hardness analysis (Figure 3, part B) (**Lines 279-281**). Samples prepared with KC and FRC1 at a concentration of 1.00 g/100 g presented the highest values of hardness, G', G'' and G^*, in the order KC>FRC1>FRC2 regardless of the polysaccharide concentration. Phase angle measurements were also affected by polysaccharide concentration ($p<0.05$). Analysis of the G^* and δ indicated a solid-like behavior for all samples over the whole experimental range (**Lines 365-369**). Therefore, we can conclude that the differences between the influence of carrageenan and furcellaran application on textural and rheological properties were significant.

5. *Line 298-305. This paragraph is about the meaning of the complex modulus and the phase angle. If for a better understanding the authors want to clarify the meaning of these parameters, they have to be introduced the first time they are mentioned in the results section.*

   Response: Corrected.

6. *Conclusion section. Authors have to remark the differences of behaviour found between the polysaccharides used in this work when they are used in a meat product. The conclusion and abstract sections are not the same thing, in the conclusion section a more in-depth analysis of the results obtained is required.*

   Response: Thank you for mentioning this and we apologize for this inaccuracy. The conclusion part was revised accordingly (**Lines 364-380**).

7. *Highlights. The highlights have to remark the novelty and key findings of this work. The current highlights are already well known by the research community.*

   Response: Thank you for mentioning this and we apologize for this inaccuracy. The highlights were corrected.

Highlights

- Restructured chicken breast hams with κ-carrageenan and furcellaran were developed.
- The hardness of the samples increased with the rising level of added polysaccharides.
- The use of polysaccharides resulted in higher G* values during the cooling stage.
- The samples exhibited a solid-like character over the experiment.
- The polysaccharides used influenced samples displacement transmissibility and stiffness.

The effect of furcellaran or κ-carrageenan addition on the textural, rheological and mechanical vibration damping properties of restructured chicken breast ham

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Abstract:

The aim of the study was to investigate the dependence of selected textural, rheological and mechanical vibration damping properties of restructured chicken breast ham (**RCBH**) on the concentration of furcellaran (**FRC1** or **FRC2**) or κ-carrageenan (**KC**) during a 14-days storage period (at 4±2 °C). The above-mentioned polysaccharides were used in concentrations of 0.25 g/100 g, 0.50 g/100 g, 0.75 g/100 g and 1.00 g/100 g. Control sample (**CS**) without any polysaccharide addition was also produced. The textural, rheological and mechanical vibration damping properties of RCBH samples were affected by the type and concentration of the polysaccharide used ($p<0.05$) and the storage period ($p<0.05$). Samples prepared with KC and FRC1 at a concentration level of 1.00 (g/100 g) presented the highest values of hardness, G', G'' and G^*. Values of G^* and δ (in all tested frequency ranges) indicated a solid-like behavior for all the samples over the experimental range. It was found that the first resonance frequency peak position increased with an increase in the RCBH stiffness leading to lower vibration damping properties of the samples ($p<0.05$).

Keywords: restructured chicken breast ham; κ-carrageenan; furcellaran; rheology; texture; mechanical vibrations damping

1. Introduction

Restructured chicken breast hams (**RCBH**) are poultry products manufactured from fresh, skinless chicken breasts with membranes removed which are injected and tumbled with a marinade or brine [commonly including water, sodium chloride, sodium tripolyphosphate (**STPP**) and sugars with a possible application of various biopolymers especially polysaccharides and other optional ingredients] for several hours followed by heat-treatment (boiling or roasting) in order to develop end-products with desirable organoleptic properties, microbiological quality and safety and enhanced functional properties. The marinating technique is a traditional culinary process applied in order to tenderize and to improve flavor and juiciness of the poultry. These techniques increase water binding capacity of the meat products, thus reducing cooking losses. After marination, connective tissue protein and myofibrillar protein in the meat structure are denatured due to the pH changes, thus improving textural properties of the product (Barbanti & Pasquini, 2005; Alvarado & McKee, 2007; Somboonpanyakul, Barbut, Jantawat, & Chinprahast, 2007).

Application of polysaccharides is focused on enhancing water binding and texture improvement of meat and poultry products. In the same token, they are used as another gelling system to improve yield, rheological properties and thus reducing the cost of the final product formulation. Carrageenans are widely used in the food industry as thickeners, stabilizers and emulsifiers (Kravchenko et al., 2020; Somboonpanyakul, et al., 2007; Yang, Gao, & Yang, 2020). Carrageenan is a general name for a family of linear sulfated polysaccharides obtained by extraction from certain species of red marine macroalgae (such as the genera of *Kappaphycus*, *Eucheuma*, *Chondrus*, *Gigartina* and *Chondracanthu*), consisting of alternating residues of 1,3-linked β-D-galactose (G-units) and 1,4-linked α-D-galactose (D-units), which may be partially or completely in the form of 3,6-anhydro-derivative (DA-units). (Dong et al., 2018; Kravchenko et al., 2020; Saluri et al., 2019). Additionally, carrageenans differ from each other by the presence/absence of 3,6-anhydrogalactose in a 1,4-linked residue, as well as by the number and location of the sulfate groups. The most important commercially applied types of carrageenans are κ-, ι- and λ-carrageenan, respectively (Kravchenko et al., 2020). In particular, κ-, and ι-carrageenans allow the formation of thermostable gels, whereas λ-carrageenan acts as a thickening agent. Moreover, the gel-forming ability of κ-carrageenan in meat products has been proven to provide a wide range of advantages by increasing yield, consistency, sliceability, spreadability, cohesiveness and decreasing purge, fat content and slicing loss (McKee & Alvarado, 2004). Furcellaran is a sulphated, negative charged polysaccharide (galactan) which can be extracted from seaweed, *Furcellaria lumbricalis*. It is composed of the fragment from (1→3) β-D-galactopyranose with a sulphategroup at C-4 and (1→4) 3,6-anhydro-α-D-galactopyranose. Furcellaran is theoretically defined as: one ester sulfate group per tetramer, on position 4 of the galactose unit. Structurally, furcellaran is related to the algal polysaccharide κ-carrageenan, with a major structural difference that furcellaran is less sulfated. Furcellaran can be described as a copolymer of β- and κ-carrageenan (Jamróz, et al., 2019; Laos, Brownsey, & Ring, 2007).

Information on the behavior of furcellaran is scarce in the literature, although the related carrageenan groups were studied in detail. Furthermore, application of furcellaran in meat/poultry products is rare and no information on its application in RCBH production is available. The scope of this study was to investigate the dependence of selected textural, rheological and mechanical vibration damping properties of RCBH on the concentration of applied furcellarans and/or κ-carrageenan [0.0 % w/w (control sample), 0.25 g/100 g, 0.50 g/100 g, 0.75 g/100 g, 1.00 g/100 g] during 14-days storage period (at 4±2 °C).

2. Materials and methods

2.1 Materials

Materials such as: chicken breast (Vodňanská drůbež, a.s., Vodňany, Czech Republic), sodium chloride (PubChem ID: 329750168; SigmaAldrich s.r.o., Prague, Czech Republic), sucrose (PubChem ID: 57647547; SigmaAldrich s.r.o., Prague, Czech Republic), sodium nitrite (PubChem ID: 329760574; SigmaAldrich s.r.o., Prague, Czech Republic), dextrose (PubChem ID: 329749562; SigmaAldrich s.r.o., Prague, Czech Republic), sodium tripolyphosphate(PubChem ID: 329752508; Fosfa a.s., Břeclav, Czech Republic), κ-carrageenan (**KC**; Mw=4.31 · 10^5 Da, 1.2 % w/w moisture content, water gel strength according to Bloom = 520 g; SigmaAldrich s.r.o., Prague, Czech Republic) and two types of commercial furcellaran products, **FRC1** (Mw=2.55 · 10^5 Da, 9.5 % w/w moisture content, water gel strength according to Bloom = 480 g; Est-Agar AS, Kärla, Estonia) and **FRC2** (Mw=2.95 · 10^3 Da, 6.4 % w/w moisture content, water gel strength according to Bloom = 420 g; Est-Agar AS, Kärla, Estonia) were used in this study. All chemicals and reagents used in this study were of analytical grade.

2.2 Production of restructured chicken breast ham samples

Model RCBH samples manufactured from fresh (24 h post mortem), skinless, deboned chicken breast (*Pectoralis major*; trimmed of fat and membrane) were purchased from a local chicken packing plant. Chicken breasts were minced using a stainless steel plate (holes with diameters of 5 mm), placed in polyethylene bags, vacuum-packed (Henkelman, Mini jumbo, The Netherlands) and frozen at -80 °C (MDF - U3286S, SANYO, Schoeller instruments, Prague, Czech Republic). All samples were produced separately according to the formulations depicted in **Table 1**, following the same manufacturing protocol.

Moreover, 13 model samples with various concentrations [0.0 g/100 g (**CS**; control sample), 0.25 g/100 g, 0.50 g/100 g, 0.75 g/100 g, 1.00 g/100 g] of κ-carrageenan and two types of commercial furcellaran products were produced in total (4 concentrations of polysaccharides

× 3 polysaccharide types + control sample = 13 model samples; 13 model samples × 3 repetitions; n=39). Chicken breasts were thawed for approx. 18 h at 4±2 °C, and then the brine and chicken breasts were added into the massage vacuum-tumbler (GM100, Gourmia, New York, USA) for 8 hours at 4±2 °C (the tumbling speed was 14 rpm). Brine consisted of water, sodium chloride, polysaccharide (κ-carrageenan or furcellaran), STPP, sucrose, sodium nitrite and dextrose according to the formulation presented in **Table 1**. Hence, the rising concentration of polysaccharides was adjusted by water addition in order to maintain constant dry matter content (**Table 1**). The vacuum tumbling process helps in distributing the brine evenly into the muscle. Thereafter, the samples were stuffed into plastic shrink-bags (CN330; Sealed Air, Cambridgeshire, UK) and then placed in cylindrical plastic molds (diameter of 52 mm, height of 75 mm) and thermally-treated in a universal combi-oven (SelfCookingCenter®, SCC WE 61; RATIONAL Czech Republic s.r.o., Prague, Czech Republic; operating at 99 °C and 90-100 % relative humidity) until the center of the product reached 72 °C (temperature was controlled by applying a thermometer probe directly into the sample), and then was kept in the oven for 10 min. Then, the samples were cooled in an ice bath until a temperature of 2±1 °C in the center of sample was reached (approx. for 20 min) and were stored for a period of 14 days (at 4±2 °C).

2.3 Chemical analysis

Standard AOAC methods (2000) were used to investigate the proximate composition of RCBH. The moisture content was determined gravimetrically by oven-drying to constant weight at 103±2 °C following the standard AOAC method, 950.46B. Protein content was measured according to the AOAC method, 981.10. The fat content in the samples was determined by AOAC method, 960.69. The non-collagen muscle protein content (**NCMP**) was determined by subtracting the amount of collagen from the protein content. The collagen content was computed from the content of hydroxyproline amino acid (recalculating coefficient f=8). Hydroxyproline was determined by photometric measurement of absorbance at 550 nm using a UV/VIS spectrophotometer UVmini-1240 (Shimadzu Europa GmbH, Duisburg, Germany; Válková, Saláková, Buchtová, & Tremlová, 2007). The pH measurements were performed with a pH-meter (Edge^{TM}; Hanna instruments Czech s.r.o.; Prague; Czech Republic), after homogenizing 5 g of the RCBH samples in 45 ml of distilled water for 5 min. All analyses were performed at least in triplicate (3 batches × 3 repetitions; n=9).

2.4 Small deformation properties

2.4.1 Rheological analysis of the samples during heating and cooling stages

After tumbling (see part 2.1) part of the heat-untreated mixture was minced (0.5 mm clearing), vacuum-treated (Henkelman, Mini jumbo, Netherland) and then loaded into the rheometer (Malvern Kinexus pro+, Malvern Instruments Ltd., United Kingdom). The rheological properties of the RCBH samples were investigated by dynamic oscillatory rheometry during heating up to 70.0±0.1 °C (the rate of 2 °C/min), holding for 10 min (at 70.0±0.1 °C) and subsequently cooling down to 5.0±0.1 °C (the rate of 2 °C/min). The gap was 2.0 mm, the frequency was 1 Hz and the shear stress amplitude was 20 Pa (in linear viscoelastic region). Before sample loading, the 40-mm serrated plate-plate geometry (Malvern Instruments Ltd., United Kingdom) was cooled to 5.0±0.1 °C. The sample edges were afterwards trimmed with a spatula. During testing, the Kinexus Active Solvent Trap Cover (Malvern Instruments Ltd., UK) was used to prevent dehydration. Storage modulus (G´; Pa), loss modulus (G´´; Pa) and the phase angle (δ; °) were determined. Subsequently, the complex modulus (G*; Pa) was calculated as (Eq. 1):

$$G^{*}(\omega) = \sqrt{\left(G'(\omega)\right)^{2} + \left(G''(\omega)\right)^{2}} \qquad (1)$$

where G* (ω) is the complex modulus value (Pa) for an individual frequency ω (Hz). Measurements were carried out at least in triplicate (n=9).

2.4.2 Rheological analysis of the final products during storage

Dynamic oscillatory shear rheometer (Rheostress 1, Haake, Bremen, Germany) equipped with a plate-plate geometry (35 mm diameter, 1 mm gap) was used in order to determine the viscoelastic properties of the RCBH samples during storage. Samples had a diameter of 35 mm and a height of 1 mm. All samples were measured in the control shear stress mode at a frequency ranging from 0.01 to 10.00 Hz (at 20.0 ± 0.1 °C). The amplitude of shear stress (20 Pa) was selected in the linear viscoelastic region. Storage modulus (G´), loss modulus (G´´) and the phase angle (δ) were determined. The complex modulus (G*; Pa) was calculated according to equation (Eq. 1). The exposed edge of the parallel-plates geometry was covered with a thin layer of silicone oil in order to prevent dehydration.

2.5 Large deformation properties

RCBH sample blocks were cut into cylinders (measuring 10 mm in height and 35mm in diameter). Texture profile analysis (**TPA**) and Warner-Bratzler shear force test were conducted with a TA.XT.plus texture analyser equipped with Texture Exponent version 4.0 software (Stable Micro Systems Ltd., Godalming, UK). TPA was performed using a P/50 probe (50 mm diameter cylinder aluminium; Stable Micro Systems) at a test speed of 2 mm/s and a trigger force of 0.050 N. The samples were compressed twice to 50% of their original height. Force–time curves were recorded and hardness, cohesiveness, gumminess and chewiness were evaluated (Ruiz-Ramírez, Arnau, Serra, & Gou, 2006). The Warner-Bratzler blade with a slotted blade was inserted in the HDP/90 Heavy Duty Platform. Samples were obtained by cutting into cuboids with dimensions of approximately 1.0×1.0×2.2 cm (height×width×length; cuboid). Samples were cut perpendicularly to the muscle fiber direction using a shear blade with triangular slot cutting edge (thickness of 1 mm; velocity of 1 mm/s and blade displacement of 25 mm) in order to cut all the way through the sample. The shear force (determined as the maximum force from force-time curve, N) represented the maximum resistance of the sample to cutting. In both TPA and WBR tests, for each parameter, the average of minimum three pieces per RCBH was used for the statistical analysis (3 batches × 3 repetitions; n=9).

2.6 Determination of mechanical vibration damping properties

Material ability to damp mechanical vibration under harmonic excitation can be expressed by displacement transmissibility (T_d) given as (Rao, 2005):

$$T_d = \frac{y_2}{y_1} = \frac{a_2}{a_1} = \sqrt{\frac{1+(2\zeta r)^2}{(1-r^2)^2+(2\zeta r)^2}} \quad (2)$$

where y_1 (m)/a_1 ($m \cdot s^{-2}$) is the displacement/acceleration amplitude on the input (excitation) side of the tested sample, y_2 (m)/a_2 ($m \cdot s^{-2}$) is the displacement/acceleration amplitude on the output (free) side of the tested sample, ζ (dimensionless) is the damping ratio and r (dimensionless) is the frequency ratio. The frequency ratio is given by:

$$r = \frac{\omega}{\omega_n} = \frac{2\pi \cdot f}{\omega_n} \quad (3)$$

where ω (rad/s) is the circular frequency of oscillation, f (Hz) is the number of cycles per unit time (frequency) and ω_n (rad/s) is the undamped natural frequency, which is proportional to the square root of the material stiffness k to the applied inertial mass m (Stephen, 2006).

Under the condition $dT_d/dr = 0$ in the equation (Eq. 2), it is possible to find the frequency ratio r_0 at which the displacement transmissibility T_d has its maximum:

$$r_0 = \frac{\sqrt{\sqrt{1+8\zeta^2}-1}}{2\zeta} \quad (4)$$

It is evident from the equation (Eq. 4) that the local extreme of the displacement transmissibility is generally shifted to lower values of the frequency ratio r with the increasing damping ratio ζ (or with the decreasing stiffness k). Generally, there are three different types of mechanical vibration, namely damped (T_d<1), undamped (T_d=1) and resonant (T_d>1).

The mechanical vibration damping tests on the RCBH samples were performed by the forced oscillation method. Displacement transmissibility (Eq. 2) was measured using the BK 4810 vibrator device in combination with a BK 3560-B-030 signal Pulse multi-analyzer and a BK 2706 power amplifier at the frequency range of 2–200 Hz. Sine waves were generated by the vibrator device. The acceleration amplitudes on the input and output sides of the samples were recorded by the BK 4393 accelerometers (Brüel & Kjær, Nærum, Denmark). Displacement transmissibility was measured for a mass load of m = 500 g located on the upper side of the periodically loaded tested samples. The sample dimensions were (60×60×10 mm; length×width×height). Each measurement was repeated 3 times (n=9) at 22±1 °C.

2.7 Statistical analysis

The obtained results were analyzed by non-parametrical analysis of variance of Kruskall-Wallis and Wilcoxon tests (Minitab®16 software; Minitab, Ltd., UK), where the significance level was 0.05.

3. Results and discussion

3.1 Chemical analysis

The applied chicken breasts (raw material) for this study presented the following values: 73.78±0.51 g/100 g moisture content; pH of 5.91±0.03; fat content 1.22±0.06 g/100 g, crude protein content 22.98±1.36 g/100 g; and non-collagen muscle protein content 22.19±0.84 g/100 g. The ultimate pH of raw material is particularly important for the production of cooked cured products, with an optimal pH level of 5.6 and 6.3. This represents a compromise between water binding (yield, cohesion of slices, consistency), ability to imbibe the cure (salt absorption, color development), shelf life (growth milieu for bacteria) and organoleptic quality (juiciness, flavor) (Cheng and Sun, 2007; Person et al., 2005; Tomović et al., 2013).

The results of the chemical analysis of the RCBH samples produced with different polysaccharides during storage are shown in **Table 2**. In particular, the moisture content of the RCBH with polysaccharides was similar in comparison with the CS ($p \geq 0.05$) due to water addition and polysaccharides application in the formulation in order to maintain constant dry matter content (**Table 1**). The protein, NCPM and fat contents were significantly different between CS and samples treated with polysaccharides ($p<0.05$). Our findings are in accordance with that of Kim et al. (2018), who reported that addition of polysaccharides can decrease the fat content of meat products, yielding relatively higher water retention.

Moreover, the functional properties of the RCBH can be affected by the pH value. The pH of the samples prepared with: (i) KC ranged from 6.06 to 6.11; (ii) FRC1 ranged from 6.07 to 6.12; and (iii) FRC2 ranged from 6.06 to 6.10 (after 1 day of storage; $p<0.05$; **Table 3**). The increasing concentration of the polysaccharide used, resulted in a minor increase in the pH values of all samples ($p<0.05$). The development of pH over the 14-days storage period revealed its growth for all samples, probably as a result of accumulation of the products with alkaline nature resulting from the degradation of proteins (Dima, Neagu, Cercel & Alexe, 2014).

3.2 The effect of the type of polysaccharide on the mechanical and rheological properties

Over the whole gelation process, a characteristic increase (up to 50 °C) in the values of G′ and G" moduli was obtained (regardless of the applied type of polysaccharide; **Figure 1 and 2**). The latter increase could be due to thermal denaturation of the myofibrillar proteins within the developed matrix. In particular, denaturation of the head and hinge portions of myosin followed by aggregation could result in the initial increase of the G′ and G" values. At a temperature range from 50 to 55 °C, a decrease in the values of the monitored dynamic moduli is observed. Thus, probably denaturation of myosin tails led to an increase in fluidity and the previously formed protein network (at lower temperatures) might have been disrupted. Moreover, dissociation of the actin-myosin complex contributed to the decrease in G′ and G" values within the temperature range from 50 to 55 °C (Verbeken, Neirinck, Van Der Meeren, & Dewettinck, 2005; Wang et al., 1990). A further increase in the values of G′ and G" during the cooling stage was monitored (regardless the applied type of polysaccharide; **Figure 2**). This phenomenon was more intensive when KC, FRC1 and FRC2 were used compared to the control sample. Hence, it could be stated that the applied algae polysaccharides undergo gelation during cooling (Verbeken et al., 2005). It has been reported that carrageenan gel networks are developed by plethora of polymer chain associations in order to enhance the formation of a three-dimensional helix framework. The chains are present as a random coil at temperatures above 50 °C (soil state). On the contrary, at temperatures below 50 °C, the chains are transformed into a helix, leading to the development of a gel, when enough of the helix is formed in order to provide cross-links. In particular, during cooling KC aligns two helical coils in a manner as to focus its four sulfate groups toward each other, and charges are neutralized by divalent cations. Thereafter, a double helix is formed by hydrogen bonding (Trius et al., 2009).

In all cases hardness of samples increased regardless of the polysaccharide used during the 14-days storage period ($p<0.05$; **Figure 3, part A**). This result can be attributed to the structuring of the mobile phase (water) due to the interaction with water through ionic and hydrogen bonding (Candogan & Kolsarici, 2003). The highest values of hardness were reported for samples containing 1.00 g/100 g of KC, whilst the lowest were for the CS, in the order KC>FRC1>FRC2 regardless of the polysaccharide concentration. The results of the shear force were analogous to those of hardness analysis (**Figure 3, part B**). The type of polysaccharide used affected also the values of cohesiveness, gumminess and chewiness of the RCBH samples ($p<0.05$; **Table 6**).

3.3 The effect of polysaccharide concentration on the mechanical and rheological properties

Degrees of elastic and viscous behavior of viscoelastic materials can be described by the complex modulus (G^*) and by the phase angle (δ). Complex modulus is a representation of the viscoelastic behavior of a material under dynamic loading at a given strain level; comprising viscous and elastic moduli. Phase angle is the corresponding lag between the elastic and the viscous response. Higher values of the phase angle indicate a tendency towards more viscous behavior, whilst lower values indicate a more elastic behavior (Widyatmoko, 2016). It can be clearly seen that polysaccharide addition resulted in higher complex modulus values than the control sample regardless of the polysaccharide concentration (**Table 5**). In addition, higher G^* values were reported during the cooling stage (at 20 and 5 °C; **Table 4**), indicating that a more rigid structure was developed during the cooling stage. No significant changes ($p<0.05$) were observed at 70 °C. Therefore, addition of polysaccharides influenced rheological properties of the RCBH samples during the cooling process (**Figure 2**). According to Verbeken et al., (2005) κ-carrageenan and furcellaran are present in the interstitial spaces of the developed protein network, where they probably can bind water and promote gelling during cooling. Phase angle measurements were also affected by polysaccharide concentration ($p<0.05$). As a result, values of phase angle where lower than 45°, indicating a more solid-like behavior. In general, the analysis of G^* and δ (in all tested frequency ranges) indicated for all samples a solid-like behavior over the whole experiment (**Table 4 and 5**). In addition, the increasing concentration of the used polysaccharide resulted in samples with higher values of G^*. The increasing elastic character of the samples with polysaccharide addition could be probably due to “better” water binding capacity (Yang et al., 2015).

Increasing the polysaccharide content resulted in increasing values of hardness, gumminess and chewiness (**Figure 3, Table 6**). Carrageenan molecules may have interacted with the protein matrix leading to highest values of hardness. This interaction can occur between carrageenan and the negatively charged carbonyl groups on the protein through cation bridging or may be a direct interaction between the carrageenan molecules and the positively charged amino groups of the present protein. Other interactions such as hydrogen bonds, hydrophobic or covalent bonds may take part in stabilizing the protein-polysaccharide matrix (Trius, Sebranek, & Lanier, 2009). The presence of polysaccharides can enhance the water-holding capacity and water-biding capacity in meat/poultry products, resulting in more rigid gels. In particular, the application of algae polysaccharides can increase yield, control purge and enhance final textural properties (Ruusunen et al., 2003). Another possible explanation could be the formation of a secondary gel network due to the presence of polysaccharides. Meat proteins can form a compact gel network, in which carrageenan or furcellaran remain in discrete regions, probably in the interstitial spaces of the protein network. Hence, a continuous carrageenan/furcellaran gel network can be formed due to connections between the polysaccharide gels and the existing protein gel network (Ayadi, Kechaou, Makni, & Attia, 2009). Conformational alignments differ due to the number of sulfate groups present in the polysaccharide molecule influencing hardness values (Ruusunen et al., 2003; Zhang, Piculell, Nilsson, & Knutsen, 1994).

Results showed that gumminess and chewiness increased during the 14-days storage period. Shear force in Warner-Bratzler test is related to preference and might serve as one of the most important attributes of meat products, providing information about product tenderness. In particular, meat/poultry products with low shear force are desirable (Jeong, O, Shin, & Kim, 2018). The experimental results of Warner-Bratzler shear force and hardness analysis showed a similar tendency. The mechanical (textural) properties of the examined samples were influenced similarly as the rheological properties. On the whole, it could be reported that higher concentrations of polysaccharides within the RCBH matrix resulted in more rigid products with better water holding capacity and decreased fat content. The latter findings might have practical significance for the industry in order to develop products with desirable functional and organoleptic properties.

3.4 Mechanical vibration damping properties

Resonant vibration ($T_d>1$) of the investigated RCBH samples was observed at low excitation frequencies. Contrarily, the vibration damping ($T_d<1$) was obtained at higher frequencies depending on the concentration of the used polysaccharides. It is evident (**Figure 4;** part A) that the vibration damping properties decreased with an increase in the KC concentration ($p<0.05$). Therefore, increase in KC concentration led to a lower transformation of the input mechanical energy into heat under harmonically excited vibrations. Higher stiffness (k) and lower damping ratio (ζ) are in accordance with the fact that higher concentrations of KC lead to higher values of hardness and G* modulus. For this reason the first resonance frequency ($f_{R1} \approx T_{dmax}$) peak position was shifted to the right (**Figure 4;** part A) with the increasing KC concentration, i.e. from 73 Hz (0.0 g/100 g) to 102 Hz (1.0 g/100 g). "Lower" vibration damping is generally obtained at higher values of the frequency ratio (r_0; Eq. (4)). It was found that the effect of furcellaran (FRC1 and FRC2) addition on the resonance frequency was similar to the addition of KC (**Table 7**). It is also evident that the polysaccharide used had a significant influence on the displacement transmissibility (**Figure 4;** part B) and thus on the sample stiffness ($p<0.05$). It was found that the RCBH sample with 0.75 g/100 g concentration of FRC2 exhibited the lowest stiffness (f_{R1}=87 Hz). Contrarily, the highest first resonance frequency (f_{R1}=98 Hz) was obtained in the case of the RCBH sample with the KC concentration of 0.75 g/100 g ($p<0.05$). Generally, the lowest vibration damping properties were observed in samples containing KC. RCBH samples containing FRC1 exhibited higher values of stiffness [f_{R1} from 78 Hz (0.25 g/100 g) to 100 Hz (1.00 g/100 g)] compared to the RCBH samples, containing FRC2 [f_{R1} from 75 Hz (0.25 g/100 g) to 91 Hz (1.00 g/100 g)] (**Table 7**).

Conclusions

The textural, rheological and mechanical vibration damping properties of the RCBH samples were influenced by the type and concentration of the polysaccharide used, and the type of the polysaccharide also affected the changes in mechanical and rheological properties during the 14-days storage period. Increase in the concentration of the polysaccharide resulted in higher values of G′, G″, G^* and hardness. Samples prepared with KC and FRC1 at a concentration of 1.00 g/100 g presented the highest values of hardness, G′, G″ and G^*, in the order KC>FRC1>FRC2 regardless of the polysaccharide concentration. Phase angle measurements were also affected by polysaccharide concentration ($p<0.05$). Analysis of the G^* and δ indicated a solid-like behavior for all samples over the whole experimental range. The vibration damping properties decreased with an increase in the polysaccharide concentration ($p<0.05$). The polysaccharide used had a significant influence on the displacement transmissibility and thus on the sample stiffness ($p<0.05$). Additionally, it was found that the first resonance frequency peak position increased with an increase in the RCBH stiffness leading to lower vibration damping properties of the samples. The lowest vibration damping properties were observed in samples containing KC. Concentrations of KC and FRC1 higher than 0.75 g/100 g might be appropriate for the production of RCBH samples presenting a more solid-like character with better water holding capacity and lower mechanical vibrations damping properties. In general, our findings could be useful for both members of the research community and industrial producers, indicating that furcellaran is a promising alternative to κ-carrageenan for obtaining RCBH of desirable functional and organoleptic properties.

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Table 1. Formulation of the restructured chicken breast hams (RCBH) preparation.

Raw materials	Ingredients composition (g)				
	Control sample	RCBH_0.25	RCBH_0.50	RCBH_0.75	RCBH_1.00
Chicken breast	740.700	740.700	740.700	740.700	740.700
Brine formulations					
Water	320.370	329.000	338.000	348.000	358.000
Sodium chloride	26.460	26.460	26.460	26.460	26.460
Polysaccharide**	0.000	2.500	5.000	7.500	10.000
STPP*	2.630	2.630	2.630	2.630	2.630
Sucrose	0.270	0.270	0.270	0.270	0.270
Sodium nitrite	0.135	0.135	0.135	0.135	0.135
Dextrose	0.135	0.135	0.135	0.135	0.135

* STPP – Sodium tripolyphosphate.

** Were applied three types of commercial polysaccharides; κ-carrageenan (KC), furcellaran (FRC1, FRC2).

Table 2. Results of chemical analysis of the restructured chicken breast ham samples manufactured with furcellaran and κ-carrageenan during the 14-days storage period (at 4±2 °C).[*]

Polysaccharide [**]	Concentration (g/100 g)	Storage time (days)	Results of chemical analysis (g/100 g)			
			Moisture content	Fat content	Protein content	NCMP content [***]
CS		1	20.38 ± 0.23 ^{a}A	0.83 ± 0.02 ^{a}A$_{a}$	15.58 ± 0.24 ^{a}A$_{a}$	15.12 ± 0.47 ^{a}A$_{a}$
		7	20.39 ± 0.22 ^{a}A	0.81 ± 0.02 ^{a}A$_{a}$	15.63 ± 0.29 ^{a}A$_{a}$	15.15 ± 0.27 ^{a}A$_{a}$
		14	20.40 ± 0.22 ^{a}A	0.83 ± 0.03 ^{a}A$_{a}$	15.63 ± 0.36 ^{a}A$_{a}$	15.08 ± 0.26 ^{a}A$_{a}$
KC	0.25	1	20.47 ± 0.23 ^{a}A	0.83 ± 0.02 ^{a}A$_{a}$	15.43 ± 0.32 ^{a}B$_{a}$	14.98 ± 0.40 ^{a}B$_{a}$
		7	20.45 ± 0.18 ^{a}A	0.83 ± 0.03 ^{a}A$_{a}$	15.44 ± 0.53 ^{a}B$_{a}$	15.00 ± 0.43 ^{a}B$_{a}$
		14	20.51 ± 0.21 ^{a}A	0.82 ± 0.02 ^{a}A$_{a}$	15.47 ± 0.33 ^{a}B$_{a}$	15.02 ± 0.34 ^{a}B$_{a}$
	0.50	1	20.48 ± 0.18 ^{a}A	0.81 ± 0.01 ^{a}A,B$_{a}$	15.28 ± 0.39 ^{a}C$_{a}$	14.76 ± 0.43 ^{a}C$_{a}$
		7	20.37 ± 0.18 ^{a}A	0.79 ± 0.01 ^{a}A,B$_{a}$	15.31 ± 0.35 ^{a}C$_{a}$	14.80 ± 0.34 ^{a}C$_{a}$
		14	20.47 ± 0.21 ^{a}A	0.81 ± 0.02 ^{a}A,B$_{a}$	15.30 ± 0.53 ^{a}C$_{a}$	14.83 ± 0.21 ^{a}C$_{a}$
	0.75	1	20.42 ± 0.20 ^{a}A	0.80 ± 0.02 ^{a}B$_{a}$	15.10 ± 0.27 ^{a}D$_{a}$	14.61 ± 0.51 ^{a}D$_{a}$
		7	20.44 ± 0.20 ^{a}A	0.80 ± 0.03 ^{a}B$_{a}$	15.08 ± 0.41 ^{a}D$_{a}$	14.62 ± 0.25 ^{a}D$_{a}$
		14	20.45 ± 0.20 ^{a}A	0.80 ± 0.02 ^{a}B$_{a}$	15.10 ± 0.52 ^{a}D$_{a}$	14.61 ± 0.50 ^{a}D$_{a}$
	1.00	1	20.52 ± 0.19 ^{a}A	0.79 ± 0.02 ^{a}B$_{a}$	14.92 ± 0.28 ^{a}E$_{a}$	14.38 ± 0.37 ^{a}E$_{a}$
		7	20.41 ± 0.20 ^{a}A	0.80 ± 0.02 ^{a}B$_{a}$	14.97 ± 0.37 ^{a}E$_{a}$	14.44 ± 0.41 ^{a}E$_{a}$
		14	20.49 ± 0.19 ^{a}A	0.79 ± 0.02 ^{a}B$_{a}$	14.94 ± 0.31 ^{a}E$_{a}$	14.43 ± 0.38 ^{a}E$_{a}$
FRC1	0.25	1	20.48 ± 0.21 ^{a}A	0.83 ± 0.02 ^{a}A$_{a}$	15.44 ± 0.37 ^{a}B$_{a}$	14.94 ± 0.29 ^{a}B$_{a}$
		7	20.41 ± 0.20 ^{a}A	0.83 ± 0.02 ^{a}A$_{a}$	15.50 ± 0.55 ^{a}B$_{a}$	14.97 ± 0.44 ^{a}B$_{a}$
		14	20.44 ± 0.21 ^{a}A	0.83 ± 0.02 ^{a}A$_{a}$	15.42 ± 0.38 ^{a}B$_{a}$	14.96 ± 0.40 ^{a}B$_{a}$
	0.50	1	20.49 ± 0.24 ^{a}A	0.81 ± 0.02 ^{a}A,B$_{a}$	15.32 ± 0.43 ^{a}C$_{a}$	14.81 ± 0.29 ^{a}C$_{a}$
		7	20.45 ± 0.22 ^{a}A	0.81 ± 0.02 ^{a}A,B$_{a}$	15.25 ± 0.59 ^{a}C$_{a}$	14.74 ± 0.41 ^{a}C$_{a}$
		14	20.45 ± 0.23 ^{a}A	0.81 ± 0.02 ^{a}A,B$_{a}$	15.28 ± 0.49 ^{a}C$_{a}$	14.79 ± 0.42 ^{a}C$_{a}$
	0.75	1	20.39 ± 0.17 ^{a}A	0.80 ± 0.02 ^{a}B$_{a}$	15.16 ± 0.47 ^{a}D$_{a}$	14.61 ± 0.45 ^{a}D$_{a}$
		7	20.34 ± 0.21 ^{a}A	0.80 ± 0.02 ^{a}B$_{a}$	15.14 ± 0.38 ^{a}D$_{a}$	14.67 ± 0.34 ^{a}D$_{a}$
		14	20.34 ± 0.22 ^{a}A	0.80 ± 0.02 ^{a}B$_{a}$	15.09 ± 0.40 ^{a}D$_{a}$	14.63 ± 0.25 ^{a}D$_{a}$
	1.00	1	20.44 ± 0.19 ^{a}A	0.79 ± 0.02 ^{a}B$_{a}$	14.97 ± 0.41 ^{a}E$_{a}$	14.40 ± 0.28 ^{a}E$_{a}$
		7	20.43 ± 0.19 ^{a}A	0.78 ± 0.02 ^{a}B$_{a}$	14.93 ± 0.45 ^{a}E$_{a}$	14.48 ± 0.37 ^{a}E$_{a}$
		14	20.38 ± 0.16 ^{a}A	0.79 ± 0.01 ^{a}B$_{a}$	14.95 ± 0.34 ^{a}E$_{a}$	14.47 ± 0.33 ^{a}E$_{a}$

Table 2 continue

Polysaccharide [**]	Concentration (g/100 g)	Storage time (days)	Results of chemical analysis (g/100 g)			
			Moisture content	Fat content	Protein content	NCMP content [***]
FRC2	0.25	1	20.46 ± 0.18 ^{a}A	0.83 ± 0.02 ^{a}A$_{a}$	15.42 ± 0.44 ^{a}B$_{a}$	14.91 ± 0.44 ^{a}B$_{a}$
		7	20.45 ± 0.18 ^{a}A	0.83 ± 0.02 ^{a}A$_{a}$	15.47 ± 0.42 ^{a}B$_{a}$	14.88 ± 0.36 ^{a}B$_{a}$
		14	20.47 ± 0.23 ^{a}A	0.83 ± 0.02 ^{a}A$_{a}$	15.46 ± 0.50 ^{a}B$_{a}$	14.98 ± 0.39 ^{a}B$_{a}$
	0.50	1	20.42 ± 0.21 ^{a}A	0.81 ± 0.03 ^{a}A,B$_{a}$	15.29 ± 0.38 ^{a}C$_{a}$	14.78 ± 0.43 ^{a}C$_{a}$
		7	20.40 ± 0.18 ^{a}A	0.81 ± 0.02 ^{a}A,B$_{a}$	15.23 ± 0.34 ^{a}C$_{a}$	14.82 ± 0.36 ^{a}C$_{a}$
		14	20.49 ± 0.22 ^{a}A	0.81 ± 0.02 ^{a}A,B$_{a}$	15.29 ± 0.34 ^{a}C$_{a}$	14.80 ± 0.36 ^{a}C$_{a}$
	0.75	1	20.49 ± 0.21 ^{a}A	0.78 ± 0.02 ^{a}B$_{a}$	15.07 ± 0.26 ^{a}D$_{a}$	14.59 ± 0.41 ^{a}D$_{a}$
		7	20.40 ± 0.22 ^{a}A	0.80 ± 0.02 ^{a}B$_{a}$	15.13 ± 0.31 ^{a}D$_{a}$	14.63 ± 0.29 ^{a}D$_{a}$
		14	20.40 ± 0.20 ^{a}A	0.80 ± 0.02 ^{a}B$_{a}$	15.13 ± 0.44 ^{a}D$_{a}$	14.60 ± 0.40 ^{a}D$_{a}$
	1.00	1	20.41 ± 0.20 ^{a}A	0.80 ± 0.02 ^{a}B$_{a}$	14.91 ± 0.31 ^{a}E$_{a}$	14.48 ± 0.18 ^{a}E$_{a}$
		7	20.45 ± 0.23 ^{a}A	0.79 ± 0.02 ^{a}B$_{a}$	14.98 ± 0.37 ^{a}E$_{a}$	14.41 ± 0.38 ^{a}E$_{a}$
		14	20.47 ± 0.21 ^{a}A	0.80 ± 0.01 ^{a}B$_{a}$	14.91 ± 0.40 ^{a}E$_{a}$	14.47 ± 0.38 ^{a}E$_{a}$

[*] Values are expressed as the mean (n=9) ± standard deviation. The means within a column (the difference between storage times) followed by different superscript letters statistically differ ($p<0.05$); samples produced with different polysaccharides and concentrations were evaluated independently. The means within a column (the difference between the polysaccharides concentrations) followed by different capital letters statistically differ ($p<0.05$); samples manufactured with different polysaccharides and storage times were evaluated independently; all products were also compared to control sample. The means within a column (the difference between applied polysaccharides at a specific concentration) followed by different subscript letter significantly differ ($p<0.05$); samples produced with different polysaccharide concentrations were evaluated independently.

[**] CS – control sample; KC – κ-carrageenan; FRC1 – furcellaran; FRC2 – furcellaran.

[***] NCMP – non-collagen muscle protein.

Table 3. Values of pH of restructured chicken breast ham samples manufactured with different types and levels of polysaccharides (κ-carrageenan, furcellaran; 0.25 g/100 g, 0.50 g/100 g, 0.75 g/100 g, 1.00 g/100 g w/w) and a control sample (CS; without any polysaccharides) during a 14-day storage period (at 4±2 °C).[*]

Polysaccharide[**]	Concentration of Polysaccharide (g/100 g)	pH values		
		Storage time (days)		
		1	7	14
CS	0.00	6.07 ± 0.01^{aA}	6.31 ± 0.01^{aB}	6.32 ± 0.01^{aB}
KC	0.25	$6.06\pm0.01^{aA}_{a}$	$6.32\pm0.01^{aB}_{a}$	$6.31\pm0.01^{aB}_{a}$
FRC1		$6.07\pm0.01^{aA}_{a}$	$6.34\pm0.01^{bB}_{a}$	$6.35\pm0.02^{bB}_{a}$
FRC2		$6.06\pm0.01^{aA}_{a}$	$6.31\pm0.01^{aB}_{a}$	$6.30\pm0.02^{aB}_{a}$
KC	0.50	$6.08\pm0.01^{aA}_{a}$	$6.36\pm0.02^{bB}_{a}$	$6.37\pm0.01^{bB}_{a}$
FRC1		$6.08\pm0.02^{aA}_{a}$	$6.35\pm0.01^{bB}_{a}$	$6.36\pm0.01^{bB}_{a}$
FRC2		$6.10\pm0.01^{aA}_{a}$	$6.37\pm0.02^{bB}_{a}$	$6.38\pm0.01^{bB}_{a}$
KC	0.75	$6.08\pm0.01^{aA}_{a}$	$6.35\pm0.03^{bB}_{a}$	$6.36\pm0.01^{bB}_{a}$
FRC1		$6.08\pm0.01^{aA}_{a}$	$6.37\pm0.01^{bB}_{a}$	$6.39\pm0.02^{bB}_{a}$
FRC2		$6.09\pm0.01^{aA}_{a}$	$6.34\pm0.01^{bB}_{a}$	$6.35\pm0.01^{bB}_{a}$
KC	1.00	$6.11\pm0.01^{bA}_{a}$	$6.37\pm0.01^{bB}_{a}$	$6.39\pm0.01^{bB}_{a}$
FRC1		$6.12\pm0.01^{bA}_{a}$	$6.39\pm0.01^{cB}_{a}$	$6.43\pm0.01^{bC}_{a}$
FRC2		$6.10\pm0.01^{bA}_{a}$	$6.38\pm0.01^{bB}_{a}$	$6.39\pm0.02^{bB}_{a}$

[*] Values are expressed as the mean (n=9) ± standard deviation. The means within a column (the difference between polysaccharide concentrates) followed by different superscript letters statistically differ ($p<0.05$); samples produced with different polysaccharides were evaluated independently; all products were also compared to control sample. Mean values followed by different capital letters within the same raw are statistically different ($p<0.05$). The means within a column (the difference between applied polysaccharides at a specific concentration) followed by different subscript letter significantly differ ($p<0.05$); samples produced with different polysaccharide concentrations were evaluated independently.

[**] CS – control sample; KC – κ-carrageenan; FRC1 – furcellaran; FRC2 – furcellaran.

Table 4. The values of complex modulus (G*; kPa) and phase angle (δ; °) during heating up and cooling down for temperature 70 °C (after holding) and 20 °C and 5 °C (during cooling down) of control sample (CS; without any polysaccharides) and samples with polysaccharides [κ-carrageenan (KC) and furcellaran (FRC1, FRC2) in concentrations of 0.25; 0.50; 0.75; 1.00 g/100 g].[*]

Temperature (°C)	Polysaccharide[**]	Concentration of polysaccharide (g/100 g)	Complex modulus G* (Pa)	Phase δ angle (°)
70	CS	0.00	16.6±1.0^{a}	4.8±0.3^{a}
	KC	0.25	17.9±0.7^{b}	5.0±0.2^{a}
		0.50	19.9±0.9^{c}	5.3±0.2^{b}
		0.75	18.0±0.8^{b}	5.4±0.2^{b}
		1.00	18.3±0.9^{b}	5.2±0.2^{c}
	FRC1	0.25	16.7±0.9^{d}	5.0±0.2^{a}
		0.50	19.3±1.2^{e}	5.1±0.3^{a}
		0.75	21.9±1.3^{f}	5.4±0.2^{b}
		1.00	22.2±1.3^{g}	5.2±0.3^{c}
	FRC2	0.25	14.5±0.7^{h}	4.8±0.3^{a}
		0.50	18.0±0.8^{b}	5.0±0.2^{a}
		0.75	20.3±1.0^{i}	5.0±0.3^{a}
		1.00	20.7±0.7^{i}	5.0±0.2^{a}
20	CS	0.00	66.0±3.6^{j}	10.1±0.5^{e}
	KC	0.25	69.5±3.0^{k}	10.2±0.4^{e}
		0.50	81.2±3.7^{l}	10.2±0.5^{e}
		0.75	82.9±4.1^{l}	10.0±0.5^{e}
		1.00	90.6±4.6^{m}	10.2±0.5^{e}
	FRC1	0.25	63.2±2.9^{j}	9.8±0.5^{f}
		0.50	81.1±4.3^{l}	9.9±0.5^{e}
		0.75	95.1±5.4^{n}	10.3±0.5^{g}
		1.00	97.0±4.8^{n}	10.1±0.5^{e}
	FRC2	0.25	53.6±2.8^{o}	9.6±0.5^{f}

		0.50	68.6±3.9^{k}	9.6±0.5^{f}
		0.75	81.5±3.9^{l}	9.4±0.5^{h}
		1.00	89.6±4.7^{m}	9.6±0.5^{f}

Table 4 continue

Temperature (°C)	Polysaccharide[**]	Concentration of polysaccharide (g/100 g)	Complex modulus G^{*} (Pa)	Phase δ angle (°)
5	CS	0.00	98.7±5.2^{p}	10.1±0.5^{e}
	KC	0.25	103.8±4.9^{u}	10.3±0.6^{i}
		0.50	118.1±6.3^{v}	10.6±0.6^{g}
		0.75	118.3±7.0^{v}	10.4±0.5^{g}
		1.00	134.7±7.5^{w}	9.5±0.5^{f}
	FRC1	0.25	94.8±4.5^{n}	9.9±0.5^{e}
		0.50	123.8±5.9^{x}	9.2±0.4^{j}
		0.75	146.8±7.4^{y}	10.5±0.5^{g}
		1.00	148.1±8.1^{y}	9.3±0.5^{h}
	FRC2	0.25	78.7±3.8^{l}	9.8±0.4^{e}
		0.50	101.7±4.4^{u}	9.8±0.5^{e}
		0.75	124.3±6.5^{x}	9.9±0.5^{e}
		1.00	136.8±7.6^{w}	9.6±0.3^{f}

[*] Values are expressed as the mean (n=9) ± standard deviation. Mean values followed by different superscript letters within the same column are statistically different ($p<0.05$). Mean values followed by different capital letters superscripts within the same raw are statistically different ($p<0.05$).

[**] CS – control sample; KC – κ-carrageenan; FRC1 – furcellaran; FRC2 – furcellaran.

Table 5. Values of complex modulus (G*; kPa) and phase angle (δ; °) of restructured chicken breast ham samples manufactured with different types and levels of polysaccharides (κ-carrageenan, furcellaran; 0.25 g/100 g, 0.50 g/100 g, 0.75 g/100 g, 1.00 g/100 g w/w) and a control sample (CS; without any polysaccharides) during a 14-day storage period (at 4±2 °C). The values of the rheological parameters were calculated at frequencies of 0.1, 1.0 and 10.0 Hz.[*]

Polysaccharide[**]	Concentration of polysaccharide (g/100 g)	Frequency (Hz)	Storage period (days)					
			1		7		14	
			G* (kPa)	δ (°)	G* (kPa)	δ (°)	G* (kPa)	δ (°)
CS	0.0	0.1	49.7±0.2^{a}	10.3±0.1^{a}	63.3±0.5^{a}	10.2±0.1^{a}	65.9±0.8^{a}	9.7±0.1^{a}
		1.0	75.9±0.1^{b}	10.4±0.2^{a}	78.4±0.8^{b}	9.2±0.1^{b}	82.0±1.5^{b}	9.7±0.1^{a}
		10.0	100.1±0.1^{c}	11.5±0.1^{b}	101.2±0.3^{c}	10.6±0.0^{c}	106.4±0.5^{c}	9.4±0.0^{b}
KC	0.25	0.1	54.6±0.2^{a}	10.8±0.0^{a}	63.2±0.4^{a}	10.5±0.0^{a}	70.4±1.5^{a}	10.3±0.1^{a}
		1.0	67.1±0.5^{b}	11.4±0.1^{b}	79.6±0.6^{b}	9.9±0.1^{b}	91.6±0.8^{b}	9.2±0.2^{b}
		10.0	98.3±0.3^{c}	10.2±0.1^{c}	105.7±0.7^{c}	10.0±0.2^{b}	118.2±0.6^{c}	9.6±0.0^{c}
FRC1		0.1	57.6±0.1^{d}	10.5±0.2^{c}	60.2±0.7^{d}	10.2±0.1^{b}	63.6±0.3^{d}	10.0±0.2^{a}
		1.0	64.9±0.2^{e}	10.3±0.1^{c}	79.0±0.1^{b}	9.4±0.1^{c}	86.5±0.3^{e}	9.2±0.0^{b}
		10.0	85.4±0.2^{f}	10.8±0.1^{d}	103.8±1.5^{c}	10.1±0.2^{b}	114.8±0.4^{f}	9.5±0.1^{c}
FRC2		0.1	55.8±0.4^{a}	10.5±0.3^{c}	56.5±0.5^{e}	10.5±0.1^{d}	63.0±0.6^{g}	9.7±0.0^{c}
		1.0	72.7±0.5^{g}	9.9±0.2^{d}	77.5±0.4^{f}	9.7±0.1^{b}	81.9±0.5^{h}	9.5±0.1^{c}
		10.0	94.8±0.6^{h}	10.4±0.1^{c}	100.7±1.6^{g}	10.0±0.1^{b}	105.4±0.8^{i}	9.7±0.1^{c}
KC	0.50	0.1	62.4±0.2^{a}	10.3±0.1^{a}	65.3±1.6^{a}	9.9±0.1^{a}	83.3±1.6^{a}	9.4±0.1^{a}
		1.0	80.6±0.3^{b}	9.6±0.0^{b}	84.1±1.4^{b}	9.5±0.1^{b}	107.1±1.4^{b}	9.5±0.1^{a}
		10.0	104.4±0.1^{c}	10.6±0.1^{c}	106.4±0.5^{c}	10.2±0.2^{c}	137.6±1.2^{c}	10.1±0.0^{b}
FRC1		0.1	52.3±0.2^{d}	10.6±0.1^{c}	63.7±0.8^{a}	10.3±0.2^{c}	68.3±0.5^{d}	10.3±0.1^{c}
		1.0	68.3±0.3^{e}	9.9±0.2^{b}	81.4±1.7^{d}	9.6±0.1^{b}	88.4±0.9^{e}	9.4±0.1^{a}
		10.0	88.7±0.4^{f}	12.8±0.1^{d}	109.3±0.5^{c}	11.1±0.0^{d}	122.2±0.4^{f}	10.4±0.1^{c}
FRC2		0.1	61.3±0.4^{a}	10.4±0.1^{c}	63.2±0.6^{a}	9.5±0.0^{b}	69.8±1.6^{g}	10.1±0.0^{b}
		1.0	77.1±0.3^{g}	10.6±0.0^{c}	82.6±0.6^{b}	9.4±0.1^{b}	89.9±2.1^{e}	9.3±0.0^{a}
		10.0	102.9±0.8^{h}	12.2±0.2^{e}	107.2±0.2^{c}	9.6±0.1^{b}	115.8±0.8^{h}	9.0±0.0^{a}

Table 5 continue

Polysaccharide**	Concentration of polysaccharide (g/100 g)	Frequency (Hz)	Storage period (days)					
			1		7		14	
			G* (kPa)	δ (°)	G* (kPa)	δ (°)	G* (kPa)	δ (°)
KC	0.75	0.1	72.9±0.1^{a}	10.9±0.0^{a}	74.3±0.5^{a}	10.6±0.1^{a}	84.7±0.7^{a}	9.9±0.1^{a}
		1.0	94.7±0.5^{b}	11.7±0.1^{b}	94.9±0.9^{b}	9.7±0.0^{b}	111.1±0.7^{b}	9.3±0.1^{b}
		10.0	123.5±1.2^{c}	11.3±0.2^{c}	128.9±1.5^{c}	9.5±0.1^{b}	143.0±0.9^{c}	9.3±0.2^{b}
FRC1		0.1	68.5±0.2^{d}	10.5±0.0^{d}	72.1±1.7^{a}	10.2±0.2^{c}	79.0±1.6^{d}	9.4±0.1^{b}
		1.0	87.3±0.1^{e}	10.4±0.0^{d}	93.4±0.8^{b}	9.4±0.1^{b}	102.5±1.5^{e}	9.2±0.0^{b}
		10.0	125.6±0.6^{c}	11.2±0.4^{c}	126.7±1.8^{c}	9.9±0.1^{d}	132.8±1.7^{f}	9.3±0.0^{b}
FRC2		0.1	61.8±0.5^{f}	10.2±0.5^{d}	70.9±1.1^{d}	9.8±0.1^{e}	74.5±1.1^{g}	9.4±0.1^{b}
		1.0	80.8±0.4^{g}	9.9±0.2^{e}	92.9±0.2^{b}	9.7±0.1^{e}	98.3±0.8^{h}	9.5±0.1^{c}
		10.0	108.1±0.4^{h}	11.1±0.1^{f}	122.1±0.4^{e}	10.9±0.2^{f}	122.4±1.5^{i}	10.4±0.0^{d}
KC	1.00	0.1	87.9±0.4^{a}	11.5±0.2^{a}	92.3±0.8^{a}	10.0±0.0^{a}	121.8±0.5^{a}	9.5±0.1^{a}
		1.0	113.2±0.6^{b}	10.0±0.1^{b}	124.0±0.5^{b}	9.5±0.1^{b}	156.8±0.6^{b}	9.1±0.2^{b}
		10.0	147.0±0.2^{c}	9.8±0.0^{c}	166.5±0.7^{c}	9.6±0.1^{b}	198.6±0.4^{c}	9.1±0.1^{b}
FRC1		0.1	86.3±0.2^{a}	10.3±0.1^{d}	73.6±0.6^{d}	10.1±0.1^{a}	99.5±0.1^{d}	9.0±0.1^{c}
		1.0	95.8±0.1^{d}	10.1±0.1^{b}	108.3±1.1^{e}	9.8±0.2^{c}	128.9±0.8^{e}	9.3±0.2^{d}
		10.0	163.1±0.4^{e}	9.9±0.2^{c}	165.4±0.8^{c}	9.5±0.2^{b}	169.9±0.7^{f}	8.9±0.2^{e}
FRC2		0.1	63.1±0.5^{f}	10.7±0.1^{e}	76.5±0.4^{f}	10.4±0.2^{d}	77.4±0.6^{g}	10.2±0.0^{f}
		1.0	83.4±0.3^{h}	10.4±0.2^{d}	100.3±0.6^{g}	10.0±0.2^{a}	101.9±0.8^{h}	9.9±0.0^{h}
		10.0	110.7±0.2^{i}	12.7±0.3^{f}	128.5±0.3^{h}	10.7±0.1^{e}	134.7±0.7^{i}	9.8±0.1^{h}

* Values are expressed as the mean (n=9) ± standard deviation. The means within a column (the difference between applied polysaccharides) followed by different superscript letters statistically differ ($p<0.05$); samples produced with different polysaccharide concentrations were evaluated independently.

** CS – control sample; KC – κ-carrageenan; FRC1 – furcellaran; FRC2 – furcellaran.

Table 6. The development of cohesiveness, gumminess and chewiness of restructured chicken breast samples manufactured with different types and levels of κ-carrageenan (KC), furcellaran [(FRC1, FRC2); 0.25 g/100 g, 0.50 g/100 g, 0.75 g/100 g, 1.00 g/100 g)] and a control sample (CS; without any polysaccharides) during a 14-day storage period (at 4±2 °C).[*]

Polysaccharides[**]	Concentration of polysaccharide (g/100 g)	Storage period (days)								
		1			7			14		
		Cohesiveness (-)	Gumminess (N)	Chewiness (N)	Cohesiveness (-)	Gumminess (N)	Chewiness (N)	Cohesiveness (-)	Gumminess (N)	Chewiness (N)
CS	0.00	0.03 ± 0.01^{aA}	4.23 ± 0.01^{aB}	9.15 ± 0.05^{aC}	0.04 ± 0.02^{aA}	4.37 ± 0.05^{aD}	9.23 ± 0.02^{aE}	0.06 ± 0.01^{aF}	4.46 ± 0.02^{aG}	9.32 ± 0.05^{aH}
KC	0.25	0.03 ± 0.01^{aA}	4.53 ± 0.05^{bB}	9.25 ± 0.04^{bC}	0.04 ± 0.01^{aA}	4.56 ± 0.01^{bD}	9.35 ± 0.01^{bE}	0.05 ± 0.02^{bF}	4.62 ± 0.01^{bG}	9.47 ± 0.04^{bH}
FRC1		0.03 ± 0.02^{aA}	4.52 ± 0.04^{bB}	9.24 ± 0.08^{bC}	0.04 ± 0.02^{aA}	4.59 ± 0.05^{cD}	9.36 ± 0.03^{bE}	0.04 ± 0.02^{cF}	4.62 ± 0.03^{bG}	9.45 ± 0.03^{cH}
FRC2		0.02 ± 0.01^{bA}	4.46 ± 0.02^{cB}	9.21 ± 0.02^{cC}	0.02 ± 0.01^{bA}	4.48 ± 0.07^{dD}	9.33 ± 0.03^{cE}	0.03 ± 0.01^{dA}	4.52 ± 0.01^{cF}	9.41 ± 0.05^{dG}
KC	0.50	0.04 ± 0.02^{cA}	4.54 ± 0.01^{bB}	9.46 ± 0.02^{dC}	0.06 ± 0.01^{cD}	4.59 ± 0.08^{cE}	9.57 ± 0.07^{dF}	0.06 ± 0.01^{aD}	4.65 ± 0.02^{dG}	9.69 ± 0.08^{eH}
FRC1		0.05 ± 0.01^{dA}	4.55 ± 0.05^{dB}	8.47 ± 0.03^{dC}	0.05 ± 0.02^{dA}	4.58 ± 0.02^{cD}	9.56 ± 0.06^{dE}	0.06 ± 0.01^{aA}	4.64 ± 0.04^{dF}	9.69 ± 0.05^{eG}
FRC2		0.03 ± 0.01^{aA}	4.51 ± 0.07^{eB}	9.42 ± 0.03^{eC}	0.04 ± 0.02^{aA}	4.65 ± 0.11^{eD}	9.51 ± 0.02^{eE}	0.04 ± 0.02^{cA}	4.57 ± 0.01^{eF}	9.62 ± 0.02^{fG}
KC	0.75	0.05 ± 0.01^{eA}	4.74 ± 0.03^{fB}	9.62 ± 0.01^{fC}	0.05 ± 0.03^{dA}	4.74 ± 0.08^{fD}	9.72 ± 0.01^{fE}	0.07 ± 0.01^{eF}	4.76 ± 0.07^{fG}	9.85 ± 0.07^{gH}
FRC1		0.05 ± 0.01^{eA}	4.76 ± 0.02^{gB}	9.62 ± 0.02^{fC}	0.05 ± 0.01^{dA}	4.72 ± 0.06^{gD}	9.74 ± 0.08^{gE}	0.07 ± 0.02^{eF}	4.75 ± 0.04^{fG}	9.84 ± 0.05^{gH}
FRC2		0.03 ± 0.02^{aA}	4.67 ± 0.01^{hB}	9.59 ± 0.08^{gC}	0.04 ± 0.02^{aA}	4.68 ± 0.01^{hD}	9.71 ± 0.05^{fE}	0.03 ± 0.02^{dA}	4.69 ± 0.06^{gF}	9.81 ± 0.05^{hG}
KC	1.00	0.06 ± 0.01^{fA}	4.77 ± 0.04^{gB}	9.73 ± 0.01^{hC}	0.06 ± 0.01^{cA}	4.82 ± 0.02^{iD}	9.80 ± 0.04^{hE}	0.06 ± 0.01^{aA}	4.83 ± 0.02^{hF}	9.96 ± 0.02^{iG}
FRC1		0.06 ± 0.01^{fA}	4.74 ± 0.08^{fB}	9.74 ± 0.07^{hC}	0.04 ± 0.01^{aD}	4.85 ± 0.08^{jE}	9.80 ± 0.02^{hF}	0.08 ± 0.01^{fG}	4.85 ± 0.02^{iH}	9.97 ± 0.02^{iI}
FRC2		0.03 ± 0.02^{aA}	4.54 ± 0.05^{bB}	9.70 ± 0.06^{iC}	0.03 ± 0.01^{eA}	4.69 ± 0.08^{hD}	9.78 ± 0.02^{iE}	0.02 ± 0.01^{gA}	4.72 ± 0.01^{jF}	9.92 ± 0.01^{jG}

[a] Values are expressed as the mean (n=9) ± standard deviation. Mean values followed by different superscript letters within the same column are statistically different (p<0.05). Mean values followed by different capital letters superscripts within the same raw are statistically different (p<0.05).

[**] CS – control sample; KC – κ-carrageenan; FRC1 – furcellaran; FRC2 – furcellaran.

Table 7. First resonance frequency (Hz) of the restructured chicken breast ham samples (after 1 day of storage at 4±2 °C) as a function of polysaccharide type and concentration (g/100 g) (sample height h=10 mm and inertial mass m=500 g).*

Sample**	Polysaccharide concentration (g/100 g)				
	0.00	0.25	0.50	0.75	1.00
CS	73±3	–	–	–	–
KC	–	80±3^{aA}	88±4^{aB}	98±4^{aC}	102±4^{aD}
FRC1	–	78±3^{bA}	82±3^{bB}	94±3^{bC}	100±3^{bD}
FRC2	–	75±3^{cA}	79±3^{cB}	87±4^{cC}	91±4^{cD}

* Values are expressed as the mean (n=9) ± standard deviation. Mean values followed by different superscript letters within the same column are statistically different ($p<0.05$). Mean values followed by different capital letters superscripts within the same raw are statistically different ($p<0.05$).

** CS – control sample; KC – κ-carrageenan; FRC1 – furcellaran; FRC2 – furcellaran

Figure captions

Figure 1. Development of storage (G´; full symbol) and loss (G´´; open symbol) moduli during heating up (bottom part of the curve; the direction of the arrow (solid) shows the temperature increase), holding at 70 °C (shown using the dot arrow) and cooling down [upper part of the curve; the direction of the arrow (dash) shows the temperature decrease] of the control sample (CS; without any polysaccharides).

Figure 2. Development of storage (G´; full symbols) and loss (G´´; open symbols) moduli during heating up (bottom part of the curve; ; the direction of the arrow (solid) shows the temperature increase), holding at 70 °C (shown using the dot arrow) and cooling down [upper part of the curve; the direction of the arrow (dash) shows the temperature decrease] of samples with polysaccharides [Parts A and B – κ-carrageenan; Parts C and D – furcerellan (FRC1); Parts E and F – furcerellan (FRC2)]. Parts A, C and E (▲△ – 0.25 g/100 g; ●○ – 0.50 g/100 g); Parts B, D and F (▲△ – 0.75 g/100 g; ●○ – 1.00 g/100 g).

Figure 3. The development of restructured chicken breast ham hardness (part A; calculated as the maximum force, N) and shear force [part B; calculated as the maximum shear force, N (which is the maximum resistance of the sample to shearing)] depending on the type and concentration of polysaccharide [κ-carrageenan (KC); furcellaran (FRC1 and FRC2); 0.00 g/100 g (control sample – CS); 0.25 g/100 g; 0.50 g/100 g; 0.75 g/100 g; 1.00 g/100 g] during a 14-day storage period at 4±2 °C (n=9; the results were expressed as means (columns) and standard deviations (bars); the restructured chicken breast hams were sampled after 1 (black), 7 (silver) and 14 (dark-grey) days of storage.

Figure 4. Frequency dependencies of the displacement transmissibility (T_d) of restructured chicken breast ham samples depending on the κ-carrageenan concentration [part A; (control sample; black circle; 0.00 g/100 g), (red triangle; 0.50 g/100 g of κ-carrageenan) and (green square; 1.00 g/100 g of κ-carrageenan)]. Frequency dependencies of the displacement transmissibility (T_d) of restructured chicken breast ham samples depending on the applied type of polysaccharide at a concentration of 0.75 g/100 g) [part B; (black circle; κ-carrageenan – KC), (red triangle; furcellaran – FRC1) and (green square; furcellaran – FRC2)]. The samples were measured after 1 day of storage (at 4±2 °C).

Figure 1

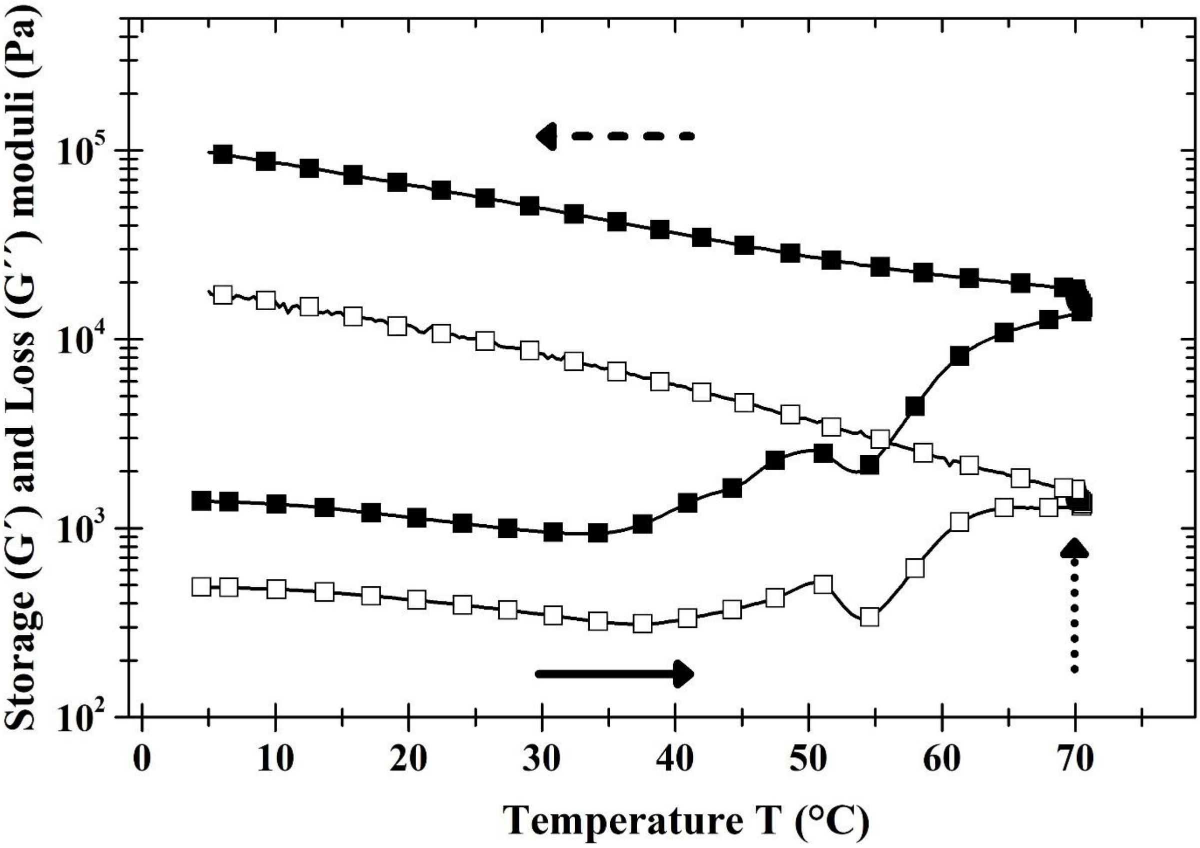

Storage (G´) and Loss (G´´) moduli (Pa)
10^5
10^4
10^3
10^2
0
10
20
30
40
50
60
70
Temperature T (°C)

Figure 2

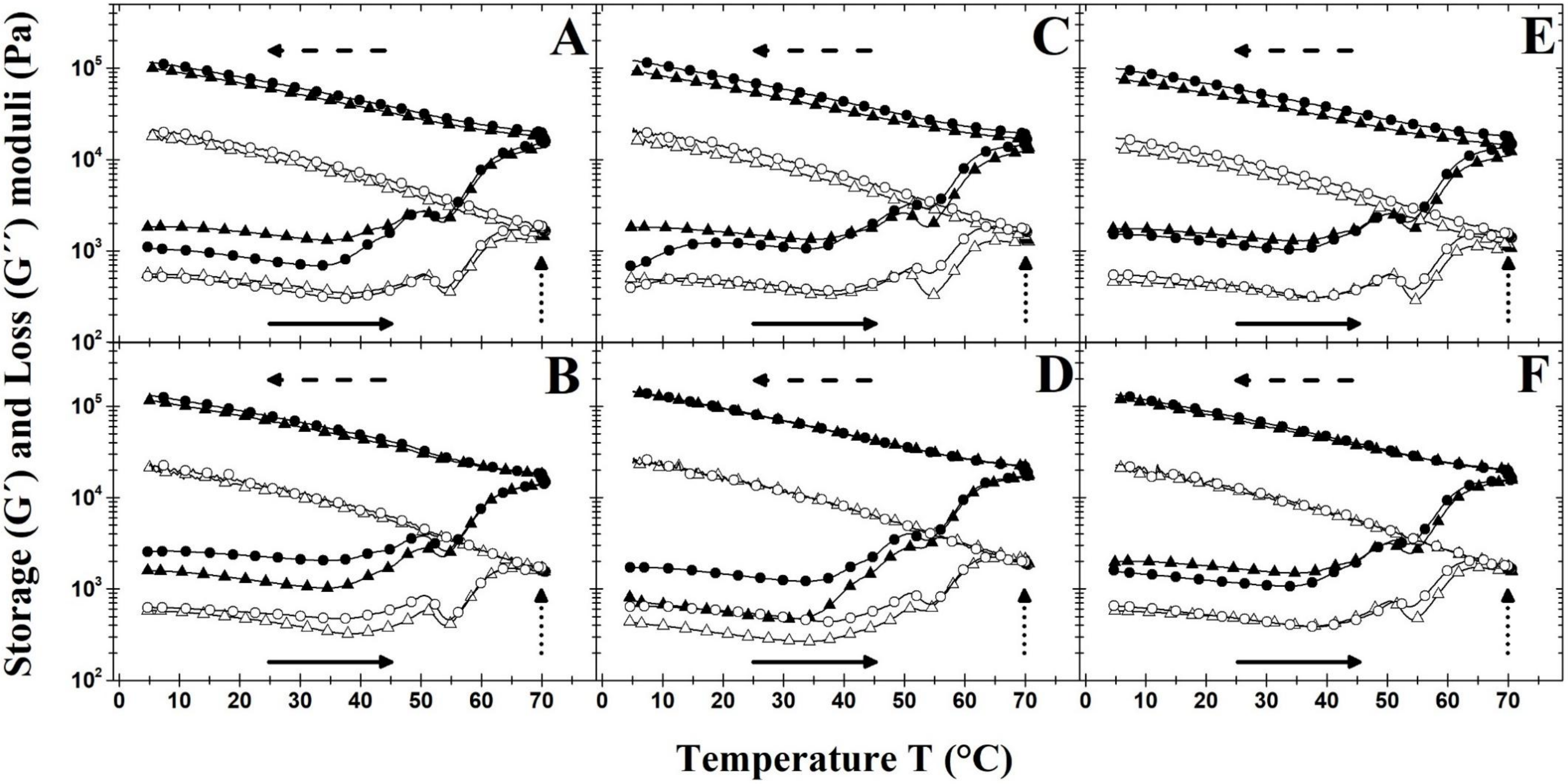

A
B
C
D
E
F
Storage (G´) and Loss (G´´) moduli (Pa)
10^2
10^3
10^4
10^5
0
10
20
30
40
50
60
70
Temperature T (°C)

Figure 3

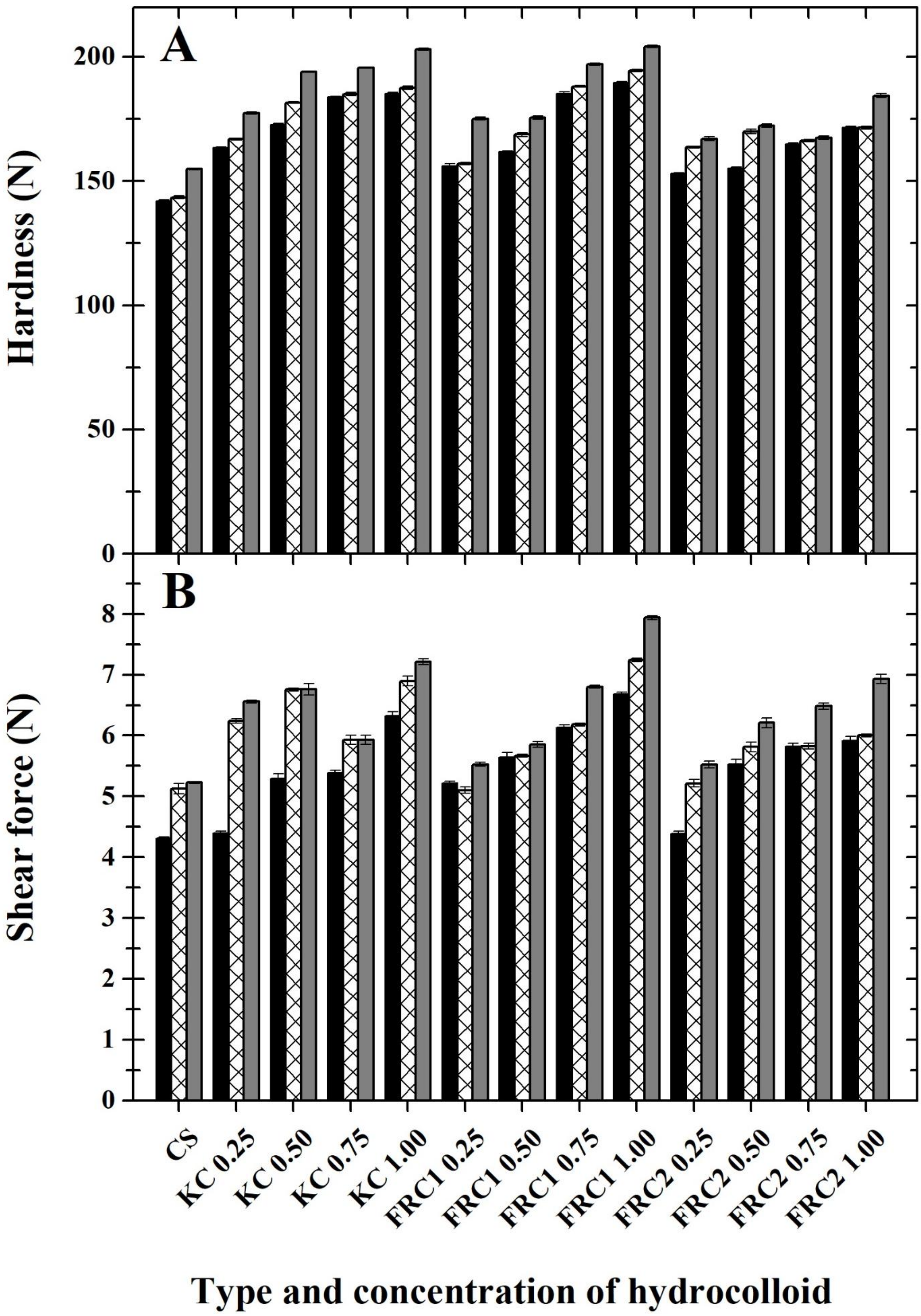
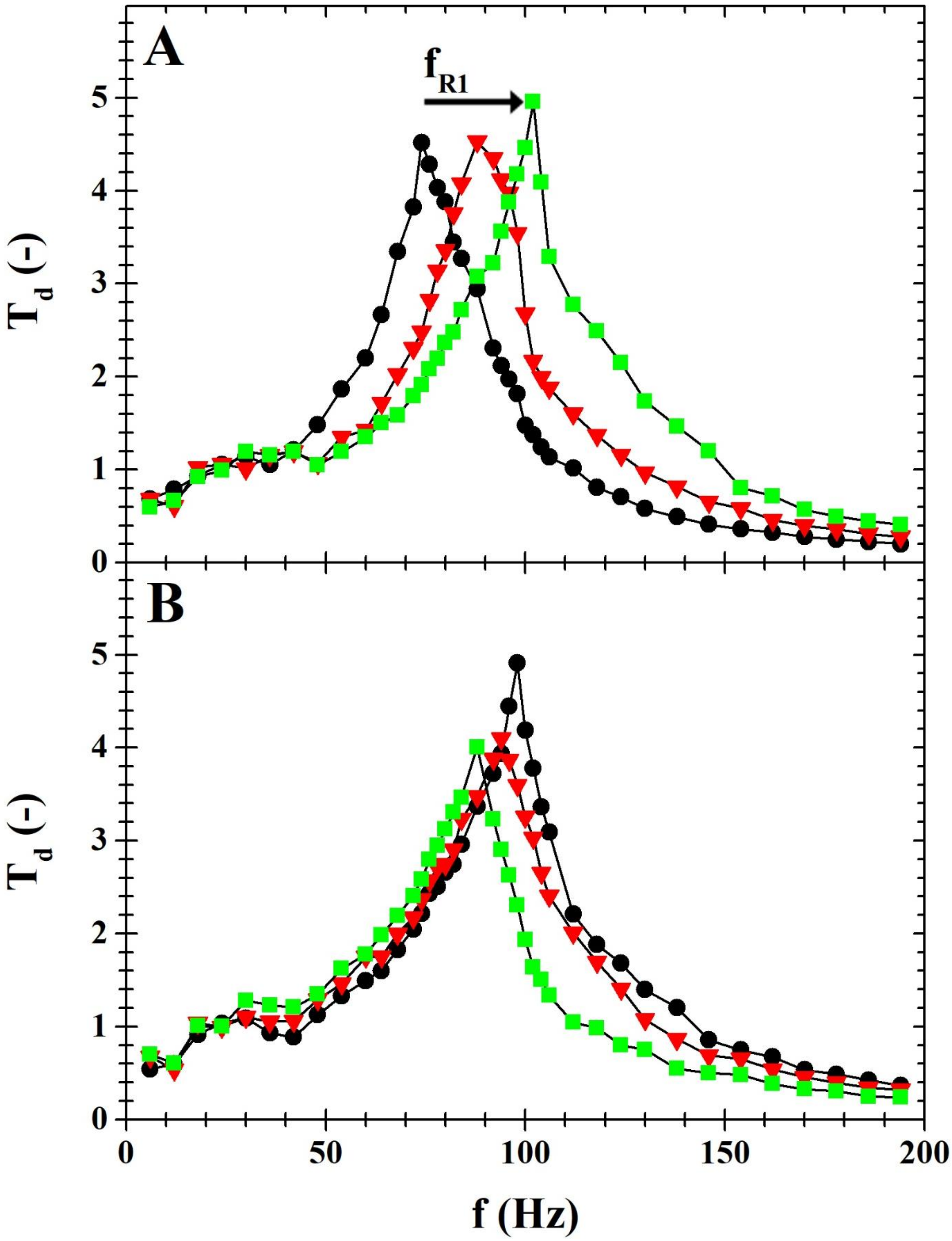

A
B
Hardness (N)
0
50
100
150
200
Shear force (N)
0
1
2
3
4
5
6
7
8
CS
KC 0.25
KC 0.50
KC 0.75
KC 1.00
FRC1 0.25
FRC1 0.50
FRC1 0.75
FRC1 1.00
FRC2 0.25
FRC2 0.50
FRC2 0.75
FRC2 1.00
Type and concentration of hydrocolloid

Figure 4



Credit Author Statement

- Dr. Zdeněk Polášek designed and performed the experiments, did the data analysis, and wrote the original version of manuscript.
- Dr. Richardos Nikolaos Salek designed the research and supervised the project, has written and edited the manuscript, and had primary responsibility for all the contents.
- Associate professor Martin Vašina aided the experiments including mechanical vibration damping properties determination, rheology, and data interpretation.
- Ms. Aneta Lyčková performed some experiments, including basic chemical analysis and rheology.
- Dr. Robert Gál performed some experiments, including Warner-Bratzler shear force test and had edited the manuscript.
- Associate professor Vendula Pachlová performed some experiments, including texture profile analysis and had edited the manuscript.
- Professor František Buňka supervised the project, edited the manuscript, and performed rheology characterization and data interpretation.

Conflict of interest Form

Dear Editors,

We would like to submit the enclosed manuscript entitled “*The effect of furcellaran or κ-carrageenan addition on the rheological and mechanical vibration damping properties of restructured chicken breast ham*”, which we wish to be considered for publication in “Carbohydrate Polymers”. Moreover, no conflict of interest exits in the submission of this manuscript, and the manuscript is approved by all authors for publication. I would like to declare on behalf of my coauthors that the work described was original research that has not been published previously, and not being under consideration for publication elsewhere, in whole or in part. All the authors listed have approved the manuscript that is enclosed.

Thank you and best regards.

Yours sincerely,

Richardos Nikolaos Salek