Destructurations in cooked cured ham

Chemical and physical characterisation of defects in processed products

Keywords

- Pork
- Cooked cured ham
- Destructured zones
- Meat quality

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During the automatic slicing of cooked cured ham, destructured zones in hams can lead to economically relevant losses. In order to obtain basic informations about the properties of the defect, two lots of two tonnes of cooked cured ham from the topside (*M. semimembranosus* and *adductor*) and silverside (*M. biceps femoris*) were produced by two different companies. After slicing (thickness 1.5 mm), normal and destructured zones within the same muscle were examined using chemical, physical and biochemical methods. Destructured zones showed significantly higher L* and b* values, an elavated myofibrillar fragmentation index, a lower a* value, a reduced pH level and lower hardness than the normal zones. The content of crude protein, various amino acids and dry matter was higher in the destructured zones. By contrast there was a lower concentration of NaCl, sugar and insoluble and total connective tissue. The elements Cr, Zn, Ga, Y, Mo, Tl and U appeared in significantly lower concentrations in the destructured zones than in the normal areas. Not only the normal and destructured areas of the cooked cured hams, but also the samples from the two meat processing plants and from both muscles differed significantly in various properties. The present study also provided indications that denaturation of proteins and proteolytic effects might be at least contributory causes of destructurations in cooked cured ham.

Destructured zones in cooked cured ham represent a long known and still topical phenomenon in the meat industry. The defect leads to economically relevant losses for meat processors in European countries in some cases and in recent months particularly has again become a focus of interest. A study conducted in 2007 in seven Swiss meat processing companies of various sizes showed that destructurations occur in 7 to 8 percent of cooked cured ham slices and can account for up to one third of the losses in cooked cured ham production (Hugenschmidt et al., 2007).

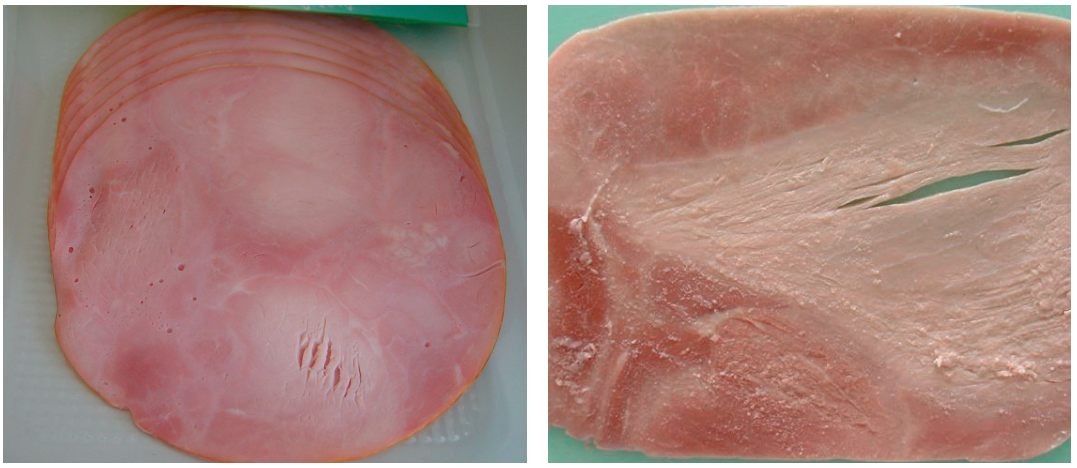
Earlier studies of the phenomena were carried out exclusively on destructured raw meat. Balac et al. (1998) described the defect as a greyish-light, structureless area inside the ham. Franck et al. (2002) and Le Roy et al. (2001) were able to show that the n-allele of the Hal gene and the RN$^-$-allele of the RN gene worsened the defect. Other factors promoting the defect are a high slaughter weight, a high muscle meat percentage, a low final pH value and a fast early-postmortal drop in pH value (Vautier et al., 2008 and 2004; Minvielle et al., 2003 and 2001; Franck et al., 2002). In addition the problem appears increasingly when warm weather conditions prevail on the day of slaughtering (Vautier et al., 2004) and in the case of short transport distances to the slaughterhouse (Minvielle et al., 2003) due to a low final pH value. At the biochemical level, initial studies indicate a strong similarity of the zones affected with those of PSE meat (Laville et al., 2005).

The present study examined normal and destructured samples of cooked cured ham from different manufacturers using chemical, physical and biochemical methods. The aim of characterising the defect in the processed product is to point up and/or confirm possible causes of this defect that are not always directly visible in the raw material, and to derive new approaches from this in order to reduce destructurations in cooked cured ham.

Material and methods

▶ Sample material

The cooked cured ham samples examined originated from two large Swiss meat companies. For the experiment, each of these produced one lot of around 1,000 kg cooked cured ham from *M. biceps femoris* (BF, silverside) and *M. semimembranosus* and *M. adductor* (topside) pieces under normal operating conditions in accordance with their own specific in-house formulation, respectively. The cooked cured hams were cut into 1.5 mm thick slices at the respective processing plants, packaged under modified gas atmosphere and stored at 5 °C up to the time of analysis. All the meat used for the cooked cured ham production originated



Destructured areas in sliced cooked cured ham

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solely from Swiss fattening farms and slaughterhouses. Destructured and normal samples of cooked cured ham were drawn from within the same muscle cord in each case for the physical and biochemical tests and for the element analyses. For the chemical tests, the same quantities of destructured and normal sample material were taken within one muscle cord and pooled in each case to produce several individual samples in order to obtain sufficient sample material for all analyses. The sample material was then homogenised and lyophilised.

▶ Physical methods

In order to determine the hardness a norm needle was driven into the sample (cooked cured ham slice, 1.5 mm thick) at a constant speed and the force applied at a penetration depth of 1 mm was measured (universal testing machine Z2.5/TN1S, Zwick, Ulm, Germany). The pH value was determined in 2 to 3 g of homogenised sample material using a glass penetration electrode (Metrohm, Herisau, Switzerland). The colour was measured on a circular sample (height 3 mm, diameter 7 mm) placed in an absorbing test dish. The colour values (L*, a* and b* value) were determined with the aid of a spectrophotometer (Spectroshade, MHT, Switzerland) (Chatelain et al., 2007). The method of Culler at al. (1978) was used to determine the fragmentation index of the myofibrils (MFI).

▶ Chemical methods

The dry matter, crude ash, crude protein, crude fat and total sugar contents were determined as described in Hadorn et al. (2008). The hydroxyproline as a measure for the connective tissue content was analysed using the method of Arneth and Hamm (1971).

▶ Analysis of elements

The analysis of elements was conducted with 0.8 g sample material using ICP-MS following the method described by Franke et al. (2008). If more than one isotope was determined for an element, only the one with the best calibration was taken into account for the statistical evaluation.

▶ Biochemical methods

Western Blots of desmin, talin and troponin T were carried out using the method of Bee et al. (2007).

▶ Statistical evaluation

A linear mixed model with the fixed factors defect (normal/destructured), muscle (silverside/topside) and processor (X/Y) together with the random factor sample were used to evaluate the analytical results with the aid of the statistics programme Systat (Systat, 2007). Possible outliers were checked using the Grubbs test and where appropriate eliminated.

Results

▶ Physical properties

The results of the colour analyses showed that the L* (brightness) and the b* (yellow) values of the destructured zones were significantly elevated in comparison with the normal zones (Tab. 1). On the other hand a lower a* (red) value could be seen in the destructured areas compared to the normal ones. The pH value of the destructured zones was only slightly lower than in the normal zones (Ä = 0.07 pH units). The MFI of the destructured areas was moreover 26.7% higher and their hardness was 37.5% lower than in the normal areas.

As regards the L* value and the MFI, there were also significant differences between the topside and the silverside. The a*, b* and the pH level of the processors X and Y also differed significantly of each other.

▶ Chemical analyses

The results of the chemical analyses showed that destructured zones had 2.3% higher dry matter and also a 2.3% higher protein content than the normal zones (Tab. 2). The 10.1% lower ash content in the destructured zones was accompanied by a 10.6% lower sugar content. The normal areas contained an 8.6% higher proportion of hydroxyproline than the destructured areas, and the share of insoluble hydroxyproline was 12.8% higher than in the destructured areas.

By analogy with the protein content, 17 of the 18 amino acids analysed in the destructured zones showed a higher concentration than in the normal areas (Tab. 3), with the differences being significant in the cases of alanine, arginine, asparagine acid, glutamic acid, isoleucine, leucine, lysine, methionine, phenylalanine, serine, threonine, tyrosine and valine.

In addition to the significantly different raw nutrient and amino acid contents of the normal and destructured zones of the cooked cured hams, there were also significant differences in the characteristics examined between the topside and silverside and between the processors X and Y.

▶ Analysis of elements

The elements Be, Cd, Sm, Ho, Tm, Hg, Na, Mg, K and Se were below the detection limit and could therefore not be evaluated. Within the same elements, only the isotope with the best calibration was evaluated, so that altogether 40 elements remained. Of these, seven showed a lower concentration in the normal zones than in the destructured ones. In the remaining 33 elements a comparably higher concentration was detected in the normal areas. Table 4 shows only those elements that occurred in significantly different concentrations between processors X and Y, topside and silverside, or normal and destructured areas. Therfore, it was decided to refrain from showing the other elements (Li, Sc, Co, Cu, As, Rb, Pd, Te, Ba, Ce, Nd, Gd, Tb, Yb, Lu, Bi, Al, Ca, V,

Tab. 1: Physical analyses of destructured and normal areas in cooked cured hams

	Defect			Muscle			Processor		
	Normal (n = 87)	Destructured (n = 87)	p value	Topside (n = 98)	Silverside (n = 76)	p value	X (n = 84)	Y (n = 90)	p value
L* value [–]	55.9	66.6	<0.001	62.3	59.9	0.002	60.5	61.9	0.089
a* value [–]	13.6	9.6	<0.001	11.2	12.2	0.080	12.2	11.1	0.029
b* value [–]	9.1[a]	9.7[a]	0.014	9.5	9.4[b]	0.330	9.9[c]	9.0	<0.001
pH value [–]	5.95	5.88	<0.001	5.87	5.96	0.126	5.93	5.89	<0.001
Hardness [N]	0.08	0.05	<0.001	0.07	0.07	0.113	0.07	0.07	0.394
MFI [–]	61.7[d]	78.1[e]	<0.001	75.7[f]	58.0[g]	<0.001	67.1[d]	68.0[e]	0.958

MFI = myofibril fragmentation index; n = number of samples: [a]n = 86; [b]n = 74, [c]n = 82, [d]n = 38, [e]n = 36, [f]n = 40, [g]n = 34

Source: Hugenschmidt et al. Fleischwirtschaft International 2/2009

Mn and Fe). The elements Zn, Ga, Y, Mo and U appeared in significantly lower concentrations in the destructured areas than in the normal ones. Once again, for certain elements significant differences were observed between the two muscles examined and between the two processors.

Tab. 2: Nutrient and connective tissue content of destructured and normal areas in cooked cured hams (g/kg dry matter)

	Defect			Muscle			Processor		
	Normal (n = 21)	Destructured (n = 17)	p value	Topside (n = 20)	Silverside (n = 18)	p value	X (n = 20)	Y (n = 18)	p value
Dry matter*	286.1	292.6	0.104	290.2	287.6	0.581	289.1	288.8	0.861
Crude ash	110.6	100.5	0.102	98.6	114.4	0.009	110.8	100.8	0.071
Crude protein	795.4	813.8	0.002	810.8	795.6	<0.001	801.0	806.6	0.052
Crude fat	80.0	79.6	0.913	80.9	78.5	0.917	71.9	88.5	0.229
Sugar	26.8	24.2	0.036	21.8	29.8	0.002	29.7	21.0	<0.001
Hyp. total	3.30	3.04	<0.001	3.27	3.08	<0.001	3.03	3.35	<0.001
Hyp. insoluble	2.12	1.78[a]	<0.001	2.00[b]	1.95	<0.001	1.76[b]	2.20	<0.001
CTP[1]	26.39	24.28	<0.001	26.18	24.62	<0.001	24.21	26.82	<0.001
CFMP[2]	768.2	789.5	<0.001	784.6	770.1	<0.001	776.7	779.4	<0.001

* g/kg fresh matter, [1] connective tissue protein (CTP) = 8 × hydroxyproline (Hyp), [2] collagen-free muscle protein = crude protein − CTP, n = number of samples: [a]n=16, [b]n=19

Source: Hugenschmidt et al. Fleischwirtschaft International 2/2009

Discussion

▶ Physical attributes

The destructured zones were characterised by a lighter colour, a higher yellow and a reduced red proportion. The elevated brightness of the destructured zones is probably attributable to denaturation of muscle proteins during the slaughtering process. This is because early post mortal temperatures above 40 °C and low pH levels can lead to partial denaturation of metmyoglobin (Zhu et al., 2002), phosphorylase, creatinkinase, triosephosphate isomerase and myokinase (Joo et al., 1999). Thereby soluble proteins precipitate too and scatter the incoming light, as a result of which the meat appears lighter. Such local, PSE-like changes can occur in regions with insufficient cooling; they may appear at the initial phase of slaughtering in the centre of legs (topside and silverside). This can be the case even if there is no genetic predisposition of the animals to PSE meat (Freise, 2005). According to a French investigation in raw *M. semimembranosus* (Laville et al., 2005), destructured meat and PSE meat show comparable changes in the proteins. Large hind legs, which are typical for heavily muscled animals with a high lean meat percentage and/or a high slaughtering weight, make optimal cooling at the centre of the legs difficult and could explain the frequent occurrence of the defect with rising lean meat percentage or slaughter weight (Hugenschmidt and Scheeder, 2008; Vautier et al., 2004; Minvielle et al., 2003 and 2001; Franck et al., 2002). The enhanced brightness of the destructured areas can also be due to greater proteolysis, that could also be responsible for the soft texture and increased MFI of the destructured areas (Veiseth et al., 2004). In various discussions with the meat industry a further possible cause of the enhanced MFI occasionally mentioned was myopathy. However, no corresponding indications in literature were found.

▶ Chemical analyses

The trend towards a higher dry matter content in the destructured zones is presumably attributable to a reduced water-binding capacity of the zones concerned. They may have a lower capacity with regard to binding the water present in the meat and the water added to cooked cured ham products via the brine, consequently leading to higher drip and cooking loss. The reduced sugar and ash content of the destructured areas is probably also due to the reduced brine absorption capacity, especially as the quantities of sugar and salts defined in advance and dissolved in the water are injected into the cooked cured hams via the brine. In the normal zones, brine is apparently bound better and thus the water, ash and sugar contents are increased. The relative accumulation of sugar and ash due to the intake of brine in the normal cooked cured hams ultimately led to

Tab. 3: Content of amino acids in destructured and normal areas of cooked cured hams (g/kg dry matter)

	Defect			Muscle			Processor		
Amino acid	Normal (n = 21)	Destructured (n = 17)	p value	Topside (n = 20)	Silverside (n = 18)	p value	X (n = 20)	Y (n = 18)	p value
Ala	43.5	46.1[a]	<0.001	45.8	43.1[b]	<0.001	44.1[c]	45.1	<0.001
Arg	48.7	50.2	0.010	50.0	48.6	0.003	49.4	49.3	0.959
Asp	72.5	75.3[b]	0.001	74.8	72.5[d]	<0.001	73.6[e]	73.9	0.002
Cys	8.8	8.8	0.882	8.7	8.8	0.319	8.8	8.8	0.983
Glu	115.5	118.1	0.001	118.0	115.1	<0.001	117.1	116.1	<0.001
Gly	35.4	36.6[b]	0.730	36.7	35.0[d]	0.006	35.5[e]	36.4	0.482
His	31.9[f]	32.9[b]	0.236	32.6	32.0[b]	0.002	32.0[e]	32.7[d]	0.001
Ile	39.6	41.0	<0.001	40.7	39.6	<0.001	40.2	40.2	0.001
Leu	63.1	65.1	<0.001	64.8	63.1	<0.001	63.9	64.0	0.004
Lys	72.6	75.2	<0.001	74.9	72.5	<0.001	73.9	73.6	<0.001
Met	20.1	20.9	<0.001	20.9	20.0	<0.001	20.5	20.4	0.441
Phe	31.5	32.7[b]	0.004	32.5	32.1[d]	<0.001	32.0[e]	32.1	0.021
Pro	29.5	30.2[b]	0.471	30.3	29.8[d]	0.013	29.7[e]	29.9	0.912
Ser	29.6	32.9[b]	<0.001	32.3	32.1[d]	<0.001	30.0[e]	32.1	<0.001
Thr	34.3	35.8[b]	<0.001	35.4	34.8[d]	<0.001	35.1[e]	34.8	<0.001
Try	9.7	9.9	0.192	9.9	9.7	0.299	9.8	9.7	0.651
Tyr	27.6	29.3[b]	0.004	29.0	28.7[d]	<0.001	28.0[e]	28.7	0.009
Val	41.0	42.5[b]	<0.001	42.2	41.7[d]	<0.001	41.5[e]	41.7	<0.001

n = number of samples: [a]n = 15, [b]n = 16, [c]n = 18, [d]n = 17, [e]n = 19, [f]n = 20

Source: Hugenschmidt et al. Fleischwirtschaft International 2/2009

Possible colour variations in the raw material (topside) of cooked cured ham

the reduced content of crude protein or collagen-free muscle protein (CFMP), which is also reflected in the amino acid pattern. However, the accumulation of sugar and ash should also affect the fat content and become evident in a comparable reduction of the fat content in the normal cooked cured hams. Yet this was not the case in the present study and cannot be explained with the data available. A physiological cause of the different contents of crude protein, CFMP and the amino acid pattern appears to be relatively improbable. Instead it is to be assumed that the actual contents were masked by a different intake of brine components in normal and destructured cooked cured ham.

A lower content of connective tissue (total and insoluble) was observed in the destructured zones. The insoluble connective tissue in particular as structure-providing tissue is co-responsible for the "background toughness" of the meat. The reduced content of insoluble connective tissue – this was also proved in a study by MINVIELLE et al. (2001) – could accordingly have been co-responsible for the brittle texture and the lack of cohesion of the destructured zones in the cooked cured hams.

▶ Analysis of elements

The element analysis could provide indications regarding the differing colour of normal and destructured zones in cooked cured hams via the formation of complexes. It is mainly nitroso (met)myoglobin in which iron functions as the central atom of the protoporphyrin that is responsible for the red colour of the cooked cured hams. However, different concentrations of iron could not be detected in the normal and destructured cooked cured hams (data not shown) and so this does not enter into question as the cause of the colour differences. In addition to nitroso (met)myoglobin, zinc-protoporphyrin IX is partly responsible for the dark red colour in raw cured products that ripen over several months (WAKAMATSU et al., 2007). A reduced zinc content could accordingly at least partially explain the less strong red colour of the destructured areas, although as far as we know the formation of zinc-protoporphyrin IX has not (yet) been detected in cooked cured hams, but instead only in long-ripening raw hams and according to HAYASHI et al. (2007) is even inhibited by the addition of nitrite. Gallium, which also occurs in significantly lower concentrations in destructured zones, can generally also bind with porphyrin (HATSCHER, 2003). However, no further knowledge is available yet about the properties of this potential complex former in meat products and it has not yet been detected in meat.

▶ Biochemical analyses

The protein analyses using Western Blot showed that the degradation of proteins in cooked cured ham can only partially be examined using this method. The changes caused by the brine that contains different salts, phosphate and sugar, as well as the heat treatment of the cooked cured hams (→ denaturation of proteins) can lead to problems in the analysis. A possible alternative consists in testing destructured raw material. However, unambiguous evidence that the destructuring in the raw material (generally on the inside and not directly visible from the outside) is always manifested in the end product too, has yet to be confirmed.

▶ Muscle and processor-specific differences

When considering the muscle-specific differences it becomes apparent that the attributes brightness, pH value and MFI of the cooked cured hams produced from the topside correspond to the mean extent of the destructured zones (Tab. 1). With regard to the chemical attributes too there is also congruence between the topside and destructured samples in dry matter, crude protein content and CFMP, while conversely the corresponding attribute characteristics were comparable for the silverside and the normal zones of cooked cured ham (Tab. 2). This indicates that the topside is more susceptible to the defect, as also confirmed by the results of LAVILLE et al. (2005). The differences in the composition of the various muscles

Tab. 4: Element analyses of destructured and normal areas in cooked cured hams (µg/kg fresh matter)

	Defect			Muscle			Processor		
	Normal (n = 15)	Destructured (n = 15)	p value	Silverside (n = 10)	Topside (n = 20)	p value	X (n = 20)	Y (n = 10)	p value
^{10}B	274.0	259.4	0.555	297.6	251.3	0.257	292.3	215.5	0.006
^{52}Cr	166.9	86.13	0.086	25.45	177.08	0.417	49.63	280.3	0.003
^{60}Ni	36.42[a]	30.34	0.716	8.47	46.38[c]	0.503	13.98[c]	70.03	0.014
^{67}Zn	3015.0[a]	2419.0	0.004	2592.0[b]	2758.0	0.468	2735.0[c]	2653.0	0.476
^{69}Ga	0.53	0.43	0.005	0.48	0.48	0.616	0.47	0.52	0.315
^{88}Sr	83.49	77.90[a]	0.263	94.18[b]	74.77	0.157	90.58[c]	62.20	0.024
^{89}Y	0.35	0.28	0.033	0.29	0.33	0.818	0.28	0.38	0.047
^{95}Mo	42.25	27.25	0.015	30.73	36.76	0.727	38.72	30.73	0.088
^{109}Ag	8.88[a]	13.52	0.131	4.66	14.77[c]	0.062	7.79	19.04[b]	0.027
^{139}La	0.49	0.54[a]	0.643	0.29	0.63[c]	0.032	0.44[c]	0.65	0.805
^{141}Pr	0.09	0.08	0.068	0.06	0.09	0.514	0.07	0.11	0.048
^{151}Eu	0.01	0.01	1.000	0.01	0.02	0.798	0.01	0.02	0.004
^{163}Dy	0.03	0.02	0.189	0.02	0.03	0.800	0.02	0.04	0.001
^{166}Er	0.03	0.03	0.135	0.03	0.03	0.558	0.02	0.04	0.031
^{178}Hf	0.33	0.28	0.096	0.21	0.35	0.444	0.23	0.44	0.018
^{205}Ti	0.37	0.33	0.095	0.24	0.41	<0.001	0.33	0.41	0.104
^{208}Pb	12.06	9.43[a]	0.104	4.38[b]	13.67	0.118	6.89[c]	18.2	0.008
^{232}Th	0.09	0.07	0.515	0.06	0.09	0.748	0.07	0.11	0.016
^{238}U	2.27	1.79	0.002	2.37	1.86	0.808	2.41	1.28	0.001

Destr. = destructured, n = number of samples: [a]n = 14, [b]n = 9, [c]n = 19

Source: HUGENSCHMIDT et al. Fleischwirtschaft International 2/2009

and pieces are well-known in the industry. Due to the availability of and the demand for various pieces, however, it is not always possible to use ideal pieces for all products.

The differences between the two processors X and Y can be attributed on the one hand to the technologies used during the slaughtering process and the subsequent processing, and on the other hand to the different fattening farms. With regard to the latter, factors such as genetics, husbandry or feeding and the fasting period and transport of the animals cannot be excluded. This variety of influences within the factor "processor" could explain why many attributes differ significantly between the two processors. Furthermore, they provide an indication of why the factor "processor" was involved chiefly in the interactions between the factors "processor", "muscle" and "defect".

Conclusions

Destructured zones in cooked cured ham are characterised particularly by a light colour and a brittle texture and thus confirm earlier experiments conducted on destructured raw meat. The cause of the light colour of the destructured areas and the brittle texture presumably lies in a combination of protein denaturation and elevated proteolytic activity in the raw product. The denaturing of the proteins is due to elevated early-postmortal temperatures and low pH values inside the ham (topside), partly due to insufficient cooling. The stronger proteolysis in the destructured areas could not be detected by analysis with Western Blot, but is indicated by the elevated MFI and the brittle texture. For future studies the influence of the interplay of denaturation and proteolysis must therefore be examined more closely.

The influence of the insoluble connective tissue, the content of which was lower in destructured raw meat according to earlier studies and lower in cooked cured ham too according to the present study than in normal raw meat and normal cooked cured ham, respectively, still remains unclear. In future experiments the elevated content of crude protein, CFMP and different amino acids in the destructured areas should also be confirmed and examined more in detail.

Importance for practice

The chemical and physical analyses showed significant differences in various properties between both normal and destructured areas of cooked cured hams and between the two processors X and Y, as well as among the two muscles silverside and topside. According to the findings, the physical and chemical nature of cooked cured hams is already subject to relatively large variations even without the occurrence of destructuring, and there may be overlaps in the extent of the attributes for the factors, "defect", "muscle" and "processor" that make studies on destructurations more difficult.

The lower water, sugar and ash contents of the destructured areas in comparison with the normal zones of the cooked cured hams indicates a lower brine intake, possibly due to the poorer water-binding capacity of denatured proteins in the defective zones. That is why primarily a specific disposition of the animals and slaughter-specific processes enter into question as causes of the defect observed in the present study. However the technology of ham production, which under certain circumstances can also contribute to a lower brine intake or protein denaturation, as well as the slicing process cannot be ruled out as critical factors for the defect.

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