Acta Agrophysica, 2004, 4(1), 211-220

SELECTED FACTORS SHAPING THE CONSISTENCY OF DRY-CURED HAMS

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A b s t r a c t. The subject of the studies undertaken was to determine the role of certain factors, affecting the shaping of the consistency of dry-cured hams in the manufacturing process. It was found that the weight of the hams after curing (*M*) and the *pH* value of meat turned out to be the main factors differentiating the consistency of dry-cured hams. The degree of dehydration of the hams, as characterized by water content (*W*) to protein content (*B*) ratio (*W/B*) was also significant, but it was differentiated depending on the weight of the hams, which indicates its secondary nature. No effect of the fat content on the results of the studies on consistency was found. From among the rheological parameters of meat, as determined by the instrumental CASRA method, the closest dependence on the *pH* value and the weight of the hams after curing was revealed by the deformation at the lowest stress (D_{min}) and fluidity (*F*), characterizing the transformation of the substance with a loose structure into one with a concentrated structure. A good compliance of the parameters of CASRA instrumental analysis texture of dry-cured hams with the sensory evaluation of the consistency was stated. The sensory evaluation was most strongly affected by the plasticity (*P*), and then by the elasticity (*E*) and fluidity (*F*) of the hams.

K e y w o r d s : pork meat, dry-cured hams, consistency, rheological characteristic

NOMENCLATURE

CASRA - Continuously Alternating Stress-Relaxation Analysis
V – cycle speed (mm min^{-1}),
F_v – initial stress – after F_v UTM start (N),
F_1 – unit force (N),
ΔF – increment of force (N),
σ_ι – modular stress = F_1/S (N m^{-2}),
P – plasticity – CASRA method parameter (N m^{-2}),
E – elasticity – CASRA method parameter (m^2 N^{-1}),
F – fluidity – CASRA method parameter (m^2 N^{-1} s^{-1}),
D_{min} – deformation under the modular stress (%),

$D_{plast.}$ – deformation under the stress (%),
W/B – water content (*W*) to protein content (*B*) ratio, dimensionless,
T – fat content (%),
CI – consistency intensity (c.u.),
CD – consistency desirability (c.u.).

INRTODUCTION

Consistency is one of the most important parameters of quality of all meat products. It may relatively easily be shaped in the case of products manufactured from comminuted meat, subjected to heat treatment; it is more difficult when the tissues retain their natural structure as it is in the case of manufacture of dry-cured hams, the consistency of which is formed as a result of complicated dehydration, salting and acidification processes occurring in muscle tissue.

A mixture of curing ingredients (salt, nitrate and/or nitrite) and adjuncts (ascorbic acid and glucose) are rubbed onto the lean muscle surface of the ham (pre-salting). Hams are subsequently placed fat side down and arranged in a single layer without touching one another. The raw tissue of ham muscles (without fat cover) consists of ca. 70% water, 20% protein and 10% fat, it has a loose, very flexible consistency.

During salting, which lasts most frequently for 2-4 weeks, the mixture's components penetrate slowly from the surface towards the inside of muscle tissues, with the simultaneous displacement of water in a reverse direction from the deeper layers towards the outside. During this phase (post-salting), a complete salt equalization takes place. The rate of development of colour, taste and flavour and texture specific for raw-ripened product is dependent on the rate of these processes. The rate of diffusion of ions and water is dependent on the concentration of sodium chloride and curing substances, temperature and duration of the process, as well as on internal factors such as morphological and chemical composition and biochemical state of the muscles [2-5,7].

The rise of the salt concentration in meat is accompanied by changes in the chemical composition and structure of muscle tissue, physico-chemical state of proteins and permeability of cellular membranes, which slows down the process of diffusion [1,2,5,6]. As a result of the above mentioned processes, the consistency of dry-cured hams becomes more and more concentrated, elastic with the characteristics of the solid state [9].

In the first place, the product has to be firm to permit slicing into very thin slices that are nearly transparent and still do not disintegrate. During consumption the product should be firm and demonstrate moderate resistance to mastication that reveals the full aroma of fermented meat. It can neither be too soft, as in the case of products insufficiently dehydrated, nor too hard, as it can be found in products over-dehydrated due to prolonged storage.

Examination of changes in the meat consistency during the manufacturing process of dry-cured hams has encountered – so-far – obstacles of methodological nature. There has been a lack of a universal method, based on the repeatable manner of sampling, well showing the properties, on the one hand – of natural raw meat with a loose flexible structure, and of a final product with a specific concentrated structure, resembling meat in *rigor* state on the other hand. In the available literature, we may find, therefore, rather scarce information on the development of texture of dry-cured hams during the salting period, preliminary ripening and after final maturation. It was possible to examine the consistency of dry-cured hams by using a modified measurement technique on the UTM Zwick 1445 MOPS apparatus.

The purpose of the study was to determine those factors that affect the development of consistency and its formation in dry-cured ham during the production process.

MATERIAL

Fourteen porcine hams of the Polish Large White breed, obtained from animals slaughtered at various age and demonstrating different body weight, were used as experimental material. The hams were deboned and formed in the shape of "Westphalia ham". Thereafter, they were treated on the surface with a mixture of halite and evaporated salt, sodium nitrite and nitrate, starter cultures and glucose. The curing procedure was carried out at 6-8^{o}C and 85-90% relative humidity during 53 days. After that time, the hams were rinsed to remove excess salt and dried to reach around 78% of their initial weight. Drying was conducted at 10 to 12^{o}C and the relative humidity of air was 90% at the end. The dried hams were packed into barrier film bags and stored for six months. After that period they were subjected to various analyses.

Apart from the above, from three other hams the largest muscles were excised and cut into slices about 35 mm thick. Two slices from each muscle were examined immediately after excision (6) and the others (22) were salted with an excess of sodium chloride, stored from one to three weeks and during that period the occurring juice was removed. Thereafter, the muscle slices were packaged into plastic film bags and air evacuated. During the subsequent ten days storage the salt concentration and water content were equalised in the muscle slices and the consistency examination followed. Those slices were used as a model of ham meat of various degree of dehydration during the processing procedure of dry-cured ham.

METHODS

Consistency was examined in a UTM Zwick 1445 MOPS-M apparatus using the modified CASRA method [8]. Deformation changes were analysed by using a flat, rectangular mandrel that was forced into the meat sample and simultaneously pressed the surface under the mandrel and cut it at its sharp edges. Adequately programmed stress distribution during the measurements made the observation of the examined sample, both under increasing stress and in relaxation, feasible. From the obtained rheograms the following rheological parameters were calculated: plasticity (*P*), elasticity (*E*) and fluidity (*F*). The modification of measurement technique was based on the application of a special device for fastening meat samples and for calculation of two new parameters concerning sample deformation during the test, namely: D_{min} (%) – deformation under modular (minimal) stress $\sigma_1 = 8.33 \cdot 10^5$ N m^{-2}, and D_{plast} (%) – deformation under stress resulting in recoverable destruction of the structure [9]. Samples in the form of ham slices were placed first onto a metal support furnished with pins 20 mm high and Ø2, distributed every 15 mm according to the plane of a hexagonal net, and then sample thickness was adjusted to 20 mm exactly to the method described earlier. Thereafter, samples in the hexagonal muscle fragments were subjected to penetration by using a mandrel of rectangular cross-section 2 x 6 mm.

The other measurement conditions were as follows: traverse velocity between bites: 120 mm min^{-1} and over bite duration: 2 mm min^{-1}; force unit: F_1 = 1 N; force increment ΔF: 1 N; stress and relaxation time – t_0 = 15 s each time; mandrel surface area: $S = 1.2 \cdot 10^{-5}$ m^2.

The following chemical and physico-chemical parameters were also determined:
- protein content (*B*) by Kiejdahl method according to PN-75/A– 04018;
- water content (*W*) by drying method according to PN–ISO 1442:2000;
- intramuscular fat (*T*) by Soxhlet method according to PN–ISO 1444:2000;
- pH values was measured using pH-meter with sharp-end electrode (PN–ISO 2917:2001);
- ratio of water to protein content (*W/B* ratio) was calculated.

Sensory evaluation was conducted by a trained sensory panel of 6 to 7 judges using the ten-score. Consistency intensity (*CI*) and consistency desirability (*CD*) were evaluated according to PN-ISO 11035:1994 and PN-ISO 41219:1998.

RESULTS AND DISCUSSION

Usefulness of texture rheological parameters in the assessment of the physical status of ham muscles in dehydration and ageing process were examined with their relation to the population of results representing: raw ham muscles (6), salted and partially dehydrated ham muscles, and hams after curing and ageing (22). The degree of meat dehydration was well characterized by the ratio of water to protein content (*W/B*). Correlations of the results of the particular rheological texture parameters: *P*, *E*, *F*, D_{min}, D_{plast} and *W/B* ratio of model of ham meat are shown in Table 1. All of texture parameters were very significantly correlated with *W/B* ratio and between each other.

Table 1. Correlation coefficients between texture rheological parameters and W/B ratio

Studied traits	*W/B* ratio	D_{plast} (%)	D_{min} (%)	Plasticity (*P*)	Elasticity (*E*)
D_{plast}	0.969 ***	–			
D_{min}	0.932 ***	0.876 ***	–		
Plasticity (*P*)	–0.886 ***	–0.811 ***	–0.836 ***	–	
Elasticity (*E*)	0.933 ***	0.873 ***	0.910 ***	–0,909 ***	–
Fluidity (*F*)	0.936 ***	0.891 ***	0,965 ***	–0.882 ***	0.955 ***

Significance level: ^{ns} not significant, * p<0.05, ** p<0.01, *** p<0.001.

The D_{min} parameter characterizes well the structure of raw meat and may be used as *rigor* indicator of muscle tissue. The examined samples of meat in natural state demonstrated a very "loose" structure – D_{min} amounted to about 30% and *W/B* ratio was 3.5. After salting and dehydratation this structure soon disappeared – D_{min} was reduced to near 1 – 2%, *W/B* ratio decreased to 1.0-1.5 and the meat was found to be in *rigor* state. The non-linear relationship between D_{min} and *W/B* can be described by the equation:

$$D_{min} = 5.424 - 9.386\,(\mathrm{W/B}) + 4.090\,(\mathrm{W/B})^2 \quad \text{and} \quad r = 0.952.$$

Table 2 contains the mean results of the following instrumentally tested, rheological parameters, determined by CASRA method, in relation to model dry cured hams: plasticity (*P*), elasticity (*E*), fluidity (*F*), deformation at the lowest strain (D_{min}) and deformation at destructing stress (D_{plast}), as well as the results of physico-chemical tests: *pH* value, ratio of water to protein content (*W/B* ratio) and fat content (*T*). Table 2 gives also the results of sensory evaluation of the hams in respect of intensity (*CI*) and consistency desirability (*CD*) and weight of the hams after curing (*M*).

The correlation between the rheological parameters and selected chemical and physico-chemical factors of the dry-cured hams was studied. The results of correlation analysis are presented in Table 3. It was found that the weight of hams was very significantly correlated with all the instrumental rheological parameters, that is with plasticity (r = –0.808***), elasticity (r = –0.788***), fluidity (r = 0.905***) and D_{min} (r = 0.932***). The above mentioned correlations indicate that, together with the increase of the ham weight, the elasticity (*E*), fluidity (*F*) and deformation at the lowest stress (D_{min}) were increasing and plasticity (*P*) was decreasing, so the hams with a lower weight were characterized by a more dense consistency in relation to the hams with a higher weight.

Table 2. Mean results of testing of dry-cured model hams

Plasticity (*P*) (x10^5 N m^{-2})	Elasticity (*E*) (x10^{-7} m^2 N^{-1})	Fluidity (*F*) (x10^{-8} m^2 N^{-1} s^{-1})	D_{min} (%)	D_{plast} (%)	Consistency intensity (*CI*) (c.u.)	Consistency desirability (*CD*) (c.u.)	*pH*	*W/B* ratio*	Fat content (*T*) (%)	Ham weight (*M*) (kg)
14.0	2.1	3.2	7.7	80.1	2.60	5.74	6.11	2.14	22.1	5.73
16.0	1.7	2.9	6.5	82.6	5.03	4.90	6.32	1.94	28.6	5.38
19.3	1.3	2.1	1.9	73.5	3.84	5.57	5.89	1.87	29.2	3.19
21.6	1.0	1.7	1.4	66.8	5.69	4.09	5.68	1.86	24.1	2.42
21.6	1.3	1.8	1.3	77.9	4.73	5.60	5.94	1.98	20.1	2.22
11.5	2.7	3.0	6.3	74.7	2.49	6.74	6.02	2.62	37.6	4.79
18.3	1.4	2.2	4.0	82.9	3.90	5.03	6.02	2.05	25.6	4.77
21.6	1.1	2.0	2.3	82.4	5.49	4.94	5.90	2.07	37.3	3.28
24.0	1.0	1.6	0.6	73.4	4.86	4.74	5.76	1.87	25.9	2.59
28.1	1.0	1.2	0.8	65.8	7.24	2.93	5.93	1.95	14.6	2.35
11.8	2.5	3.3	7.6	74.5	2.94	6.00	6.39	1.92	33.1	6.04
15.9	2.1	2.4	3.1	76.5	4.31	6.06	6.08	2.27	24.8	4.32
27.3	0.9	1.6	1.3	77.8	6.67	3.93	5.84	1.90	27.1	3.62
18.3	1.8	2.1	3.7	79.6	4.23	5.40	5.99	2.06	18.1	4.45

W/B ratio* - water content (W) to total protein content (B).

Similarly, *pH* value revealed a highly significant correlation in the case of plasticity (*P*) and elasticity (*E*), and a very significant correlation in respect to fluidity (*F*) and deformation at the lowest stress (D_{min}) with the rheological parameters of CASRA method. Also, *pH* was very highly significantly correlated with the weight of hams after curing (r = 0.837***).

Table 3. Correlation between rheological and chosen physico-chemical parameters of tested hams

Studied traits	Plasticity (*P*) (x 10^5 N m^{-2})	Elasticity (*E*) (x 10^{-7} m^2 N^{-1})	Fluidity (*F*) (x 10^{-8} m^2 $N^{-1}s^{-1}$)	D_{min} (%)	Consistency Intensity (*CI*) (c.u.)	Ham weight (*M*) (kg)
Ham weight (*M*) (kg)	–0.808 ***	0.788 ***	0.905 ***	0.932 ***	–0.675 **	–
W/B ratio	–0.577*	0. 701 **	0.477 ns	0.445 ns	–0.522 ns	0.383 ns
pH	–0.700**	0.721 **	0.803***	0.832 ***	–0.491 ns	0.837***
Fat content (T)	–0.452ns	0.349 ns	0.476 ns	0.384 ns	–0.382 ns	0.334 ns

Significance level: ns not significant, * p<0.05, ** p<0.,01, *** p<0.001.

W/B ratio was significantly correlated with plasticity (*P*) (r = –0.577*) and significantly with elasticity (*E*) (r = 0.701**). No correlations between fat content and all the remaining parameters tested were found (Tab. 3).

Relationship between texture rheological parameters and sensory evaluation of texture is shown in Table 4. It was found that there is a strong relationship among the majority of rheological parameters of texture and the consistency intensity evaluated by sensory method. The comparison of the results of sensory evaluation of the studied hams and the results of instrumental analyses showed their very significant, highly significant, or at least significant correlation. The correlation coefficients between plasticity (*P*) and consistency intensity (*CI*) and consistency desirability (*CD*) were equal, respectively, to: r = 0.903*** and r = –0.863***, between elasticity (*E*) and *CI* and *CD* parameters, respectively: r = –0.820*** and r = 0.814*** and between fluidity (*F*) and *CI* and *CD* parameters, respectively: r = –0.828 *** and r = 0.754**. Also, the deformation at the lowest strain (D_{min}) was correlated with the consistency intensity (*CI*) and consistency desirability (*CD*). The correlation coefficients amounted, respectively, to: r = –0.736** and r = 0.598*. The deformation at the destructive stress (D_{plast}) was not correlated with the intensity and desirability of consistency (Tab. 4).

Table 4. Correlation between texture rheological parameters and sensory evaluation of consistency of dry-cured hams

Studied traits	Consistency intensity (CI) (c.u.)	Consistency desirability (CD) (c.u.)
Plasticity (P) (x 10^5 N m^{-2})	0.903***	−0.863***
Elasticity (E) ([x 10^{-7} m^2 N^{-1})	−0.820***	0.814***
Fluidity (F) (x 10^{-8} m^2 N^{-1} s^{-1})	−0.828***	0.754**
D_{min} (%)	−0.736**	0.598*
D_{plast} (%)	−0.329 ^{ns}	0.404 ^{ns}

Significance level: ^{ns} - not significant, * - p<0.05, ** - p<0.01, *** - p<0.001.

The relationships between the rheological parameters or consistency intensity and the weight of hams and pH value may be described with a good accuracy using the following linear equations:

$$P \text{ (x } 10^5 \text{ N m}^{-2}) = 63.745 - 5.448 \text{ pH} - 2.853 \text{ M} \qquad (r = 0.830^{***}),$$

$$E \text{ (x } 10^{-7} \text{ m}^2 \text{ N}^{-1}) = -4.282 + 0.788 \text{ pH} + 0.271 \text{ M} \qquad (r = 0.823^{***}),$$

$$F \text{ (x } 10^{-8} \text{ m}^2 \text{ N}^{-1} \text{ s}^{-1}) = -5.615 + 1.078 \text{ pH} + 0.336 \text{ M} \qquad (r = 0.911^{***}),$$

$$D_{min} \text{ (\%)} = -21.550 + 3.297 \text{ pH} + 1.323 \text{ M} \qquad (r = 0.929^{***}),$$

$$CI \text{ (c.u.)} = -2.575 + 1.822 \text{ pH} - 0.957 \text{ M} \qquad (r = 0.689^{*}).$$

It results from the above that the weight of the hams after curing and pH value of the hams turned out to be the main factors affecting the consistency of dry-cured hams.

We should also pay attention to the fact of the strongest relationship of the rheological parameters: fluidity (F) and deformation at the lowest stress (D_{min}), characterizing the degree of transformation of a substance with a loose structure, specific to raw meat, into a substance with a concentrated structure, with the parameters characterizing the physico-chemical state of the hams: pH and weight of the hams.

CONCLUSIONS

1. The deformation at minimal stress (D_{min}) was found to be used as *rigor* indicator of the rheological status of dry-cured ham muscles in various stages of the processing procedure.
2. Ham weight (*M*) and *pH* had the highest effect on consistency intensity evaluated by sensory analysis and texture rheological parameters, especially on the deformation at the lowest stress (D_{min}) and fluidity (*F*), characterizing the transformation of substances with a loose structure into those with a concentrated structure.
3. A strong relationship was noted between the sensory evaluation of dry-cured ham consistency and the rheological texture parameters analysed by CASRA method, i.e. plasticity (*P*); fluidity (*F*); elasticity (*E*) and D_{min} indicator.

REFERENCES

1. **Cierach M., Żywica R., Budny J.:** Changes of physical properties of meat during curing process (in Polish). Zesz. Probl. Nauk. Roln., 430, 13-18, 1996.
2. **Fox J.B. Jr:** Diffusion chloride, nitrite and nitrate in beef and pork. J. Food Sci., 45 (6), 177, 1980.
3. **Lautenschlager R.:** Diffusion of sodium chloride and sodium nitrite in raw meat model system. Proceedings of 41st ICoMST, 2, 507, 1995.
4. **Ockerman H.W., Kwiatek K.:** Effect of electrical stimulation and boning temperature on distribution and migration of curing ingredients (nitrite, salt, glucose) in pork tissue. J. Food Sci., 50 (4), 844, 1985.
5. **Palmia F., Bolla E.:** Salt diffusion in dry cured ham. Proceedings of 37th ICoMST, 2, 918-919, 1991.
6. **Paterson B.C., Parrish F.C., Jr, Stromer M.H.:** Effect of salt and pyrophosphate on physical and chemical properties of beef muscle. J. Food Sci., 53 (5), 1258, 1988.
7. **Tyszkiewicz S., Kłossowska B.:** Penetration of salt and nitrite in the pilot process of curing and dehydration of dry cured ham. Proceedings of 44th ICoMST, Vol. II, C-76, 976-977, 1998.
8. **Tyszkiewicz S., Olkiewicz M., Daun D.:** Multi-parametric method for the rheological evaluation of meat and other solid foods. Journal of Texture Study, 28,337-348,1997.
9. **Tyszkiewicz S., Olkiewicz M.:** Meat consistency changes caused by dehydratation and salting in the production of raw ripening ham. Proceedings of 44th ICoMST, Vol. II, C-75, 974-975, 1998.

WYBRANE CZYNNIKI KSZTAŁTUJĄCE KONSYSTENCJĘ SZYNEK SUROWO DOJRZEWAJĄCYCH

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Streszczenie. Przedmiotem podjętych badań była próba określenia roli niektórych czynników wpływających na kształtowanie konsystencji szynek surowo dojrzewających w procesie przetwórczym. Stwierdzono, że masa szynek po peklowaniu (*M*) i *pH* mięsa okazały się być głównymi czynnikami różnicującymi konsystencję szynek surowo dojrzewających. Istotnym czynnikiem okazał się również stopień odwodnienia szynek charakteryzowany indeksem *W/B*, ale był on zróżnicowany w zależności od masy szynek, czyli miał charakter wtórny. Nie stwierdzono wpływu zawartości tłuszczu na wyniki badań konsystencji. Z pośród parametrów reologicznych mięsa określanych metodą instrumentalną CASRA najściślejszą zależność od *pH* i masy szynek po peklowaniu wykazały: odkształcenie przy najmniejszym naprężeniu (D_{min}) i płynność (*F*) charakteryzujące przemianę ciała o luźnej strukturze w ciało o strukturze skoncentrowanej. Wykazano dobrą zgodność parametrów konsystencji szynek surowo dojrzewających badanych instrumentalnie metodą CASRA z wynikami sensorycznej oceny konsystencji. Na ocenę sensoryczną najsilniej wpływała plastyczność (*P*), a w dalszej kolejności elastyczność (*E*) i płynność (*F*) szynek.

Słowa kluczowe: mięso wieprzowe, szynki surowo-dojrzewające, konsystencja, charakterystyka reologiczna