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Texture and Quality Parameters of Slovenian Dry-Cured Ham Kraški pršut According to Mass and Salt Levels

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Summary

The aim of the present study is to investigate the effects of fresh ham mass and the amount of salt added during processing on the technological, sensorial and physicochemical qualities of Slovenian dry-cured ham (Kraški pršut) produced under Protected Geographical Indication. A total of 84 fresh ham samples (pH=5.6–5.9 measured 24 h *post mortem*) originating from pigs (Landrace × Large white) were divided into subgroups according to mass (light, 9.5–10.5 kg *vs.* heavy, 11.5–13.0 kg) and salt addition during production (normal *vs.* low salt). These formed four subgroups for the analyses: light and normally salted, light and low salt, heavy and normally salted, and heavy and low salt. After the salting period, the NaCl concentration in the normally salted muscles was 3.8 to 4.0 %, and in the less salted muscles 2.8 to 3.0 %. During the processing of the dry-cured ham (at the beginning, after salting, and after resting), the *semimembranosus* (SM) and *biceps femoris* (BF) muscles were analysed for water activity (a_w), pH, salt content, moisture, total minerals, non-protein nitrogen, and total nitrogen. One year after the processing, the instrumental (stress relaxation and texture profile) and sensory qualities were also analysed. After the salting and resting periods, the pH of the samples was significantly decreased in comparison with the fresh ham, although after ageing period this increased again, to reach nearly the initial values (pH=5.59–5.74). At the same time, the a_w of both muscles in all experimental groups dropped below 0.90. The total mass losses varied between the groups (34.75–36.63 %), with the samples of heavy and low salt ham showing the greatest mass loss. The light and low salt SM muscles showed slightly higher proteolysis indices (non-protein nitrogen/total nitrogen ratio) after one year, which indicated a trend towards more rapid proteolysis as compared to the normally salted hams. Generally, the softer texture of the BF muscle compared to the SM muscle was confirmed by stress relaxation test, texture profile analysis, and the related chemical parameters (higher moisture content, a_w, and proteolysis index). As for the effect of salt on the texture parameters, the SM muscle from the light and low salt ham samples showed greater softness (stress relaxation test), and lower hardness, cohesiveness, gumminess, chewiness and resilience (texture profile analysis) than those from the normally salted hams; the BF muscle showed similar trends to those of the SM muscle. In contrast, the heavy ham samples showed higher values of almost all of the instrumental texture parameters in the low salt hams as compared to the normally salted hams. Significant differences in the majority of the ham sensory traits were mainly due to the differences between the SM and BF muscles.

Key words: dry-cured ham, Kraški pršut, salt, fresh ham, chemical parameters, texture parameters, sensory quality parameters

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Introduction

Slovenia is a Mediterranean country known for the sunshine of the Alps and the Adriatic Sea, which creates optimal conditions for the production of the dry-cured ham called Kraški pršut. This is a traditional Slovenian dry-cured meat product that has Protected Geographical Indication (PGI) at the national level (*1*). Kraški pršut is highly appreciated by Slovenian consumers and foreign visitors. It belongs to the semi-open type of ham, which is more exposed to dehydration (total mass loss approx. 35 %), and the production technology and its appearance are similar to the well-known Italian Parma ham (prosciutto di Parma) (*2*). Kraški pršut has a typical composition and high nutritional value, as well as specific sensory and other quality parameters. However, these have not been systematically analysed and defined according to the scientific methods to date, as has been done for similar protected products, such as for some of the most important dry-cured ham products in Italy (prosciutto di Parma, prosciutto di San Daniele), France (jambon de Bayonne), and Spain (jamon Serrano, jamon Iberico) (*3–18*).

Kraški pršut is produced only with sea salt (without smoking and other additives), and for the development of its complete flavour and texture, it undergoes a long maturation period of 12 to 24 months, or more. Proteolysis is one of the most important and relevant factors for the final product quality. It has an important influence on the texture and taste, and indirectly on the aroma development (*19*). Texture is the sensory and functional manifestation of the structural, mechanical and surface properties of a food that is detected through the senses of vision, hearing and touch (*20*).

At present, there is a general tendency to reduce the salt content in dry-cured ham, in agreement with the Global Strategy on Diet, Physical Activity and Health of the World Health Organisation. Indeed, the World Health Organisation indicates that salt is one of the main factors for the development of hypertension, cardiovascular disease, and cancer (*21*). Nowadays, consumer demand for low salt consumption in general has increased, and less salted dry-cured meat products offer an important possibility for the reduction of salt intake in nutrition. However, this implies increases in the incidence of some textural problems in dried meat products (*22*). Excessive softness and pastiness are two of the main texture problems, and these have been associated with high proteolysis (*4,23, 24*). Proteolysis is, in turn, affected by the pH of the raw meat (*5,25–27*), salt, moisture and protein contents (*27*), and the processing temperature (*28,29*).

The stress relaxation test (SRT) and the texture profile analysis (TPA) are instrumental methods that are commonly used for the evaluation of the texture of dry-cured ham (*5,22*). The SRT gives information about the physical properties of dry-cured ham that can be correlated with the sensory characteristics, such as hardness, softness and brittleness (*24,30*). Relationships between the TPA and the moisture content have been studied in dry-cured loin (*31*) and dry-cured ham (*27,32*).

However, limited data are available related to the texture and other quality parameters of the Slovenian dry-cured ham Kraški pršut (*2,33–38*), with no data concerning the influence of different ham masses and salt levels through the production process, and of muscle proteolysis on the sensory and other physicochemical quality parameters. The aim of the present study is thus to determine these effects on the texture and other quality parameters of two muscles of this Slovenian dry-cured ham: *semimembranosus* (SM) and *biceps femoris* (BF).

Materials and Methods

Experimental design

A complete four-way factorial design was applied to fresh ham samples of different mass and salt contents in the dry-cured ham muscles at four stages of processing: (*i*) at the beginning, the fresh ham stage; (*ii*) after salting (17 days); (*iii*) after the resting period (95 days); and (*iv*) after the ageing period (370 days). The ham samples were weighed after the shaping (stage *i*) and after each further stage (stages *ii–iv*). The pH was measured in the *gluteus medius* muscle 24 h *post-mortem* to select ham samples with normal muscle quality), and in the SM and BF muscles (stages *i–iv*), using a combined glass electrode attached to a portable pH meter (Testo 230, Testo AG, Lenzkirch, Germany). At all stages (*i–iv*), further measurements were done for: a_w, moisture, non-protein nitrogen (NPN), total nitrogen (TN), intramuscular fat and total minerals. Additionally, instrumental texture parameters (as SRT and TPA) and the sensory properties of the dry-cured ham were analysed at the end of the ageing period (stage *iv*).

Ham selection

A total of 84 fresh ham samples (pH=5.6–5.9 measured 24 h *post mortem*) from Landrace × Large white farm pigs were divided into four subgroups according to mass as light (L; 9.5–10.5 kg) and heavy (H; 11.5–13.0 kg), and the addition of salt (NaCl) during processing as normally salted (NS) and low salt (LS). The four subgroups formed were thus: light and normally salted (L/NS), light and low salt (L/LS), heavy and normally salted (H/NS), and heavy and low salt (H/LS).

The first physicochemical analysis was performed on 12 fresh ham samples. The remaining 72 ham samples were processed according to the regulations of the dry-cured ham technology for Kraški pršut. At each production stage (*ii–iv*), 24 ham samples from the four experimental subgroups (N=6 per subgroup) were analysed (Table 1).

Ham processing and sampling

As indicated, the ham samples were processed according to the consortium rules for Kraški pršut. Briefly, the samples (≥9 kg) with a subcutaneous fat thickness ≥10 mm were trimmed into the prescribed shape (stage *i*), dry-salted with sea salt (3.8–4.0 % per kg of ham for normally salted and 2.8–3.0 % per kg of ham for low salt hams), and kept for 2–3 weeks at a temperature of 2–4 °C. One week after the first salting, the excess salt was removed, the ham samples were weighed, and fresh salt was added. After this salting period (stage *ii*), the samples were left to 'rest' in a controlled environment (temperature 4–6 °C, and relative humidity 70–85 %) for 10 weeks

Table 1. Analyses of the ham samples at the four production stages

Processing stage	Analysis of SM and BF muscles			
	Physical	Chemical	Sensory	Instrumental texture
(*i*) fresh ham	pH, a_w	moisture, non-protein nitrogen, total nitrogen, intramuscular fat, salt, total minerals	–	–
(*ii*) salting	pH, a_w	moisture, non-protein nitrogen, total nitrogen, salt, total minerals	–	–
(*iii*) resting	pH, a_w	moisture, non-protein nitrogen, total nitrogen, salt, total minerals	–	–
(*iv*) ageing (end product)	pH, a_w	moisture, non-protein nitrogen, total nitrogen, intramuscular fat, salt, total minerals	colour, intermuscular fat, texture and flavour profile	SRT, TPA

SM=*semimembranosus*; BF=*biceps femoris*; SRT=stress relaxation test; TPA=texture profile analysis

(stage *iii*). The ageing period (stage *iv*) started with the washing of the hams with lukewarm water. The washed samples were kept in a drying room (temperature ≥20 °C, and relative humidity 65–85 %) for at least 6 days, and then moved to the ageing section (temperature ≥15 °C, and relative humidity 75–90 %) until the required mass loss was reached (22–25 %). The open surface of the ham was then coated with a mixture of pork leaf fat, salt and pepper to allow ageing but prevent further desiccation. After 12 months of processing, the dry ham samples were weighed and deboned, and the SM and BF muscles were taken for further analyses (Fig. 1).

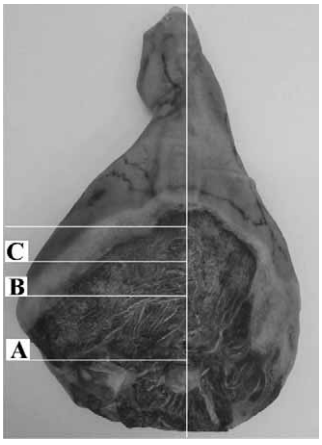

Fig. 1. Photograph illustrating a schematic view for the sampling of a dry-cured ham: (A) sample used for physical and chemical analysis (length of the sample 4.5 cm), (B) sample used for sensory analysis (length of the sample 2.5 cm), and (C) sample used for instrumental measurement of texture (length of the sample 2.5 cm)

Physical and chemical analyses

The pH of the dry-cured ham samples was measured directly in the SM and BF muscles using a micro pH meter (Testo 230, Testo AG). The water activity (a_w) was measured at (25±0.3) °C with a CX-1 water activity system (v. 1/3.88; Campbell Scientific Ltd., Shepshed, UK). Total nitrogen (TN) was determined according to the Kjeldahl method (*39*) (Büchi Kjeldahl System: digestion unit K-424, scrubber B-414, and destilation unit B-324). Non-protein nitrogen (NPN) content was determined by precipitation of the protein with trichloroacetic acid followed by determination of nitrogen in the extract according to the Kjeldahl method (*39*). The proteolysis index was calculated as the ratio between the NPN and the TN (expressed in percentage) (*40,41*). Salt content was analysed according to the Volhard method (*42*). Moisture content was determined by drying at (103±2) °C to constant mass (*43*). The intramuscular fat content was determined according to AOAC International method (*44*), with petroleum ether as solvent. Minerals were determined by burning and combustion (4–5 h) at 525–550 °C (*45*).

Instrumental texture analysis

The SRT and TPA were performed in three repetitions for the SM muscle and two repetitions for the BF muscle, using a TA.XT *plus* Texture Analyser (Stable Micro Systems Ltd., Godalming, Surrey, UK) with a 50-kg load cell and a 50-mm diameter compression plate. The SM and BF muscles were accurately carved out with a scalpel into parallelepipeds (dimensions 20×20×15 mm), covered with plastic polyethylene wrap to avoid drying, and conditioned at 4 °C for 2 h before analysis.

For the SRT, the samples were compressed to 25 % of their original length, perpendicular to the fibre bundle direction, at a crosshead speed of 1 mm/s. The relaxation curves obtained for each specimen were normalised, *i.e.* the force decay $Y(t)$ was calculated as follows:

$$Y(t) = \frac{F_0 - F_t}{F_0} \qquad /1/$$

where F_0 (measured in N) is the initial force, and F_t (N) is the force recorded at relaxation time t (s). The force decay at 2 s (Y_2) and 90 s (Y_{90}) was calculated (*22*).

For TPA, the samples were compressed twice to 50 % of their original length, perpendicular to the fibre bundle direction, at a crosshead speed of 1 mm/s. The force *vs.* time curves were recorded on Instron universal testing machine (modified from Pons and Fiszman (*46*)) and the following parameters were calculated, as illustrated in Fig. 2: hardness, adhesiveness, springiness, resilience, gumminess, chewiness and cohesiveness.

Sensory analyses

The sensory analyses were performed on two dry--cured ham slices (of 1.5 mm thickness) by a six-member

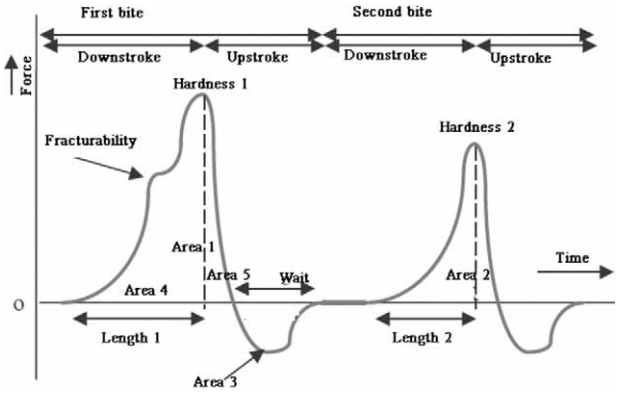

Fig. 2. Generalized TPA curve: adhesiveness=area 3; springiness=length 2/length 1; resilience=area 5/area 4; cohesiveness=area 2/area 1; gumminess=cohesiveness×hardness 1; chewiness=gumminess×length 2/length 1=hardness 1×cohesiveness×springiness

expert panel in two sessions (7 days apart). The first slice was used to evaluate the flavour and the second to evaluate the texture. The assessors were selected and generically trained following the procedures of the ISO standard 11035 (*47*). A total of twelve different sensory descriptors were evaluated in each of the two muscles (SM and BF). All of the properties were evaluated using 1 to 7 point scales, according to increasing intensity of sensation. The traits evaluated were: colour intensity (individual BF and SM red colour, bright/dark), fat colour (whiteness); intermuscular fat (quantity), 'marbling' (quantity of intramuscular fat), adhesiveness (degree to which the surface of the muscle sample adheres to the palate when compressing with the tongue), hardness (initial force necessary to compress the muscle sample between the molars), pastiness (mouth-coating sensation, similar to that produced by flour-water paste during mastication), crumbliness (ease with which the sample separates into smaller particles), moisture absorption (saliva absorption during mastication; for the saliva excreted, if the sample is very dry, there is a high intensity of saliva absorption perceived), smell (typical smell of mature dried meat, with no off smells, *i.e.* rancid, fungi), taste (typical taste of mature dried meat, with no off tastes, *i.e.* bitter taste), and saltiness (basic taste perceived due to salt).

Statistical analysis

The experimental data were evaluated statistically using the SAS/STAT programme (*48*). The basic statistical parameters were calculated using the MEANS procedure. The data were tested for normal distributions and analysed according to the general linear model. Statistical model 1 for the analysis of the initial mass of the samples included the main effects of a group (L/LS, L/NS, H/LS, or H/NS) and production stage (*i–iv*). Statistical model 2 for the analysis of the physicochemical properties and chemical composition of the ham samples included the main effects of a group, muscle (SM, BF) and production stage, as well as the interactions of group× muscle (BF×L/LS, BF×L/NS, BF×H/LS, BF×H/NS, SM× L/LS, SM×L/NS, SM×H/LS, SM×H/NS). Finally, statistical model 3 for the analysis of the textural parameters and sensory properties included the main effects of the group and muscle, as well as an interaction group×muscle. For the sensory analysis, the effects of session (1–2) and assessor (1–6) were not significant, and these were excluded from the model. The mean values for the experimental groups were obtained using the Duncan's test, and they were compared at the 5 % probability level.

Results and Discussion

Mass loss of the ham during processing

As shown in Table 2, there were significant ($p<0.0001$) effects of group and production stage on the ham mass. The average total mass loss (TML) as a result of dehydration and trimming during the processing was between 34.75 and 36.63 %. The lowest TML was found in normally salted heavy ham (H/NS). A small difference (0.76 %) for both normally salted and low salt subgroups of light ham (L/NS, L/LS) was observed. The low salt heavy ham samples (H/LS) showed higher TML compared to the normally salted (H/NS) ones, while those that were normally salted (H/NS) showed even lower TML compared to the L/NS ham; the TML of the H/LS ham was the greatest (36.63 %).

The TML of Kraški pršut is approx. 5 to 7 % greater than of the Italian Parma and San Daniele dried hams (*10,41*), although it is similar to that of the Spanish Se-

Table 2. Effects of experimental group and production stage on the mass and total mass loss of ham samples (N=12, Duncan's test, α=0.05)

Production stage	*m*(ham)/kg				p-value (group)
	L/LS	L/NS	H/LS	H/NS	
(*i*) fresh ham (without added salt)	(10.15±0.3)aB	(10.15±0.3)aB	(11.60±0.4)aA	(11.60±0.4)aA	<0.0001
(*ii*) salting	(9.90±0.1)bB	(9.99±0.1)bB	(11.17±0.4)bA	(11.18±0.3)bA	<0.0001
(*iii*) resting	(8.11±0.2)cB	(8.18±0.2)cB	(9.21±0.3)cA	(9.23±0.2)cA	<0.0001
(*iv*) ageing	(6.68±0.3)dC	(6.62±0.2)dC	(7.26±0.2)dB	(7.46±0.1)dA	<0.0001
p-value (stage)	<0.0001	<0.0001	<0.0001	<0.0001	
total mass loss/%	35.33	36.09	36.63	34.75	

Data are mean values±standard deviation; N=number of observations between group; L/LS=light, low salt; L/NS=light, normally salted; H/LS=heavy, low salt; H/NS=heavy, normally salted; mean values with different lower case letters (a, b, c, d) within each column are significantly different ($p<0.05$; differences between the production stages); mean values with different capital letters (A, B, C) within each row differ significantly ($p<0.05$; differences between groups)

ranno ham (*27*) and the French Bayonne dried ham (*49*). There is no data in the literature related to the effects of different fresh ham mass and salt content on the mass loss during processing.

Physical and chemical parameters of dry-cured hams

Generally, during the salting and resting periods, the pH values of both SM and BF muscles significantly decreased, although after the ageing period these increased slightly, to reach nearly the initial values (5.59–5.74) (Table 3). These data are in agreement with previous investigations of Kraški pršut (*38*) and Spanish dry-cured ham (*26*).

Regarding the end-product, after ageing period, in both of the muscles from all four subgroups the ham a_w dropped below 0.90 ($p<0.0001$). After ageing, both the SM and BF muscles of the L/LS ham showed significantly higher a_w than the same muscles of the L/NS ham (BF 0.896 *vs*. 0.886; SM 0.890 *vs*. 0.878). In contrast, the SM and BF muscles of the H/LS ham had lower a_w

Table 3. Effects of experimental group and production stage on the physical and chemical parameters of the two muscles in the dry-cured ham (N=12, Duncan's test, α=0.05)

Parameter	Production stage	Experimental group (interaction of groups and muscles)				p-value (group×muscle)
		BF×L/LS	BF×L/NS	BF×H/LS	BF×H/NS	
pH	fresh ham	(5.72±0.3)ab	(5.72±0.3)a	(5.81±0.3)a	(5.81±0.3)a	0.3708
	salting	(5.81±0.1)aA	(5.78±0.2)aAB	(5.73±0.1)aAB	(5.75±0.1)B	<0.0001
	resting	(5.55±0.1)bB	(5.57±0.1)bB	(5.57±0.1)abB	(5.65±0.1)A	<0.0001
	ageing	(5.61±0.2)bCD	(5.74±0.1)aA	(5.68±0.1)aABC	(5.70±0.1)ABC	0.0008
	p-value (stage)	0.0135	0.0097	0.0074	0.2042	
a_w	fresh ham	(1.000±0.000)a	(1.000±0.000)a	(1.000±0.000)a	(1.000±0.000)a	–
	salting	(0.999±0.004)aA	(0.999±0.003)aA	(1.000±0.006)aA	(0.999±0.008)aA	<0.0001
	resting	(0.964±0.006)bB	(0.963±0.006)bB	(0.968±0.006)bAB	(0.971±0.006)bA	<0.0001
	ageing	(0.896±0.005)cA	(0.886±0.012)cBC	(0.891±0.007)cAB	(0.894±0.004)cAB	<0.0001
	p-value (stage)	<0.0001	<0.0001	<0.0001	<0.0001	
proteolysis index/%	fresh ham	(11.4±0.5)cB	(11.4±0.5)dB	(11.5±1.0)cB	(11.5±1.0)cB	<0.0001
	salting	(11.7±0.6)cAB	(12.2±0.7)cA	(11.4±0.6)cB	(12.0±1.0)cAB	0.0005
	resting	(14.8±0.8)bA	(13.8±1.4)bB	(14.9±0.7)bA	(14.6±0.8)bA	<0.0001
	ageing	(22.9±1.7)aAB	(22.0±1.0)aB	(23.2±1.1)aA	(22.8±1.6a)AB	<0.0001
	p-value (stage)	<0.0001	<0.0001	<0.0001	<0.0001	
Parameter	Production stage	Experimental group (interaction of groups and muscles)				p-value (group×muscle)
		SM×L/LS	SM×L/NS	SM×H/LS	SM×H/NS	
pH	fresh ham	(5.63±0.3)a	(5.63±0.3)a	(5.73±0.3)a	(5.73±0.3)a	0.3708
	salting	(5.57±0.0)abC	(5.49±0.1)bC	(5.54±0.1)bC	(5.55±0.0)bC	<0.0001
	resting	(5.46±0.1)bCD	(5.46±0.1)bCD	(5.39±0.1)cD	(5.52±0.2)bBC	<0.0001
	ageing	(5.59±0.2)abD	(5.73±0.1)aAB	(5.65±0.1)abBCD	(5.72±0.1)aAB	0.0008
	p-value (stage)	0.1436	<0.0001	<0.0001	0.0036	
a_w	fresh ham	(1.000±0.000)a	(1.000±0.000)a	(1.000±0.000)a	(1.000±0.000)a	–
	salting	(0.939±0.011)bC	(0.933±0.011)bC	(0.949±0.007)bB	(0.934±0.009)bC	<0.0001
	resting	(0.941±0.010)bC	(0.926±0.012)bE	(0.936±0.007)cCD	(0.932±0.007)bED	<0.0001
	ageing	(0.890±0.008)cAB	(0.878±0.011)cD	(0.883±0.009)dCD	(0.891±0.009)cAB	<0.0001
	p-value (stage)	<0.0001	<0.0001	<0.0001	<0.0001	
proteolysis index/%	fresh ham	(12.5±0.4)cA	(12.5±0.4)bA	(12.3±0.7)cA	(12.3±0.7)dA	<0.0001
	salting	(11.5±0.6)dB	(11.9±0.3)cAB	(10.7±1.2)dB	(11.8±0.5)cAB	0.0005
	resting	(13.6±0.8)bB	(12.5±0.7)bC	(13.2±1.1)bB	(13.6±0.7)bB	<0.0001
	ageing	(15.0±0.9)aCD	(14.1±0.5)aD	(14.4±0.9a)CD	(15.2±0.9)aC	<0.0001
	p-value (stage)	<0.0001	<0.0001	<0.0001	<0.0001	

Data are mean values±standard deviation; N=number of observations in experimental group; BF=*biceps femoris*; SM=*semimembranosus*; L/LS=light, low salt; L/NS=light, normally salted; H/LS=heavy, low salt; H/NS=heavy, normally salted; mean values with different lower case letters (a, b, c, d) within each column are significantly different ($p<0.05$; differences between the production stages); mean values with different capital letters (A, B, C, D, E) within each row differ significantly ($p<0.05$; differences between the interactions of the groups and muscles)

than those of the H/NS ham (BF 0.891 *vs*. 0.894; SM 0.883 *vs*. 0.891). The BF muscle from the light ham had similar a_w to the heavy ham. After ageing, the effect of ham mass on a_w was significant in the SM muscle: the L/LS ham had higher a_w than the H/LS ham, and the opposite, the L/NS ham had lower a_w than the H/NS ham.

The initial proteolysis index in the SM muscle of the fresh ham was significantly greater than in the BF muscle (about 1.0 %), although there was no significant difference in the proteolysis index between the light and heavy ham samples (Table 3). During the dry-cured ham production, the proteolysis index in both of the muscles from all four of the experimental subgroups significantly increased ($p<0.0001$). The SM muscle is an external muscle that is directly exposed to salt, and therefore its water content dropped rapidly. Consequently, the proteolytic activity of the BF muscle with higher water content was greater (*23,50*). An ultimately greater proteolysis index was seen in the BF muscle (about 23) compared to the SM muscle (about 15). Toldrá (*51*) reported that proteolytic enzymes are still relatively active at the usual a_w values at the end of the production process (0.85–0.90), despite the fact that low a_w reduces the activity of cathepsins and other muscle enzymes, such as aminopeptidases.

The salt content at the end of the processing was lower in the SM muscle than in the BF muscle, corresponding to its lower water content, as can be seen in Table 4. Similar results have also been reported in other studies (*27,37,49,52,53*). High salt content of the SM muscle during the first stages and low water content in the later stages are considered to be the main reasons for the lower proteolysis in the SM muscle, in comparison with the BF muscle (the proteolysis index in the SM muscle was very low and significantly ($p<0.05$) different from that in the BF muscle).

The SM and BF muscles of fresh ham contained 73.0 to 74.1 % water, 21.8 to 22.8 % protein, and 1.14 to 1.17 % minerals, and they were not influenced across the experimental subgroups. The intramuscular fat content in BF muscles was slightly higher (5.00–4.08 %) than in SM muscles (2.02–3.27 %) (Table 4). During three production stages (*ii–iv*), the water content was significantly reduced ($p<0.0001$) in all of the experimental subgroups, in the SM muscle from 45.2 to 49.1 %, and in the BF muscle from 57.2 to 59.3 %. The total reduction of water content was greater in the L/LS ham. The BF muscle of the aged ham contained 10 to 13 % more water ($p<0.05$) than the SM muscle.

The protein content of the dry-cured ham increased significantly ($p<0.05$) in all of the experimental subgroups, mainly in the manufacturing stages of resting and ageing. This reached 40.3 to 43.3 % in the SM muscle, and 28.7 to 30.1 % in the BF muscle.

The fat content in the mature ham samples was significantly reduced only in the BF muscle of the L/NS ham. This trend was unexpected and it remains difficult to explain. In the SM muscle of all experimental subgroups, the fat content increased by about 1.5 %, although this increase was significant ($p<0.05$) only in the light ham.

The total minerals of the fresh ham were around 1.15 %, and there were no significant differences between the subgroups. After the salting and resting periods, the salt content significantly increased ($p<0.05$) from 4.98 to 5.70 % in the SM muscle, and from 3.4 to 3.8 % in the BF muscle. After the resting period, the salt content in the BF muscle was essentially unchanged ($p>0.05$) among the corresponding subgroups. The salt content in the SM muscle (6.57 %) and BF muscle (8.55 %) of the light ham subgroup was significantly higher in the L/NS samples than in the L/LS samples (SM 5.58 %; BF 7.16 %).

Texture analysis of dry-cured ham

The SRT parameters of the SM and BF muscles of Kraški pršut are shown in Table 5. The water content can explain the main texture differences in the dry samples (*32,49*). At higher water content, as in the BF muscles in the present study, the meat quality and process traits can affect the texture. A harder texture (high F_0, low Y_{90}) is expected in the SM muscle due to the lower water content. The hardness (F_0) of the BF muscle was not affected by the fresh ham mass and salt content ($p>0.05$), while the SM muscle of the L/LS ham showed significantly lower hardness ($p<0.05$) than the normally salted ham. This finding is consistent with the hypothesis that lower salt content in the ham promotes proteolysis, which results in a softer texture of the final product. A similar salt effect on the hardness has been reported in studies of different Spanish dry-cured ham samples (*11*). García-Rey *et al.* (*26*) related low pH measured 24 h *post mortem* in SM muscle with the softness of dry-cured ham as a result of higher proteolytic activity.

TPA showed that interaction among muscles, fresh ham mass and saltiness affected ($p<0.001$) all textural parameters of Kraški pršut with the exception of springiness and adhesiveness. The SM muscle generally showed greater hardness, gumminess and chewiness, but lower cohesiveness and resilience than the BF muscle.

Different salt content of the dry-cured ham did not affect the hardness and chewiness of the BF muscle, while the cohesiveness, gumminess and resilience of the L/NS ham were the highest ($p<0.05$). Also the lowest values ($p<0.05$) of cohesiveness and resilience in the BF muscle of the H/NS ham were observed. The outer SM muscle of the L/LS ham showed significantly lower values of hardness, cohesiveness, gumminess and resilience, with the highest values of these properties, however, observed in the subgroup of H/LS ham. The BF muscle (L/LS) had a higher content of fat and water (and a lower salt content), so it was softer and the proteolysis index was a little higher (Tables 3 and 4). Our data here are in accordance with the findings of Serra *et al.* (*32*), and Ruiz-Ramírez *et al*. (*54*), who applied TPA to dry-cured muscles with lower moisture content. The dry-cured ham with lower proteolysis at the surface is more prone to develop a harder surface (*i.e.* a crust) (*27*). Serra *et al.* (*55*) also reported the relationships of a_w and moisture with the TPA primary parameters of hardness, cohesiveness and springiness. García-Garrido *et al.* (*56*) reported that Serrano ham with lower salt levels (3 % salt per dry matter) showed a defectively soft texture, whereas pastiness was not affected.

Table 4. Effects of experimental group and production stage on the chemical composition of the two muscles in the dry-cured ham (N=12, Duncan's test, α=0.05)

w/(g/100 g)	Production stage	Experimental group (interaction of the groups and muscles)								p-value (group×muscle)
		BF×L/LS	BF×L/NS	BF×H/LS	BF×H/NS	SM×L/LS	SM×L/NS	SM×H/LS	SM×H/NS	
water	fresh ham	(73.0±1.0)a	(73.0±1.0)a	(73.3±2.5)a	(73.3±2.5)a	(74.1±0.8)a	(74.1±0.8)a	(74.1±1.6)a	(74.1±1.6)a	0.2055
	salting	(71.9±1.6)bB	(73.3±0.7)aA	(71.3±1.4)bB	(71.6±1.8)bB	(65.2±1.5)bD	(64.7±1.5)bDE	(66.3±1.2)bC	(63.9±1.3)bE	<0.0001
	resting	(67.3±1.4)cA	(64.8±3.6)bB	(67.9±1.1)cA	(67.9±1.3)cA	(59.4±1.6)cC	(57.1±2.0)cD	(61.0±2.5)cC	(60.8±1.1)cC	<0.0001
	ageing	(58.2±0.6)dAB	(57.2±1.3)cB	(58.0±1.4)dAB	(59.3±0.8)dA	(44.9±3.8)dD	(46.2±1.5)dD	(45.2±3.2)dD	(49.1±1.7)dC	<0.0001
	p-value (stage)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	
protein	fresh ham	(22.4±1.1)c	(22.4±1.1)c	(21.8±1.7)c	(21.8±1.7)c	(22.6±1.2)d	(22.6±1.2)d	(22.8±1.5)d	(22.8±1.5)d	0.2313
	salting	(22.6±1.5)cB	(23.0±0.9)cB	(22.3±0.6)cB	(22.3±1.4)bcB	(24.8±1.0)cA	(25.5±0.8)cA	(25.2±0.8)cA	(25.4±0.7)cA	<0.0001
	resting	(23.7±0.5)bCD	(24.6±2.5)bC	(24.0±1.0)bCD	(23.1±0.6)bD	(29.4±1.0)bB	(30.9±1.4)bA	(29.5±1.9)bB	(30.1±1.8)bAB	<0.0001
	ageing	(30.1±0.7)aC	(29.4±0.6)aCD	(29.4±0.8)aCD	(28.7±0.7)aD	(43.3±2.4)aA	(42.5±1.7)aA	(42.7±2.1)aA	(40.3±1.2)aB	<0.0001
	p-value (stage)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	
fat	fresh ham	(5.00±1.9)A	(5.00±1.9)aA	(4.08±2.1)AB	(4.08±2.1)AB	(2.02±0.7)bC	(2.02±0.7)bC	(3.27±1.9)BC	(3.27±1.9)bBC	<0.0001
	ageing	(3.60±1.4)BC	(3.28±0.6)bC	(3.62±1.2)BC	(4.45±0.8)A	(3.53±0.6)aBC	(3.49±0.3)aBC	(4.16±1.5)AB	(4.67±0.6)aA	0.0015
	p-value (stage)	0.0552	0.0024	0.2200	0.5427	<0.0001	<0.0001	0.1611	0.0119	
total minerals	fresh ham	(1.14±0.1)d	(1.14±0.1)d	(1.16±0.1)c	(1.16±0.1)c	(1.17±0.1)d	(1.17±0.1)c	(1.16±0.1)c	(1.16±0.1)d	0.9206
	salting	(1.62±0.1)cC	(1.79±0.1)cC	(1.56±0.1)cC	(1.42±0.1)cC	(7.61±1.0)aA	(7.76±0.5)abA	(6.64±0.7)bB	(7.86±0.5)aA	<0.0001
	resting	(4.86±0.5)bC	(4.61±0.5)bCD	(4.38±0.3)bD	(4.71±0.6)bCD	(6.50±0.3)cB	(7.41±0.6)bA	(6.72±0.3)bB	(7.19±0.3)cA	<0.0001
	ageing	(9.06±0.4)aB	(10.01±0.7)aA	(9.25±0.3)aB	(9.06±0.5)aB	(7.00±0.4)bE	(8.00±0.6)aC	(7.24±0.5)aDE	(7.43±0.4)bD	<0.0001
	p-value (stage)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	
salt	fresh ham	(0.00±0.0)d	(0.00±0.0)d	(0.00±0.0)d	(0.00±0.0)d	(0.00±0.0)c	(0.00±0.0)c	(0.00±0.0)d	(0.00±0.0)c	–
	salting	(0.62±0.1)cC	(0.41±0.1)cC	(0.54±0.2)cC	(0.29±0.1)cC	(5.66±1.0)aA	(5.81±0.5)bA	(4.90±0.4)cB	(5.87±0.4)bA	<0.0001
	resting	(3.80±0.4)bC	(3.50±0.4)bCD	(3.39±0.4)bD	(3.78±0.6)bC	(4.98±0.3)bB	(5.61±0.8)bA	(5.45±0.2)bA	(5.70±0.2)bA	<0.0001
	ageing	(7.16±0.6)aB	(8.55±0.6)aA	(7.25±0.4)aB	(7.03±0.6)aB	(5.58±0.3)aE	(6.57±0.5)aC	(5.83±0.4)aDE	(6.18±0.5)aCD	<0.0001
	p-value (stage)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	

Data are mean values±standard deviation; N=number of observations in experimental group; BF=*biceps femoris*; SM=*semimembranosus*; L/LS=light, low salt; L/NS=light, normally salted; H/LS=heavy, low salt; H/NS=heavy, normally salted; mean values with different lower case letters (a, b, c, d) within each column are significantly different ($p<0.05$; differences between the production stages); mean values with different capital letters (A, B, C, D, E) within each row differ significantly ($p<0.05$; differences between interaction of the groups and muscles)

Table 5. Effects of experimental group (ham mass, salt content, and muscle type) on the textural properties of the dry-cured hams, as measured by SRT and TPA (N=12, Duncan's test, α=0.05)

Parameter	Experimental group (interaction of the groups and muscles)				p-value (group×muscle)
	BF×L/LS	BF×L/NS	BF×H/LS	BF×H/NS	
SRT					
F_0/N	(11±3)C	(13±6)C	(11±4)C	(12±6)C	<0.0001
Y_{90}	(0.669±0.03)A	(0.670±0.08)A	(0.679±0.03)A	(0.674±0.03)A	0.0004
TPA					
hardness/N	(72±12)C	(82±11)C	(77±23)C	(62±19)C	<0.0001
cohesiveness	(0.59±0.04)AB	(0.63±0.03)A	(0.58±0.04)ABC	(0.56±0.07)BCD	<0.0001
gumminess/N	(42±8)D	(51±8)C	(46±16)D	(35±13)D	<0.0001
springiness	1±0	1±0	1±0	1±0	0.6978
chewiness/N	(42±8)D	(52±9)CD	(46±16)D	(35±13)D	<0.0001
resilience	(0.21±0.02)B	(0.22±0.02)A	(0.21±0.03)B	(0.19±0.03)C	<0.0001
adhesiveness/(N·s)	0.97±0.23	0.96±0.25	0.82±0.32	0.98±0.30	0.1027
Parameter	Experimental group (interaction of the groups and muscles)				p-value (group×muscle)
	SM×L/LS	SM×L/NS	SM×H/LS	SM×H/NS	
SRT					
F_0/N	(56±24)B	(95±35)A	(64±24)B	(58±20)B	<0.0001
Y90	(0.632±0.09)AB	(0.593±0.01)B	(0.615±0.04)B	(0.629±0.09)B	0.0004
TPA					
hardness/N	(157±53)B	(200±60)A	(205±48)A	(163±38)B	<0.0001
cohesiveness	(0.43±0.12)E	(0.51±0.13)D	(0.53±0.03)BCD	(0.53±0.04)CD	<0.0001
gumminess/N	(68±31)C	(98±34)AB	(110±29)A	(86±19)B	<0.0001
springiness	1.00±0.06	1.00±0.13	1±0	1±0	0.6978
chewiness/N	(68±31)C	(97±34)AB	(110±29)A	(86±19)B	<0.0001
resilience	(0.15±0.01)E	(0.17±0.01)D	(0.18±0.01)D	(0.17±0.01)D	<0.0001
adhesiveness/(N·s)	0.95±0.37	0.80±0.36	0.73±0.38	1.00±0.39	0.1027

Data are mean values±standard deviation.; SRT=stress relaxation test; TPA=texture profile analysis; N=number of observations in experimental group; BF=*biceps femoris*; SM=*semimembranosus*; L/LS=light, low salt; L/NS=light, normally salted; H/LS=heavy, low salt; H/NS=heavy, normally salted; mean values with different capital letters (A, B, C, D, E) within each row differ significantly ($p<0.05$)

Sensory properties of dry-cured ham

The amount of intermuscular fat was significantly higher in the heavier ham samples. Marbling of the SM muscle in all of the ham samples was significantly higher ($p<0.05$) than in the BF muscle (Table 6). Surprisingly, the marbling of both of these muscles in both of the subgroups of the light ham samples was lower than in the heavy ham subgroups, with some of these differences close to the significance level ($p<0.05$). The colour intensity of the SM muscle was scored higher than that of the BF muscle in all of these samples of dry-cured ham, but the differences between the two muscles were not large, which is good in terms of the uniformity of the colour crosssection of the ham. Here, a score of 4 points was considered optimal rubin red colour, with scores of 4.5 or more indicating greater (to excess) expression of colour (dark red), and those of 3.5 or less indicating lesser (insufficient) expression of colour (pale, light).

Different fresh ham masses and salt content did not affect crumbliness, smell or taste of the final ham, which was not expected. The differences between the ham mass and salt content are probably insufficient under our experimental conditions to reflect differences in these sensory properties.

Hardness and moisture absorption were significantly higher in the SM muscle than in the BF muscle, irrespective of the fresh ham mass and the salt content of the dried ham, which are not considered to affect either of these textural properties (Table 6). This indicates a problem of the nonuniformity of the texture of Kraški pršut, despite the use of more modern technology phases of resting and ageing. Changes in the hardness during Bayonne ham ageing have been attributed to both water content and the state of the protein (*49*). Buscailhon *et al.* (*3*) reported hardness increase in French dry-cured ham when comparing ham samples of 179 and 273 days of processing. Also, Guerrero *et al.* (*5*) and Arnau *et al.* (*25*) reported higher sensorial hardness of low pH ham than of high pH ham. In the present study, the pH values of the fresh ham and the finished product were equal between the subgroups, so that an impact of various muscle qualities on the texture of the ham was not expected.

Table 6. Sensory parameters (properties) for the two muscles of one-year aged Kraški pršut with the two masses and salt levels (N=12, Duncan's test, α=0.05)

Parameter (score scales)	Experimental group (interaction of the groups and muscles)				p-value (group×muscle)
	BF×L/LS	BF×L/NS	BF×H/LS	BF×H/NS	
colour intensity (1-4-7)	(4.0±0.4)D	(4.2±0.7)CD	(3.9±0.6)D	(3.6±0.4)E	<0.0001
marbling (1-7)	(2.3±0.7)C	(2.5±0.5)C	(2.6±0.7)BC	(2.9±0.6)B	<0.0001
hardness (1-7)	(3.7±1.2)B	(3.8±0.9)B	(3.6±0.8)B	(3.8±1.3)B	<0.0001
pastiness (1-7)	(4.2±1.0)AB	(3.9±1.0)BC	(4.6±0.9)A	(4.0±1.2)B	<0.0001
crumbliness (1-7)	5.2±0.8	5.1±0.5	5.4±0.4	5.3±0.9	0.1573
moisture absorption (1-7)	(2.9±0.6)B	(3.0±0.4)B	(3.0±0.5)B	(3.1±0.6)B	<0.0001
adhesiveness (1-7)	(3.6±0.7)B	(4.1±0.7)A	(3.6±0.8)B	(3.7±0.6)AB	<0.0001
smell (1-7)	5.4±0.4	5.4±0.5	5.5±0.4	5.4±0.5	0.3146
taste (1-7)	5.4±0.3	5.3±0.4	5.3±0.3	5.4±0.3	0.3778
saltiness (1-4-7)	(4.7±0.4)B	(5.0±0.4)A	(4.8±0.4)AB	(4.8±0.3)AB	<0.0001
whole slice					
fat colour (1-7)	(5.7±0.3)A	(5.5±0.3)B	(5.6±0.4)B	(5.8±0.3)A	<0.0001
intermuscular fat (1-7)	(2.2±0.5)C	(2.5±0.6)B	(2.9±1.0)A	(2.8±0.5)A	<0.0001
Parameter (score scales)	Experimental group (interaction of the groups and muscles)				p-value (group×muscle)
	SM×L/LS	SM×L/NS	SM×H/LS	SM×H/NS	
colour intensity (1-4-7)	(4.6±0.3)AB	(4.8±0.8)A	(4.4±0.5)BC	(4.3±0.5)BC	<0.0001
marbling (1-7)	(2.4±0.3)C	(2.6±0.7)BC	(2.4±0.6)C	(3.3±0.8)A	<0.0001
hardness (1-7)	(4.7±0.5)A	(5.1±0.4)A	(4.9±0.4)A	(5.0±0.5)A	<0.0001
pastiness (1-7)	(3.4±0.8)CD	(3.2±0.7)D	(3.4±0.7)CD	(3.2±0.6)D	<0.0001
crumbliness (1-7)	5.1±0.6	5.0±0.6	5.0±0.6	5.1±0.6	0.1573
moisture absorption (1-7)	(3.6±0.7)A	(3.9±0.7)A	(3.9±0.6)A	(3.6±0.8)A	<0.0001
adhesiveness (1-7)	(3.0±0.6)C	(3.2±0.7)C	(2.9±0.6)C	(3.0±0.9)C	<0.0001
smell (1-7)	5.4±0.4	5.4±0.4	5.4±0.4	5.6±0.3	0.3146
taste (1-7)	5.3±0.3	5.3±0.4	5.4±0.4	5.4±0.3	0.3778
saltiness (1-4-7)	(4.3±0.3)D	(4.5±0.4)C	(4.4±0.3)CD	(4.4±0.4)CD	<0.0001
whole slice					
fat colour (1-7)					<0.0001
intermuscular fat (1-7)					<0.0001

Data are mean values±standard deviation; N=number of observations in experimental group; BF=*biceps femoris*; SM=*semimembranosus*; L/LS=light, low salt; L/NS=light, normally salted; H/LS=heavy, low salt; H/NS=heavy, normally salted; mean values with different capital letters (A, B, C, D, E) within each row differ significantly ($p<0.05$; differences between interaction of the groups and muscles)

Pastiness was significantly lower in the SM muscle than in the BF muscle, and higher in the BF muscle of the heavy compared to the light ham, although salinity did not affect this property (Table 6). Pastiness of the SM muscle was not affected by either fresh ham mass or salinity.

The adhesiveness of the SM muscle was significantly lower ($p<0.05$) than of the BF muscle. The less salty ham showed decreased adhesiveness of the BF muscle, while the mass of the fresh ham had no effect on this textural property. The SM muscle adhesiveness was not influenced ($p>0.05$) by different masses and saltiness of the ham samples (Table 6). The lower salt content and higher water content of the ham might have increased the enzyme activity (*3*,*57*) and proteolysis, which would increase the pastiness and adhesiveness in these ham samples (*4*, *23*,*27*).

The sensory saltiness of the SM muscle was generally significantly lower than that of the BF muscle (Table 6). Significantly lower sensory saltiness was detected in both of these muscles in the L/LS ham, while in the heavy ham these differences in saltiness were not detected. These findings are consistent with the data for the chemically analysed salt content of the dry-cured ham. All of the samples of Kraški pršut were sensorially too salty (estimates higher than the optimal limit of 4.0), and mainly the BF muscle, which contained more salt and water in comparison with the SM muscle. This phenomenon of more salt in the interior BF muscle of the ham (7.0–8.5 %) compared with the exterior SM muscle (5.6–6.6 %) is known and is associated with greater internal diffusion of salt in the muscle, as these contain more water, and thus this is consistent with other studies (*27*,*49*,*54*,*55*). The amount of salt, and hence the sensory saltiness of Kraški

pršut, is still too high compared to some other types of ham, such as prosciutto di Parma (BF muscle, 4.0–5.5 %) (*10,15*) and jambon de Bayonne (SM muscle, 4.9 %; BF muscle, 5.6 %) (*16*).

Increased saltiness of Kraški pršut in comparison with other Mediterranean types of dry-cured ham is due to the increased dehydration and TML, total mass loss is 35 %, aprox. 5 to 7 % greater than of Italian ham (prosciutto di Parma, prosciutto di San Daniele) (*10,41*), although similar to that of Spanish Serrano ham (*27*) and French ham (jambon de Bayonne) (*49*).

Conclusions

To follow modern trends of reducing salt in the human diet, we investigated here the effects of a reduction in the salt used in the processing of traditional Slovenian dry-cured ham known as Kraški pršut. In the *semimembranosus* and *biceps femoris* muscles of these light and normally salted dry-cured ham samples, there is indeed a significantly higher salt content, as compared to the low salt ham. Therefore, the light and low salt *semimembranosus* muscles have a slightly higher proteolysis index, due to accelerated proteolysis, and lower hardness, gumminess, chewiness, cohesiveness, initial force (stress relaxation test), and resilience (texture profile analysis), as compared to the normally salted hams. Generally, harder texture of the *semimembranosus* muscles compared to the *biceps femoris* muscles was confirmed by the instrumental measurements of texture, sensory evaluations and chemical determinations of moisture content. To summarise the effects of different salt levels (normally salted and low salt) on the sensory quality parameters of Kraški pršut, it is possible to conclude that light and low salt ham samples tend to be less hard, less dry, less adhesive, more crumbly and more pasty, as compared to normally salted ham.

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