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Research Article

Factors Influencing the Prevalence of PSE Like Destructured Zones in Top Side Muscles from Fresh Hams – A Growing Industrial Problem

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Abstract

PSE like zones in topside ham muscles are a problem for the cooked ham industry. In this study two experiments were carries out. In two different trials [1] the effects of carcass pH and temperature decline curves and [2] different ham weights on the incidence of destructured PSE-like zones in the deeper regions of fresh hams were studied. Experiment 1 showed that low preslaughter stress leading to a slower pH decline and preferably a higher ultimate pH are important to reduce the incidence of PSE like zones in ham muscles. A faster carcass chilling will help to improve pork quality. The core temperature of the hams will chill, however, at the slowest rate in the carcass. In experiment two it was shown that conditions to form PSE zones inside the core of the ham is significantly higher in heavier hams compared to smaller hams. Growing carcass weights will lead to larger ham weights and continue to increase the incidence of PSE likes zones in the core of the hams.

Keywords: Pork quality; Destructured meat; PSE; Carcass chilling; Colour; Topside ham muscle

Introduction

Pork quality is influenced by the interaction between pig genetics, the entire system of live animal production, processing and chilling of the carcass [3], and finally storage and handling of the meat and derived case-ready and further processed products [1,4]. Pork quality characteristics like drip loss and colour are determined by the interaction between the rate and extent of postmortem pH fall and temperature in the muscle. High postmortem muscle temperature in combination with a low pH can cause denaturation of muscle proteins and a decrease in the electrostatic repulsion between myofilaments. The subsequent increase in light scattering properties and the extent of lateral shrinkage of the myofibrils provokes the meat to become Pale, Soft, and Exudative [2,5]. PSE-like zones of destructured meat in deep regions of fresh hams, mainly top side muscles (M. semimembranosus and M. adductor) represent a serious economic problem for the cooked ham industry [6]. These destructured zones will result in a lower yield and cohesiveness of the finished cooked product, which becomes unsuitable for mechanical high speed slicing [7-9]. The incidence of PSE like zones in hams still appears to increase across the entire pork industry. Increasing carcass weights and more muscular and well conformed hams may have slowed down the temperature decline in the deeper regions of a ham. The higher core temperatures in combination with lower post mortem pH values may locally cause PSE conditions.

The influence of different pig processing conditions and carcass chilling levels in combination with rate of pH fall on general pork quality characteristics like drip loss and colour has been shown in a number of studies [6,10,11]. Vautier et al. [12] studied the prediction level of meat quality characteristics on “PSE-like zones” in pig hams and concluded that the ultimate pH seems to be a reliable predictor of the defect. Several studies have shown that an increase in the chilling rate of the ham will reduce the incidence of destructed zones within a ham [3,13] developed a standardized method to study the pH and temperature decline curves of carcasses in a commercial pig processing plant in relation to drip loss and color of loin samples.

The objective of this study was to review the effects of carcass pH and temperature decline curves and different ham weights on the incidence of destructured PSE-like zones in the deeper regions of fresh hams.

Material and Methods

Two different and separate experiments were carried out at the same commercial pig processing plant on different slaughter days. This commercial slaughterhouse processes around 450 pigs per hour using a CO_2 stunning system, with 90-92 % CO_2 at the bottom of the pit, and a cycle of 220 seconds. Pre-slaughter treatment of the pigs was optimal without use of electrical prods in the stunning area and low noise and stress levels. Pigs were bled and exsanguinated within 45 sec after stunning. Slaughterhouse had a rapid chilling/cooling system, where carcasses enter a freeze chiller at 45 minutes postmortem. They remain in the chiller for 1 hour and 45 minutes with an effective air temperature of about –12°C around the carcasses. After the chiller the carcasses are stored overnight in the cooling area at 3°C. In the first trial we determined the relationship between postmortem temperature and pH decline curves and the occurrence of destructured meat in random pig carcasses from different pig suppliers. In a second experiment hams were selected into different weight groups, according to their AutoFOM carcass information, to determine the effect on the occurrence of destructured meat in the topside muscles of these hams.

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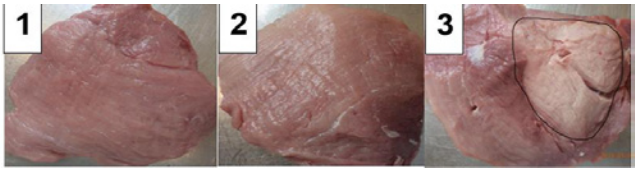

Figure 1: Visual destructured meat classes (1 = Normal, 2 = Potential, 3 = Destructured) defined in topside muscle from the ham.

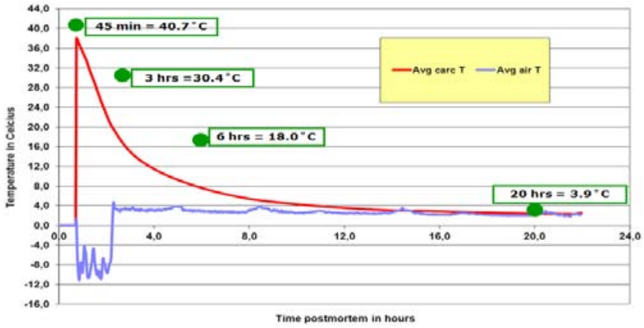

Figure 2: Temperature decline curve of the loin (red line), ham (green dots), and the average air temperature around the carcass (blue line) from time of exsanguination until the cutting of the carcasses after overnight storage.

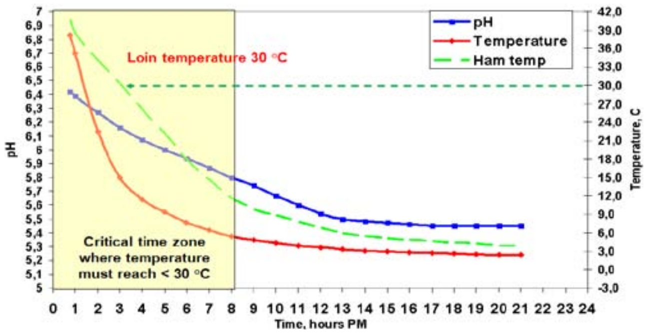

Figure 3: The pH (loin = blue line) and temperature profiles of loin (red line) and ham (green line) in randomly selected pig carcasses at a slaughterhouse from time at exsanguination until cutting of the carcasses after overnight storage.

Experiment 1

Relationship between postmortem pH and carcass temperature decline and the occurrence of PSE like zones in topside muscles.

A total of 175 carcasses were randomly selected on one processing day from 6 different pig suppliers. Hot carcass weight was collected for each of the selected carcasses. The pH at 45 minutes after slaughter was measured in the loin (Musculus longissimus dorsi) of each carcass at the height of the 3rd and 4th rib. Temperature probes (Model Scientific Multi-Use, Temprecord International, New Zealand) were inserted in loin muscles of 12 carcasses around 40 min after stunning at the height of the 10th rib. Six temperature probes were attached to carcasses (around the ham) to measure the cooling air temperature around the carcass during the chilling/cooling process. The temperature loggers were set to measure every 2 minutes. Loin pH measurements were carried out at 3 and 6 hours in the cooling room. Core temperatures in the ham were measured manually with a hand-held thermometer (Testo 925, Sensortype K, Netherlands) at 45 minutes, 3, 6, and 24 hours after slaughter.

The day after slaughter one loin per carcass was collected for measurements of ultimate pH, and Minolta L^*, a^*, and b^* colour values. A boneless loin sample of more than 100 gram was taken from the blade end of the loin, which was weighed in and stored in a case ready meat tray that contained a meat juice absorbing layer. The loin samples were weighed back after 48 hours storage at 4°C for the determination of the drip loss percentage. Hams from all selected carcasses were collected and deboned, after which the top sides were visually categorized in three different quality classes (1. Normal, 2. Potential/slight destructuring, and 3. Destructured zone within the topside (see Figure 1).

All statistical analyses were done in SAS 9.4. The response variables were tested for normality using the Shapiro-Wilk test at an alpha of 0.05 [14]. Non-normal variables were transformed to approach normality if needed. Subsequently, the Tukey test was used in ANOVA analyses to check for differences among groups (i.e., suppliers and PSE category) at an alpha of 0.05 [15]. The models for evaluating differences among PSE types included ham category as covariable to account for differences in PSE type related to the latter.

Experiment 2

Relationship between ham weight, gender and PSE like zones in hams.

A total of 350 carcasses were collected from 19 different suppliers within 7 different ham weight / gender combinations (see Table 1). The left hams from each selected carcass were deboned and the top side muscles were visually categorized in three different quality classes (see Figure 1).

All deboned topsides were measured for ultimate pH. Furthermore, the Minolta colour L^* value was measured on the location where a PSE like zone appears (in the centre of the ham).

All statistical analyses were done in SAS 9.4. The response variables were tested for normality using the Shapiro-Wilk test at an alpha of 0.05 [14]. Non-normal variables were transformed to approach normality if needed. Subsequently, the Tukey test was used in ANOVA analyses to check for differences among groups (i.e., suppliers and PSE category) at an alpha of 0.05 [15]. The models for evaluating differences among PSE types included ham category as co-variable to account for differences in PSE type related to the latter.

Results and Discussion

Experiment 1

The results from the temperature decline measurements of the loin muscle and air temperature around the carcass are shown in Figure 2. Temperature decline curves of the loin were good and relatively fast when compared to 4 different slaughterhouses measured by [3] in a similar way. The ham core temperature, however, cool at a significantly slower rate than the loin.

The pH decline was measured in the loin as shown in Figure 3. The pH decline of the hams was not measured in this case, but will have followed a similar pattern. Overall the rate of pH fall was modest when compare to similar measurements in 4 other pig processing plants measured by Kurt et al. [3]. The low pre-slaughter stress levels at this slaughterhouse resulted in a lower initial muscle temperature and slower pH decline. Nevertheless, since the temperature decline in ham muscles is significantly slower, there still may be the opportunity to get a combination of high muscle temperature and low muscle pH conditions in some of the hams.

The results from the carcass weights and different meat quality measurements from pigs carcasses of different farms are presented in Table 2.

The average carcass weight from was 96 kg, which is higher than the average carcass weights that ranged from 91,7 to 94,8 kgs at four different slaughterhouses by Kurt, et al [3] measured more than 10 years ago. The trend of increasing carcass weights will continue and further reduce carcass chilling decline rates, especially at the core of the hams. Kurt, et al [3] measured 4 different slaughterhouses (A, B, C and D). The temperature decline curves from our experiment were most comparable with slaughterhouse B, which had a blast chilling for 2 hours before storing carcasses at 3°C. The preslaughter stress level determined by postmortem pH decline was similar. Compared to slaughterhouse B the meat quality measurements were excellent in this trial with a drip loss of 1, 5% compared to 2, 1% slaughterhouse B. The carcass cooling curves were slower and preslaughter stress levels higher in slaughterhouses A, C and D, leading to respectively 2, 8%, 2, 9%, and 4, 5% drip loss of the loin samples. The low drip loss values in combination with the lower L^* values shows that the general meat quality at this pig processing plant was very good.

The results in Table 2, however, show that there is a difference in meat quality measured between pig carcasses coming from different farmers. Farm B had significantly the best meat quality with the lowest drip loss % measurements and a slow postmortem pH decline. The significantly highest drip loss % measurements were found with farm A loin samples, which also had a more rapid postmortem pH decline.

Table 3 shows the results from the visual score and assessment of the topside muscles into the three different quality categories. A total of 19 % of the topside muscles was classified as having a PSE-like destructured zone on the inside of the muscle. This is in the core of the ham that will stay warmer the longest. Even tough, the general meat quality was very good, it still resulted in 19 % destructured PSE like zones, and 30 % of the topside muscles that had the right colour but a loose muscle fiber structure.

The carcasses of the category 3 topside muscles had a faster postmortem pH decline in the loin muscle and a significantly lower ultimate pH compare to the category 1 muscles. These results are in agreement with Vautier et al. [12] and Minveille et al. [11] who found a significantly lower pH at 30 min postmortem and higher ultimate pH of the hams with severe PSE-like zones. They concluded, however that the PSE-like zones appear to be more related to ultimate pH values rather than rate of pH fall, with the risk of getting a severe PSE like zone is very low with ultimate pH values of the semimembranosus muscle 5,7 or higher. In our opinion the combination of a lower pH and high muscle temperature will cause protein denaturation conditions in the deep side of a ham muscle. A higher ultimate pH will not reach these conditions, but a slow postmortem pH decline in combination with a fast chilling rate will also prevent the formation of PSE like zones.

The colour and drip loss % after 48 hours storage of the loin samples also tended to be lighter and higher for the category 3. This shows that the circumstances that promote a worse meat quality in the loin (faster postmortem pH decline) also increase the possibility for the occurrence of a PSE like zone in the core of a ham. Hugenschmidt et al. [8] also found sign faster pH fall and higher ultimate pH in cooked hams with destructured PSE like zones. They concluded that a combination of high early p.m. temperature and/or low ultimate pH-values are important causative factors for destructured parts in cooked hams. They also conclude, however, that choosing hams with a high ultimate pH may not necessarily prevent cooked cured hams from developing the defect.

Experiment 2

To study the effect of ham size on occurrence of PSE like zones different ham categories were selected. The average carcass weight, ultimate pH and Minolta L^* value of the deboned topside muscles are shown in Table 4. The ham weight categories were related to the carcass weights with lighter carcasses having smaller hams. The hams from entire males were taken randomly. There was no weight selection within the hams from the entire males, but their average carcass weight was between the medium and heavy carcass / ham groups. The lighter hams tended to have slightly higher ultimate pH values and significantly lower L^* values compare to the topside muscles of

Table 1: Selection criteria for ham categories based on AutoFOM ham weight (in kg), fat thickness (in mm) and gender.

Category	Ham weight range (kg)	Ham fat thickness (mm)	Gender	Number
Light	1,0 – 11,0	15-Jan	Castrates/Gilt	50
Medium – C	11,0 – 12,7	1 – 16,5	Castrate	50
Medium – G	11,0 – 12,7	1 – 16,5	Gilt	50
Heavy – C	> 12,7	12,5 – 16,5	Castrate	50
Heavy – G	> 12,7	12,5 – 16,5	Gilt	50
Entire male	> 1,0	1 – 16,5	Entire male	100

Table 2: Mean and standard deviation of carcass weight, pH 45 minutes, 3, 6 and 24 hours postmortem, Minolta L^* value and drip loss % from all measured carcasses and individual farms (A, B, C, D,,F and G).

	Weight (kg)	pH 45	pH 3	pH 6	pH 24	pH 24 Ham	L*- value	Drip loss %
Total (n=175)	96,0 ± 5,6	6,43 ± 0,21	6,15 ± 0,27	5,92 ± 0,27	5,45 ± 0,10	5,64 ± 0,13	52,6 ± 3,7	1,5 ± 1,0
Farm A (n=31)	96,3 ± 4,4^{a,b}	6,37 ± 0,19 ^{b}	6,10 ± 0,32	5,88 ± 0,31	5,37 ± 0,08	5,62 ± 0,10^{b,c}	53,8 ± 3,5	1,9 ± 1,3 b
Farm B (n=27)	97,1 ± 8,2^{b}	6,50 ± 0,15^{a,b}	6,23 ± 0,18^{a,b}	6,07 ± 0,22^{a,b}	5,40 ± 0,09	5,61 ± 0,11^{b,c}	52,7 ± 3,1	1,1 ± 0,8 a
Farm C (n=45)	92,8 ± 5,1^{a}	6,41 ± 0,23 ^{a,b}	6,13 ± 0,25 ^{a,b}	5,89 ± 0,22	5,43 ± 0,08	5,58 ± 0,11^{c}	52,6 ± 4,1	1,5 ± 0,6^{a,b}
Farm D (n= 6)	96,7 ± 3,6^{a,b}	6,55 ± 0,19 ^{a,b}	6,23 ± 0,22^{a,b}	6,05 ± 0,34 ^{a,b,c}	5,55 ± 0,11	5,70 ± 0,11^{a,b}	52,0 ± 2,3	2,6 ± 2,5^{a,b}
Farm E (n=27)	96,9 ± 4,3^{b}	6,53 ± 0,20	6,30 ± 0,24	6,10 ± 0,25	5,50 ± 0,06	5,67 ± 0,10 ^{a,b}	51,9 ± 3,6	1,2 ± 0,5^{a,b}
Farm F (n=39)	98,0 ± 4,7 ^{b}	6,35 ± 0,21	6,04 ± 0,29	5,76 ± 0,22^{c}	5,52 ± 0,09 ^{a,b}	5,71 ± 0,15	52,1 ± 3,9	1,7 ± 1,2 ^{a,b}

Means with different superscripts (a,b,c) differ significantly between farms (P< 0,05).

Table 3: Classification of ham topside muscles into three different PSE like zone categories (Normal, Potential and Destructured) with their rate of pH fall and means (± standard deviation) of carcass weight, ultimate pH, Minolta L^* value and drip loss% of the corresponding loin sample.

	% PSE like zone category in ham topside muscle		
	Cat. 1 - Normal	**Cat. 2 - Potential**	**Cat. 3 - Destructured**
Percentage per category	51%	30%	19%
ΔpH loin (7,20 – pH 6 hrs)	1,20	1,29	1,45
pH 24 hours ham	5,69 ± 0,13^{a}	5,61± 0,10^{a,b}	5,56 ± 0,10^{b}
Carcass weight (kg)	95,5 ± 4,9	96,7 ± 6,6	96,3 ± 6,1
L* value loin sample	51,8 ± 3,6	53,1 ± 3,8	53,6 ± 3,6
Drip loss % loin sample	1,43 ± 1,02	1,48 ± 0,97	1,93 ± 0,97

Means with different superscripts (a,b) differ significantly between categories (P< 0,05).

the heavy ham categories. Even though, the hams from the entire males were heavier they had only slightly higher L^* values compared to the light hams, but a significantly lower ultimate pH. One reason for the relatively darker L^* values of the entire male topsides might be that the conformation of a boar ham is flatter than those of gilt hams, which will lead to a more rapid temperature decline inside the ham. No significant differences were seen in ultimate pH and L^*-values between castrate or gilt muscles from the medium and heavy weight ham categories.

The results from Table 5 show a clear effect of ham size on the occurrence of PSE like destructured zone in the topside muscle. Overall in the total data set there was a significant lower ultimate pH and higher L^* values in the category 3 destructured meat category, which confirms earlier research [12,9]. There was a tendency for slightly higher carcass weights.

The % of category 3 destructured top side muscles is the lowest in the light ham category (26%) compared to the higher percentages in the heavy ham categories (54 and 42%). An increased temperature early postmortem in the raw muscle was identified as an important predictor for the occurrence of destructurations in cooked cured hams [9]. The breakdown of glycogen to lactate after slaughter also leads to an increased postmortem muscle temperature. Early postmortem temperatures can reach over 41°C in the center of hams, which is directly involved in the development of the defect by protein denaturation.

Table 4: Means and standard deviation of carcass weight, ham ultimate pH and Minolta L^* colour values from the ham core side of the topside muscle from different ham weight (and gender) groups.

Ham category	Carcass weight (kg)	Ultimate pH	L*-value
Light	83,5 ± 4,2^{a}	5,60 ± 0,09^{a}	56,6 ± 2,9^{a}
Medium Castrate	94,9 ± 3,5^{b}	5,59 ± 0,10^{a}	58,4 ± 4,1^{a,b}
Medium Gilt	95,0 ± 3,3 ^{b}	5,57 ± 0,09^{a,b}	57,8 ± 3,7^{a,b}
Heavy Castrate	103,7 ± 3,3^{c}	5,55 ± 0,08^{a,b}	59,0 ± 3,7^{b}
Heavy Gilt	105,6 ± 3,5^{c}	5,55 ± 0,08^{a,b}	59,3 ± 3,8^{b}
Entire Males	101,4 ± 6,7^{b,c}	5,54 ± 0,08^{b}	57,1 ± 3,9^{a,b}

Means with different superscripts (a,b,c) differ significantly between ham categories (P< 0,05).

A slower internal cooling rate in the heavier sized hams eventually can create a combination of low pH (even when there is

Table 5: Percentage of topside muscles from different weight/gender ham categories into three different PSE like zone categories (normal, potential and destructured) and the corresponding means and standard deviation of carcass weight, ham ultimate pH and L* values measured on the core side of the topside muscle.

Ham type		% PSE like zone category in ham topside muscle		
		Cat. 1 - Normal	Cat. 2 - Potential	Cat. 3 - Destructured
Total	% Category	30%	34%	36%
	Ultimate pH	5,58 ± 0,09[a]	5,58 ± 0,09[a]	5,53 ± 0,08[b]
	L* value	55,3 ± 3,1[a]	57,1 ± 3,0[b]	60,8 ± 3,6[c]
	Carcass weight (kg)	97,1 ± 8,1	96,6 ± 9,3	99,9 ± 7,5
Light	% Category	20,0 %	54,0 %	26,0 %
	Ultimate pH	5,62 ± 0,10	5,60± 0,07	5,59 ± 0,10
	L* value	54,8 ± 2,3[a]	56,0± 2,2[b]	59,4 ± 2,6[c]
	Carcass weight (kg)	82,0 ± 5,4	83,4 ± 3,6	84,9 ± 4,2
Medium Gilt	% Category	28,6 %	38,8 %	32,7 %
	Ultimate pH	5,63 ± 0,10[a]	5,58 ± 0,08a,b	5,53 ± 0,06[b]
	L* value	53,8 ± 3,2[a]	56,4 ± 2,7b	63,0 ± 2,9[c]
	Carcass weight (kg)	93,3 ± 3,1	95,3 ± 2,7	96,3 ± 3,5
Heavy Castrate	% Category	22,0 %	24,0 %	54,0 %
	Ultimate pH	5,53 ± 0,06	5,56 ± 0,12	5,57 ± 0,11
	L* value	56,5 ± 1,9[a]	56,5 ± 3,0[a]	61,1 ± 3,2[b]
	Carcass weight (kg)	104,5 ± 3,0	103,4 ± 3,7	103,5 ± 3,2
Heavy Gilt	% Category	16,0 %	42,0 %	42,0 %
	Ultimate pH	5,59 ± 0,07	5,59 ± 0,08	5,57 ± 0,05
	L* value	54,9 ± 3,8[a]	58,2 ± 2,2[b]	62,2 ± 2,7[c]
	Carcass weight (kg)	105,6 ± 3,6	105,9 ± 3,8	105,2 ± 3,1
Entire Male	% Category	39,8 %	26,5 %	33,7 %
	Ultimate pH	5,56 ± 0,08	5,55 ± 0,07	5,50 ± 0,06
	L* value	55,7 ± 3,2[a]	56,7 ± 3,8[a,b]	59,0 ± 4,1[b]
	Carcass weight (kg)	99,5 ± 7,0	101,9 ± 6,6	103,1 ± 6,1

Means with different superscripts (a,b,c) differ significantly between "PSE like zone" categories (P< 0,05).

low preslaughter stress and a slow postmortem pH fall) and higher muscle temperature that will cause protein denaturation. Within the ham weight categories there is a significant difference in L* values with higher values for the destructured groups.

Vautier et al. [13] studied two industrial chilling rates that resulted in a 4°C difference in core ham temperature after 2 hours of chilling. The chilling rate had a strong influence on "PSE-like zones" defect frequency in the hams with 3 times more defects at the slower chilling rate. Scheeder et al. [16] did an elegant trial where the rapidly cooled down one ham of a set of carcasses by opening the core of the ham and exposing it to the chill temperatures. The opposite hams from the same carcasses were kept intact an therefore could not be chilled rapidly. The PSE like zone was completely absent from the rapidly chilled hams. Unfortunately, the opening of hams is not practically feasible in a modern commercial pig processing plant.

Conclusion and Practical Importance

The results in this paper confirm the importance of fast chilling for good pork quality. Low preslaughter stress leading to a slow pH decline and preferably a higher ultimate pH are important to reduce the incidence of PSE like zones in ham muscles. One of the major reasons that the issue of PSE like zones in topside muscle is still growing in the pork industry is the fact that the average carcass weight and thereby the size of the hams is still increasing in the market. The increased carcass weight with larger hams will, however, lead to higher internal muscle temperature conditions that, even with a slow pH fall, will create conditions for protein denaturation and destructured meat zones in the core ham muscles. Increasing ultimate pH and optimizing preslaughter stress levels will help to reduce this issue, but at the same time there has to be an increased chilling rate, especially at the core of the hams. New methods to increase the internal temperature decline will be important to solve the problem of PSE like zone in top side muscles.

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