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EFFECT OF CRYOGENIC-VENTILATION FREEZING ON THE QUALITY OF PORK DURING COLD STORAGE

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Key words: pork, fat, freezing methods, cold storage, physicochemical properties

The experiment was conducted on samples of the dorsal muscle (*musculus longissimus dorsi*), taken from 60 carcasses of fattening pigs with average live weight of *ca*. 110 kg, characterized by meat of normal quality. A total of 120 samples, each weighing *ca*. 500 g, were collected. They were divided into two groups and frozen according to a cryogenic-ventilation method (60 samples) and a ventilation method (60 samples).

After 2 weeks, 6, 12 and 18 months of storage at a temperature of 245 K (-28°C), the samples were taken for laboratory analyses. It was confirmed that freezing of portioned pork according to the cryogenic-ventilation method allows prevention of excessive raw material loss during chilling, storing and thawing. After two weeks of cold storage, pork frozen in the cryogenic-ventilation system was characterized by higher pH, a slightly darker colour and better water-holding capacity than pork frozen in the ventilation system. During a long period of cold storage its pH decreased, the colour became lighter and the water-holding capacity decreased to a lower extent than in the samples frozen according to the ventilation method. An analysis of hydrolytic and oxidative changes in intramuscular lipids confirms that pork may be stored up to 18 months regardless of the freezing method employed.

INTRODUCTION

The techniques of meat freezing based on liquefied gases offer new opportunities for technological applications. Studies on qualitative changes taking place in meat frozen in liquid nitrogen or carbon dioxide have already provided important information [Kondratowicz, 1991; Gardin, 1994; Van der Wal *et al.*, 1995; Facco *et al.*, 1998; Sobina, 1998]. It was found, among others, that pork frozen in liquid nitrogen, compared with pork frozen according to the ventilation method, was characterized by higher pH, a darker colour and higher water-holding capacity after thawing. The values of these indices were at an intermediate level in the case of meat frozen in liquid carbon dioxide. As the time of cold storage was extended, meat pH decreased, its colour became lighter and water-holding capacity decreased. These changes were more visible in meat frozen employing the ventilation method than in meat frozen in liquid nitrogen or carbon dioxide.

Professional literature on the topic gives scant information on two-stage (combined or mixed) meat chilling. This technology consists in combining very fast pre-freezing in liquid nitrogen or carbon dioxide, with proper freezing in the traditional ventilation system. According to Sebranek [1982], this would assure a fast rate of freezing (which seems important at the initial stage of the process) and good economic effects, because the ventilation method applied at the next stage is less expensive. A combined system would increase the freezing capacity and assure meat quality similar to the quality obtained in the case of a continuous cryogenic system. A few papers only [Rasmussen, 1977] deal with the use of liquid nitrogen or carbon dioxide in ventilation or fluidization tunnels. According to Remy [1985], technological solutions combining different freezing methods in a way allowing to benefit from each of them will be applied more often in the future.

The aim of the present studies was to determine the effect of cryogenic-ventilation freezing on the chemical composition and physicochemical properties of pork after various periods of storage at low temperatures. A comparative criterion was the traditional ventilation method of meat freezing in the air.

MATERIAL AND METHODS

The experiment was conducted on samples of the dorsal muscle (*musculus longissimus dorsi*), taken from 60 carcasses of fattening pigs resembling Polish Large White and Polish Landrace breeds, with average live weight of *ca*. 110 kg, characterized by meat of normal quality. Their slaughter and post-slaughter processing were carried out according to the relevant regulations applied in the meat industry. Before muscle preparation all carcasses were chilled at a temperature of *ca*. 275 K (2°C) for 18 h. The criterion of selecting experimental carcasses was the value of pH_{24} of the dorsal muscle. It was assumed that pH_{24} of normal meat varies from 5.6 to 5.9 (PSE and DFD meat was eliminated). Meat reaction was determined by means of a pH-meter (Radiometer) with a combined electrode GK 2311C. A total of 120 samples, each weighing *ca*. 500 g, were collected from the left and right sides. They were divided into two groups and frozen according to a cryogenic--ventilation method (60 samples) and a ventilation method (60 samples). All samples were stored for 2 weeks, 6, 12 and 18 months (n=15).

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Cryogenic-ventilation freezing. An experimental freezing line of the cryogenic-ventilation system consisted of a freezing tunnel with liquid carbon dioxide and a traditional ventilation tunnel. Meat samples with the initial temperature of *ca.* 275 K (2°C) were subjected to pre-freezing by spraying with liquid carbon dioxide in a freezing tunnel. The temperature in the tunnel during this process was *ca.* 203 K (-70°C). The time of sample pre-freezing to a temperature of *ca.* 270 K (-3°C) was 20 min. Then the samples were subjected to further freezing in a traditional ventilation tunnel, to a temperature of 245 K (-28°C) for 10 h. They were frozen unwrapped, on trays.

Traditional ventilation freezing. Traditional freezing of pork samples was conducted in a container ventilation tunnel, at a temperature of 245 K (-28°C) and air circulation rate of 3–4 m/s. The mean temperature of samples during freezing was equal to *ca.* 275 K (2°C). The process lasted for 18 h. All samples were frozen unwrapped, on trays. When the process of freezing was over, the temperature of samples was 245 K (-28°C).

Deep-frozen samples from both experimental groups were wrapped in thermocontractible polyethylene sheeting (PA/PE) and open-work cardboard boxes, which were then placed at a cold store at a temperature of *ca.* 245 K (-28°C) for the period of 2 weeks, 6, 12 and 18 months.

Methods of meat quality evaluation. After cold storage, meat samples were successively collected for laboratory analyses. The studies on the sample quality were preceded by their thawing: wrapped samples were placed in the air, at a temperature of 278 K (5°C). The thawing process was stopped when the temperature of *ca.* 273 K (0°C) was achieved. Then, to prepare meat for analyses, fatty and tendinous tissue was removed from the surface of the samples. All samples were minced in a mincer with 2 mm meshes. The following quantitative and qualitative analyses of meat and intramuscular fat were performed:

- total loss in sample weight in the processes of freezing, storing and thawing, determined by weighing samples at particular stages of freezing (exact to 0.1 g),
- the content of basic constituents (dry matter, crude protein, fat, crude ash), determined by conventional methods [Znaniecki, 1983],
- meat reaction (after thawing), determined on the basis of pH of meat water homogenates (the ratio between meat and distilled water was 1:1), using an electrode GK 2311C and a pH-meter (Radiometer),
- colour brightness, determined on the basis of the percentage of light reflection against the surface of minced meat samples, by means of a spectrometer "Specol" and remission attachment R45/0, at a wavelength of 560 nm (the white reference standard was a magnesium oxide plate),
- water-holding capacity, determined by the Grau-Hamm method [Znaniecki, 1983],
- parameters characterizing hydrolytic (acid value) and oxidative (peroxide value) of intramuscular fat [PN-60/A-86921].

The results of the experiment were analyzed statistically, calculating the basic statistical measures ($\bar{x}$, s). The significance of differences between groups was determined by an analysis of variance, using a computer program Statistica 5.0.

RESULTS AND DISCUSSION

The numerical values characterizing the quality of meat samples are presented in Tables 1 and 2. It is commonly known that natural weight loss observed in meat during freezing, storing and thawing affects its physicochemical properties dependent upon the water content [Kondratowicz *et al.*, 1999]. The data included in Table 1 show that the total loss in the pork weight after 2 weeks of storing was similar and amounted to 2.17% in the cryogenic-ventilation method and 2.16% in the ventilation method. After 6, 12 and 18 months of cold storage it was significantly higher in meat frozen in the ventilation system – 3.66% after 18 months, compared with 3.03% in the cryogenic-ventilation system. Similar tendencies were observed by Kondratowicz [2001] during horsemeat freezing according to a two-stage method. It follows that pork freezing in the cryogenic-ventilation system allows to reduce – to some extent – the weight loss during storing and thawing, compared with the commonly applied ventilation method. This solution should be employed when deep-frozen meat is designed for distribution, and not for further processing.

TABLE 1. Effect of the freezing method and time of storage on the weight losses and chemical composition of pork.

Specification	Statistical measure	Freezing method								Statistical significance of differences
		LCO_2 – Ow				Ow				
		Time of storage (months)								
		0.5 (A)	6 (B)	12 (C)	18 (D)	0.5 (E)	6 (F)	12 (G)	18 (H)	
Total weight losses, %	$\bar{x}$	2.17	2.54	3.05	3.03	2.16	3.12	3.62	3.66	A,E<C,D,F,G,H**
	s	0.47	0.54	0.88	0.51	0.55	0.75	0.69	0.50	B<F*, G,H** C,D<G,H*
Dry matter, %	$\bar{x}$	24.43	25.10	25.90	25.95	24.99	25.26	26.30	26.35	B,E,F<G,H*
	s	1.24	1.27	1.36	1.30	1.16	1.18	1.27	1.15	A<C,D,G,H**
Crude protein, %	$\bar{x}$	21.31	22.15	22.40	22.41	21.35	22.14	22.51	22.53	A,E<B,C,D,F,G,H**
	s	0.52	0.87	0.93	0.97	0.58	0.87	0.83	0.74	
Fat, %	$\bar{x}$	1.26	1.43	1.55	1.57	1.34	1.45	1.78	1.78	A<G,H*
	s	0.55	0.51	1.07	1.01	0.57	0.48	0.77	0.70	
Ash, %	$\bar{x}$	1.14	1.05	1.04	1.03	1.09	1.04	1.04	1.02	A>E*,B,C,D,F,G,H**
	s	0.05	0.07	0.05	0.07	0.05	0.06	0.05	0.03	E>C,D,F,G,H*

* – significant differences at the level of α=0.05; ** – significant differences at the level of α= 0.01; LCO_2 – Ow – cryogenic-ventilation freezing; Ow – freezing in a ventilation tunnel.

The statistical analysis made in the studies (Table 1) shows no differences in the dry matter content of samples frozen according to the cryogenic-ventilation and ventilation methods, after 2 weeks and 6 months of storage at low temperatures. Significant differences in its content were noted after 12 and 18 months, when meat frozen in the ventilation system was characterized by a higher dry matter content. This is connected with the weight loss observed in both freezing technologies. Changes in the protein content were similar to those concerning dry matter. Its level increased as the time of storage was extended from 6 to 18 months. As said before, the water loss was higher in samples stored for a longer time, so the dry matter content increased, leading to an apparent increase in the percentage of crude protein.

The data regarding the ash content seem to confirm the above correlation. A decrease in the content of this constituent during 18-month storage, expressed as a relative value, was probably caused by spontaneous drip during thawing, leading to higher loss in mineral components [Sobina & Kondratowicz, 2000].

Table 2 presents the results concerning selected functional properties of meat, *i.e.* pH, colour brightness and water-holding capacity, depending on the freezing method and time of cold storage. As regards the effect of freezing methods, lower pH (by 0.1), *i.e.* higher acidity, was noted in meat frozen according to the ventilation method. A distinct increase in acidity (a decrease in pH) was observed when the time of storage was extended from 2 weeks to 12 months. This indicates glycogenolysis and accumulation of acid metabolites [Van der Wal *et al.*, 1995]. At the same time the level of acidity suggests slightly better quality of pork chilled in the cryogenic-ventilation system. A further analysis of meat quality, based on the measurement of its colour brightness, did not show big differences in the percentage of light reflection between the samples frozen by the cryogenic-ventilation and ventilation methods. It was only found that pork frozen in the two-stage system was characterized by a darker colour after two weeks of storage. The water-holding capacity of meat was determined on the basis of the amount of pressed juice, measured as the difference between the infiltration area and sample squeeze on a filter. The freezing methods and time of cold storage affected the quality of pork. After 2 weeks, 6, 12 and 18 months of storage, the samples frozen in a ventilation tunnel showed a lower level of water absorption. As a consequence, their quality was poorer than the quality of pork frozen by the cryogenic-ventilation method.

It is a well known fact that hydrolytic and oxidative changes accompanying lipolysis shorten the shelf-life of stored meat [Sobina & Kondratowicz, 2000]. An evaluation of these changes, taking place in intramuscular fat, was made on the basis of acid and peroxide values.

The results included in Table 2 show that the freezing methods employed in the experiment had no significant effect on the rate of lipolysis. The acid value was gradually increasing over the whole period of cold storage. In pork frozen in a ventilation tunnel, the acid value of fat increased from 1.41 after 2 weeks of storage to 2.72 after 18 months, whereas in pork frozen in the cryogenic-ventilation system – from 1.39 to 2.57. A similar growing tendency was observed for the peroxide value. However, it should be emphasized that its level in intramuscular fat from meat chilled according to both methods did not exceed the relevant norms after 18-month storage (2.5 mL $Na_2S_2O_3$ per g of fat). The results of studies on the quality of fatty tissue frozen in liquid gases [Sobina & Kondratowicz, 2000; Kondratowicz & Podlejska, 2000], conducted so far, are not clear-cut. However, they concern fat obtained from carcasses of animal species other than pigs, whose susceptibility to rancidity is different. It was also found [Kondratowicz, 1991] that pork freezing in a ventilation tunnel, compared with cryogenic freezing in liquid nitrogen, accelerated fat rancidity, limiting the time of cold storage to 18 months.

CONCLUSIONS

The studies on the effect of two methods of pork freezing and time of cold storage (up to 18 months) on its quality allow to formulate the following conclusions:

1. It was found that freezing of portioned pork according to the cryogenic-ventilation method allows reduction of raw material loss during chilling, storing and thawing.

2. After two weeks of cold storage, pork frozen in the cryogenic-ventilation system was characterized by higher

TABLE 2. Effect of the freezing method and time of storage on the physicochemical properties of pork and chemical indices of fat.

Specification	Statistical measure	Freezing method								Statistical significance of differences
		LCO_2 – Ow				Ow				
		Time of storage (months)								
		0.5 (A)	6 (B)	12 (C)	18 (D)	0.5 (E)	6 (F)	12 (G)	18 (H)	
pH (after thawing)	$\bar{x}$	5.87	5.55	5.44	5.40	5.75	5.40	5.39	5.50	A>B,C,D,F,G,H**
	s	0.38	0.32	0.31	0.34	0.29	0.27	0.24	0.42	E>C,D,F,G,H**
Colour brightness, %	$\bar{x}$	13.27	14.67	14.60	14.70	14.40	14.33	14.93	15.40	A,G*,H**
	s	3.28	1.63	2.35	2.28	2.53	2.69	2.52	3.03	
Water-holding capacity, cm^2	$\bar{x}$	5.59	5.84	6.55	7.68	6.11	7.17	7.65	9.37	A,B<D,F,G,H**
	s	1.45	1.07	1.02	2.39	1.26	1.61	1.15	2.25	C<D,G,H** E<F*,D,G,H**
Acid value, mg KOH/g	$\bar{x}$	1.39	1.31	1.62	2.57	1.41	1.23	1.55	2.72	F<G*,C,D,H**
	s	0.36	0.18	0.34	2.27	0.33	0.29	0.36	2.33	B<C*,D,H**
Peroxide value, mL $Na_2S_2O_3$/g	$\bar{x}$	0.30	0.83	2.05	2.11	0.58	0.87	2.16	2.10	A<B,F*,C,D,G,H**
	s	1.16	0.44	0.71	0.75	0.30	0.38	0.84	0.35	B,E,F<C,D,G,H**

* – significant differences at the level of α=0.05; ** – significant differences at the level of α= 0.01; LCO_2 – Ow – cryogenic-ventilation freezing; Ow – freezing in a ventilation tunnel.

pH, a slightly darker colour and better water-holding capacity than the pork frozen in the ventilation system.

3. As the time of cold storage was extended from 2 weeks to 12 months, the pork acidity increased, the colour became lighter and the water-holding capacity decreased. These changes were less intense in the samples frozen according to the cryogenic-ventilation method.

4. An analysis of hydrolytic and oxidative changes in intramuscular lipids confirms that pork may be stored up to 18 months regardless of the freezing method employed.

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WPŁYW MROŻENIA KRIOGENICZNO-OWIEWOWEGO NA JAKOŚĆ MIĘSA WIEPRZOWEGO W CZASIE ZAMRAŻALNICZEGO PRZECHOWYWANIA

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Materiał do badań stanowiły próby mięśnia najdłuższego grzbietu 60 tusz, pochodzących od tuczników o masie przedubojowej około 110 kg, charakteryzujące się normalną jakością. Łącznie pobrano 120 prób mięsa, każda o masie około 500 g. Pobrany materiał podzielono na dwie grupy w celu zamrożenia metodą kriogeniczno-owiewową (60 prób) i owiewową (60 prób). Po 2 tygodniowym oraz 6, 12 i 18 miesięcznym okresie przechowywania mięsa w chłodni o temp. 245 K (-28°C) pobierano próby do analiz laboratoryjnych. Wykazano, że zastosowanie mrożenia porcjowanego mięsa wieprzowego metodą kriogeniczno-owiewową zapobiega nadmiernym stratom surowca mięsnego podczas mrożenia, przechowywania i rozmrażania w porównaniu do tradycyjnej metody owiewowej. Potwierdzono, że mięso mrożone systemem kriogeniczno-owiewowym po 0,5 miesięcznym okresie zamrażalniczego przechowywania charakteryzowało się wyższym pH, nieco ciemniejszą barwą oraz lepszą wodochłonnością w porównaniu do prób zamrożonych owiewowo. W czasie długotrwałego przechowywania zamrażalniczego obniżało się pH mięsa, pojaśniała barwa oraz obniżała się wodochłonność w mniejszym stopniu w próbach mrożonych metodą kriogeniczno-owiewową niż owiewową. Badania zmian hydrolitycznych i oksydacyjnych lipidów śródmięśniowych potwierdziły możliwość przechowywania mięsa w chłodni do 18 miesięcy, niezależnie od zastosowanych metod mrożenia.