Foods and Raw Materials, 2018, vol. 6, no. 2

ISSN 2308-4057 (Print)
ISSN 2310-9599 (Online)

Research Article
Open Access

DOI: http://doi.org/10.21603/2308-4057-2018-2-429-437
Available online at http:jfrm.ru

Marbled beef quality grades under various ageing conditions

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Received October 11, 2017; Accepted in revised form February 15, 2018; Published December 20, 2018

Abstract: The Russian beef market is growing, which means that the problem of meat quality is getting more and more relevant. The gradually improving culture of meat consumption raises the demand for beef maturation, or ageing. The current research is the first of its kind in Russia. It features the quality of Russian marbled beef in the process of its open-air and vacuum-packed maturation. The authors studied the changes in the quality grades of dry-aged and vacuum-packed marbled beef during 4, 16 and 28-day ageing and defined the optimal maturation conditions and terms. The study included pH, colour, microstructure, organoleptic properties, the qualitative and quantitative composition of the volatile aroma-forming compounds, and the area of intramuscular fat. The samples were on-the-bone beef cuts obtained from 18-month-old Aberdeen-Angus castrated bulls that had received 200 days of grain fattening. The pH value remained stable throughout the ageing period in the dry-aged and vacuum-packed samples. Approaching the end of the test period, the change in pH reached 0.12 for the dry-aged samples and 0.21 for the vacuum-packed ones. The surface of the dry-aged samples obtained a dark red to burgundy-red dry crust after 16 and 28 days of ageing. The colour was significantly different from the colour of the samples after 4 days of ageing. The colour of the vacuum-packed samples remained unchanged throughout the maturation period. However, the microstructure of the packed beef showed a deeper and more widespread decomposition of muscle tissue on days 16 and 28. The changes in the dry-aged samples were less obvious. All in all, the process of extended ageing improved the organoleptic properties of the beef.

Keywords: Beef industry, beef quality, marbling, ageing, destructive changes

Please cite this article in press as: Kozyrev I.V., Mittelshtein T.M., Pchelkina V.A., Kuznetsova T.G., and Lisitsyn A.B. Marbled beef quality grades under various ageing conditions. *Foods and Raw Materials*, 2018, vol. 6, no. 2, pp. 429–437. DOI: http://doi.org/10.21603/2308-4057-2018-2-429-437.

INTRODUCTION

The Russian beef industry is currently experiencing a period of growth. According to the Federal Service for National Statistics, 263,430 tons of beef were produced in 2016, which is 103.3% of the amount produced in 2015. The proportion of fresh-killed, fresh and refrigerated beef was about 80% of the total production in 2016 [1]. The current production growth is connected with such large, vertically-integrated holdings as Miratorg Agribusiness Holding and Zarechnoye Group. Besides, there are numerous state support programs for beef farming and production. However, the share of beef cattle in the total number of Russian livestock hardly exceeds 10%, whereas in the largest beef producing countries it is 40% or higher [2].

The meat consumption in Russia often falls below the recommended level, especially if compared to the United States, Germany and the United Kingdom. However, it is increasing at a significant rate year by year [3]. Hence, the culture of meat consumption is improving. Nowadays, there are specialized restaurants and shops, where consumers can buy various meat products, including aged beef.

The issues of beef ageing became subject of scientific studies in Russia and abroad in the middle of the XX century. For instance, according to a study conducted in 1966, there are three stages of after-slaughter biochemical processes: rigor mortis, rigor mortis resolution and maturation [4]. Still, the problem of meat ageing maintains its relevance. In January 2017, a team of scientists from the United States studied the effect of stepwise dry/wet-aging (10 days in carcass and 7 days in vacuum-packed cuts) and subsequent freezing on beef quality. It was concluded that the stepwise ageing method accompanied by cryogenic freezing can be a good solution for the industry, since it improves such parameters as Warner-Bratzler shear stress and water retention capacity [5].

Another American research featured the ageing of vacuum-packed prefabricated steaks and cuts. It revealed that consumers preferred the strip loin aged as steaks; there were no differences in colour formation and shelf life, but the shear stress was slightly lower in the beef aged as vacuum-packaged cuts [6].

Another team of US researchers studied the effect of open-air and packed extended ageing (14–49 days) on the quality of on-the-bone and boneless beef with low marbling. They discovered that consumers preferred boneless, 28-days wet-aged strip steak, cooked to 71°C [7]. Similar results were obtained by other American scientists who conducted a study of the quality characteristics of *biceps femoris* and *semimembranosus* steaks. Consumer panel results were in favour of the beef aged 14–21 days, while the objective indicators of tenderness, such as Warner-Bratzler shear force values, reached the optimum after 21–42 day ageing [8]. However, a team of Japanese researchers established that for Japanese Aberdeen-Angus cattle the best duration of dry aging for highly marbled beef was 40 days [9]. Researchers from Sweden aged beef samples in a water vapour-permeable dry-ageing bag for 14 days. Compared to ordinary dry ageing, they achieved higher quality characteristics and managed to reduce thawing loss and development of pathogenic microorganisms [10]. G. Lindahl from the Swedish University of Agricultural Sciences found that 5 or 15 days of vacuum ageing was preferable to vacuum ageing in high oxygen modified atmosphere, since it had no negative effect on colour stability [11].

The abovementioned studies prove that the issues of post-mortem changes in meat and proper ageing timing have a significant impact on consumer properties and preferences and are relevant for meat production and sales. Besides, meat ageing studies are important for the current situation in Russia, with its fast development of beef cattle breeding, introduction of new systems for cattle growing and fattening, and new sorts of high-quality marbled beef.

The research objective was a comparative study of the quality of dry-aged and vacuum-packed marbled beef during 4, 16 and 28 days.

STUDY OBJECTS AND METHODS

The on-air and packaged ageing was carried out in a refrigerated compartment at a temperature of 1–2°C and relative humidity < 90%.

The experiment measured the microstructural, organoleptic and technological characteristics of on-the-bone beef cuts obtained from 18-month-old Aberdeen-Angus (Black Angus) castrated bulls that had received 200 days of grain fattening. The slaughter and cutting of the carcasses was carried out in the facilities provided by OOO Bryansk Meat Company (Miratorg Agribusiness Holding), Bryansk Region, Russia.

24 hours after the slaughter, dorsal on-the-bone samples were obtained from the dorsal lumbar cut of 4 carcasses. Each sample was divided into three parts and vacuum-packaged for transportation. A total of 12 samples were obtained, each sample weighed ≥ 3–4 kg. 4 samples (2 open-air and 2 packed) were taken 4, 16 and 28 days after slaughter. The samples from the left side of the carcass were marked with the letter L, those from the right side – with the letter R.

The on-the-bone dorsolumbar pieces were further divided into dorsal and lumbar cuts between the first lumbar and the last (13^{th}) dorsal vertebra. According to the beef cutting pattern established by the interstate standard, the incision continued along the posterior edge of the 13^{th} rib.

Before the beef was put on the shelves of the maturing room, samples 1L and 2L had been unpacked, while samples 1R and 2R remained packaged.

For investigation, the rib eye was excreted from the on-the-bone dorsal cut.

Its degree of marbling is shown in Table 1.

Colour assessment was conducted in the CIE Lab colour space [12] with the help of a Konica Minolta CM-2300d spectrophotometer (Japan).

The measurements involved the following spectrophotometer settings:

– light source D65 (standard daylight);
– viewing angle 2°; and
– exclusive of the mirror component (SCE).

Each measurement was repeated twice, the arithmetic mean of two measurements was taken as the measurement result.

Table 1. The area percentage of intramuscular fat and marbling score

Characteristics	Sample			
	1L	1R	2L	2R
Marbling	Good	Good	Moderate	Moderate
Proportion of fat, % of the loin eye area	23.54	20.43	10.98	11.82
Photos of loin eye samples				

The colour difference (ΔE) was calculated according to the CIEDE 2000 formulas approved by the CIE committee [13].

The potentiometric measurement of pH was conducted with a portable test meter Testo 205. Its electrode was immersed 3 cm in the muscle tissue. The final result was the arithmetic mean of three single measurements; the difference between the limiting values of the three measurement results did not exceed 0.15 pH units.

To study the microstructure, histological samples were taken from intact muscles, which were oriented according to the axis of cutting. Three pieces of 2 × 1.5 × 0.5 cm with longitudinal and transverse orientation of the muscle fibres were selected from each sample. The pieces were placed in a 10% buffered formalin solution for 72 hours at room temperature. After that they were washed under cold running water for 12 hours. Then the material was compacted in gelatine at an ascending concentration (12.5%, 25%) at 37°C for 12 hours [N]. A MIKROM-HM525 cryostat (Thermo Scientific, USA) was used to produce 18-μm slices. The slices were placed on Menzel-Glaser slides (Thermo Scientific, USA) and stained with Ehlich's hematoxylin and 1% aqueous-alcoholic eosin solution (BioVitrum, Russia). An Axio Imaiger A1 light microscope (Carl Zeiss, Germany) and AxioCam MRc-5 camera were used to study and photograph the histological specimens. Image processing involved a computerized image analysis system AxioVision 4.7.1.0 (Carl Zeiss, Germany), adapted for histological studies. Morphometric studies followed the principles of systemic quantitative analysis.

Samples from each cut underwent an organoleptic examination before and after cooking. Before cooking, the appearance and colour of the samples were determined by visual inspection. The colour and consistency of the muscles were evaluated in the deeper layers of muscle tissue on a fresh cut. The odour was defined organoleptically on the surface and inside the sample.

To determine the clarity and odour of the broth, each sample was separately passed through a meat grinder with a 2 mm diameter hole in the grate. 20 g of the minced meat was weighed on a laboratory scale and placed in a 100 cm^2 conical vessel, which then was filled with 60 cm^3 of distilled water, and thoroughly stirred. The vessel was covered with crystal glass and set in boiling-water bath. The odour of meat broth was defined while the vessel was heated up to 80–85 °C at the moment when steam started to emerge from the slightly opened vessel. To determine the transparency, 20 cm^3 of broth was poured into a graduated cylinder (20 mm in diameter, 25 cm^3).

During the cooking process, 1 kg of meat was boiled for 1 hour until the core temperature reached 75°C. The ratio of water and meat was 3:1 (v/v). Salt was added in an amount of 1% to the weight of the meat, 30 minutes before the end of cooking. The meat and the broth were evaluated on a 9-point scale according to the following parameters: appearance, faste, texture, juiciness (for the meat) and appearance, colour, odour, faste and thickness (for the broth). Instrumental studies of the odour intensity were conducted with the help of the 'electronic nose' multi-sensor system (VOCmeter, Germany). The method was developed in V.M. Gorbatov All-Russian Scientific Research Institute of Meat Industry.

The method of multisensory analysis is based on the ability of the e-nose to sense the volatile components that are released from the surface of the meat sample during cooking. When a volatile component passes over the sensor surface, the physicochemical changes that occur in its sensitive layer are converted into an electronic signal via a converter and transferred to the computer.

The readings of the MOS1-MOS4 sensors of the e-nose were used to determine the freshness of the meat. The signals were transmitted to a PC and recorded in the form of graphs in the Argus programme. Argus was also used to process the signals according to the principal component analysis to obtain the qualitative and quantitative measurement of the volatile components. The principal component analysis is based on the construction of factors, or principal components. Each component represents a linear combination of the original values. The first principal component PC1 defines an axis in the space of initial characteristics with the greatest dispersion of objects (points). The axis of the second principal component PC2 is orthogonal to the axis of PC1 and explains as much of the residual dispersion as possible. Since the separation of the principal components occurs in decreasing order from the point of view of the fraction of variance they explain, the values with large coefficients that enter PC1 exert maximum influence on the differentiation of the objects under study.

The principal components method allowed the team to construct calibration graphs, which made it possible to identify the category of beef freshness.

The indicator of freshness was the boundaries of the clusters that were established in standard samples.

This method has a low detection limit of volatile components that characterize the odour of meat during its ageing.

The surface of beef in the dry-aged samples after 16 and 28 days was characterized by a dry crust of dark red to burgundy-red (Table 3), which was significantly different from the colour of the meat after 4 days of ageing. This is consistent with the results obtained by Aroeira et al., who established that redness (a*) changed during the ageing period [14]. The colour of vacuum-packed samples remained the same throughout the entire ageing period (Table 3).

RESULTS AND DISCUSSION

The pH value remained virtually unchanged, which indicates a stable acidity of meat throughout the ageing period (Table 2).

The histological examination of the structure made on the 4th day of ageing revealed that all the samples had similar microstructural characteristics, with muscle fibres in dense primary bundles. The shape of the fibres was polygonal or slightly rounded on the cross section. Interlayer endomysium and the boundaries between individual muscle fibres were well-defined. The diameter of muscle fibres was 55–60 μM.

Table 2. Value of pHL. dorsi during ageing (mean observation)

Ageing period, days	Dry-aged	Vacuum-packed
4	5.74	5.57
16	5.61	5.81
28	5.62	5.78

Table 3. Colour values (L*; a*; b*; mean)

Ageing period, days	Dry-aged	Vacuum-packed
4	42 ± 2.0; 38 ± 2.0; 31 ± 1.5 Bright red	42 ± 2.0; 41 ± 3.0; 31 ± 1.5 Bright red
16	25.8 ± 1.0; 2.47 ± 1.8; 0.59 ± 1.5 Dark red	41 ± 2.0; 39 ± 0.9; 30 ± 1.5 Bright red
28	23.3 ± 1.0; 1.6 ± 1.2; 0.37 ± 0.9 Burgundy-red	41 ± 1.6; 40 ± 1.4; 31 ± 1.8 Bright red

The longitudinal section demonstrated predominantly rectilinear muscle fibres. However, some fibres were wavy, which is typical of the stage of rigor mortis resolution. Transverse striation was well pronounced. Individual fibres showed areas with longitudinal striation, i.e. zones of contraction. The nuclei in the muscle fibres were well-coloured, oval in shape and located directly under the sarcolemma.

The connective tissues of the perimysium were wavy; they were located snugly against the bundles of muscle fibres. The nuclei in the connective tissue layers were clearly visible. Areas of adipose tissue with a typical histological structure were revealed between the bundles of muscle fibres in perimysium.

The functional state of the muscle tissue was quite homogeneous. There were occasional transverse microcracks and sarcomeres with signs of local decay. No damaged sarcolemma, myofibrils or muscle fibre were detected. The microstructure of the samples corresponds to fresh meat at the initial stage of ageing.

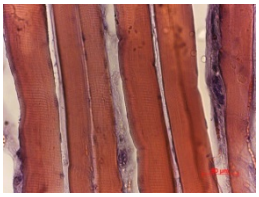
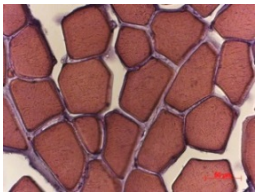
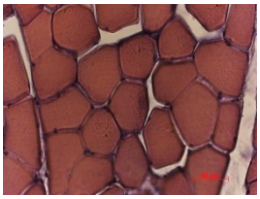
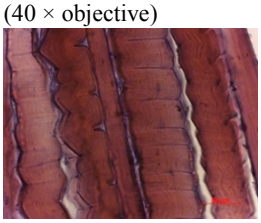
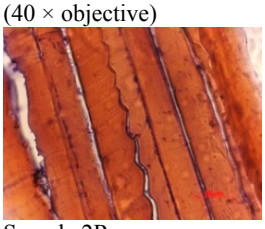
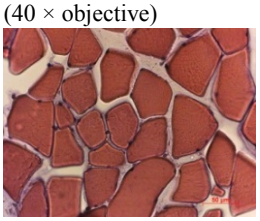
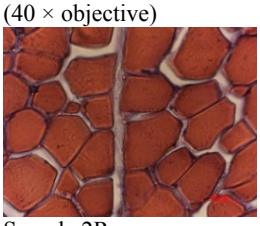
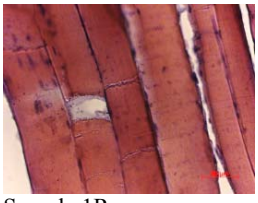
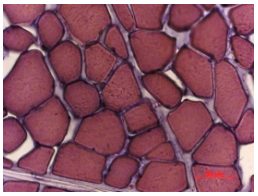
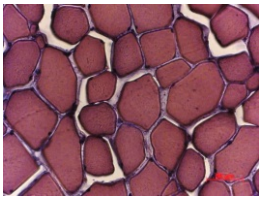
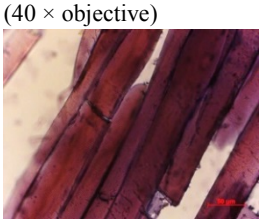
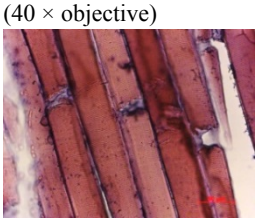
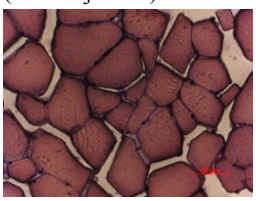
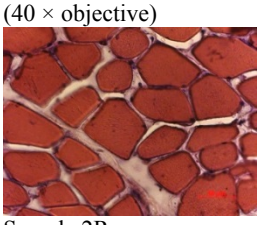
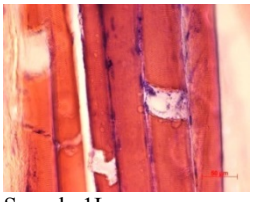
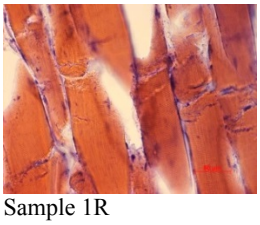
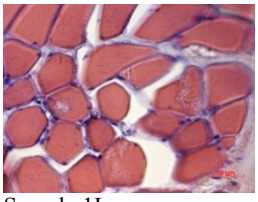
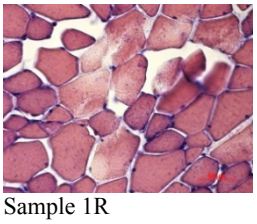
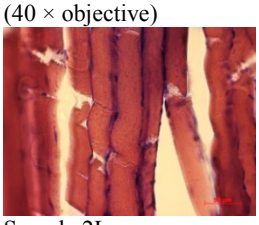
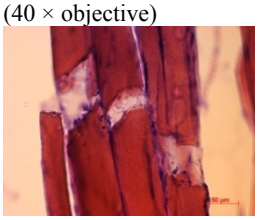
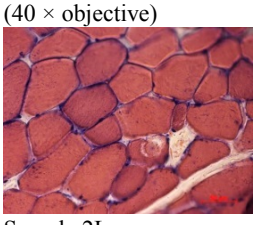
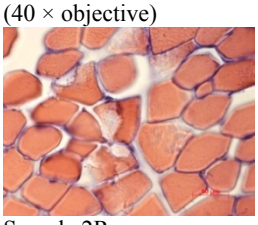
The histological examination of the structure conducted on the 16th day of ageing revealed the following microstructural changes in the dry-aged samples. Along with a well-defined transverse striation, some muscle fibres displayed sites with a smoothed striation. The colour of the fibres was uneven. The nuclei in the muscle fibres were shadowy, not as well-defined as in the corresponding samples on the 4th day of ageing. The muscle fibres showed multiple transverse-slit integrity disorders, occasional ruptures and fragmentations. There were areas of sarcolemma exfoliation and destruction of the internal fibre structure (local decomposition of sarcomeres). The connective tissue of perimysium showed signs of loosening. The microstructure of the samples corresponded to that of fresh, short-term storage meat at the second stage of ageing.

The vacuum-packed samples revealed more pronounced changes in tissue structure. The muscle fibres showed large areas with a smoothed striation. The nuclei were shadowy; in some fibres they were in a state of complete decay. Multiple transverse-slit integrity disorders and ruptures were present in the muscle fibres. A fine-grained protein mass appeared between the fragments in the areas of fragmentation. There were long sections of sarcolemma exfoliation and destruction of the internal fibre structure (local decomposition of sarcomeres). The connective tissue of perimysium showed signs of loosening, with occasional detachment from the muscle fibres. The microstructure of the samples corresponded to that of fresh, short-term storage meat at the second stage of ageing.

The histological examination of the structure on day 28 showed that the destructive changes intensified in all the samples. The dry-aged samples revealed a transverse smoothened striation in some areas of muscle fibre. The colouring of fibres was bleak and uneven in the areas infested by microflora. The nuclei in the muscle fibres were either shadowy or in a state of complete decay. The number of areas with muscular fibre ruptures and fine-grained protein mass formation increased in comparison with the corresponding samples on day 16. There were areas with exfoliation and destruction of the sarcolemma, as well as with the destruction of the internal fibre structure (local decomposition of sarcomeres). The connective tissue of perimysium showed signs of loosening, with occasional detachment from the muscle fibres and foci of microflora. The nuclei were poorly visible. The microstructure of the samples corresponded to that of raw meat of the so-called ‘dubious freshness’ category.

The vacuum-packed samples revealed smoothed striation in most muscle fibres and shadowy nuclei. Individual foci of coccal microflora were identified in the surface layers of muscle tissue. The muscle fibres showed multiple ruptures and fragmentation. Fine-grained protein mass appeared between the fragments in the areas of fragmentation. There were long sections of sarcolemma exfoliation and destruction of the internal fibre structure. A granular mass indicated decomposition of myofibrils on sarcomeres. The connective tissue layers of perimysium were loosened, with detachment from the muscle fibres, which indicated deep destructive changes in muscle tissue.

Table 4. Microstructure of samples at different stages of ageing

Microstructure of samples			
Dry-aged	Vacuum-packed	Dry-aged	Vacuum-packed
Ageing period, days 4			
 Sample 1L Longitudinal section (40 × objective)	 Sample 1R Longitudinal section (40 × objective)	 Sample 1L Cross section (40 × objective)	 Sample 1R Cross section (40 × objective)
 Sample 2L Cross section (40 × objective)	 Sample 2R Cross section (40 × objective)	 Sample 2L Cross section (40 × objective)	 Sample 2R Cross section (40 × objective)
Ageing period, days 16			
 Sample 1L Longitudinal section (40 × objective)	 Sample 1R Longitudinal section (40 × objective)	 Sample 1L Cross section (40 × objective)	 Sample 1R Cross section (40 × objective)
 Sample 2L Longitudinal section (40 × objective)	 Sample 2R Longitudinal section (40 × objective)	 Sample 2L Cross section (40 × objective)	 Sample 2R Cross section (40 × objective)
Ageing period, days 28			
 Sample 1L Longitudinal section (40 × objective)	 Sample 1R Longitudinal section (40 × objective)	 Sample 1L Cross section (40 × objective)	 Sample 1R Cross section (40 × objective)
 Sample 2L Longitudinal section (40 × objective)	 Sample 2R Longitudinal section (40 × objective)	 Sample 2L Cross section (40 × objective)	 Sample 2R Cross section (40 × objective)

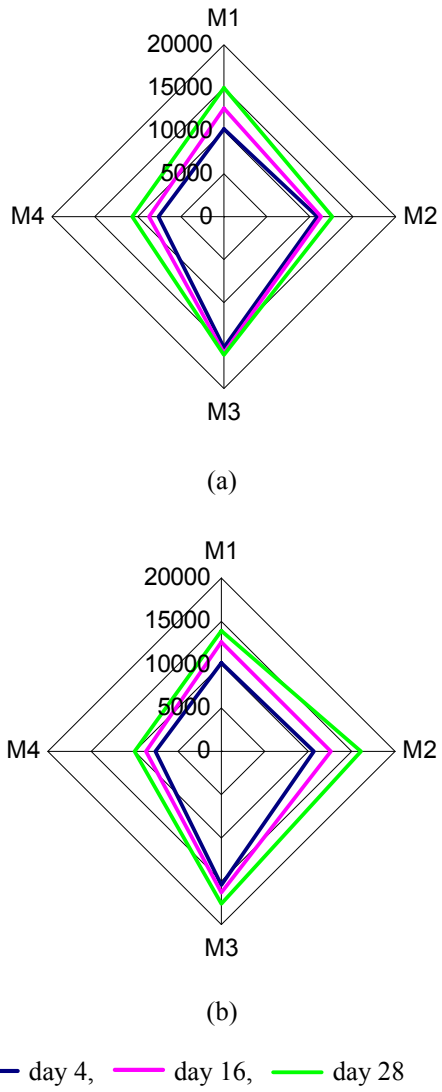


Fig. 1. 'Visual footprints' of odour in the vacuum-packed samples during ageing: (a) sample 1R; (b) sample 2R.

Table 5. Areas of 'visual footprints' of odour in the vacuum-packed samples during ageing

Period of ageing, days	Areas of 'visual footprints', c.u. × 10^7	
	Samples	
	1R	2R
4	22.89	24.08
16	26.75	27.79
28	29.82	32.88

The histological studies revealed increasing destructive changes in the tissue. The vacuum-packed beef samples 1R and 2R showed significant destructive changes on days 16 and 28. The dry-aged samples 1L and 2L demonstrated less pronounced changes on the corresponding day of ageing. However, they showed signs of rotting. Therefore, the ageing process was faster and more intensive in the vacuum-packed samples while the beef remained fresh. The dry-aged samples demonstrated signs of meat spoilage by day 28. Similar results were obtained by E. Veiseth-Kent et al., whose research featured 403 beef samples of Norwegian red cattle [15].

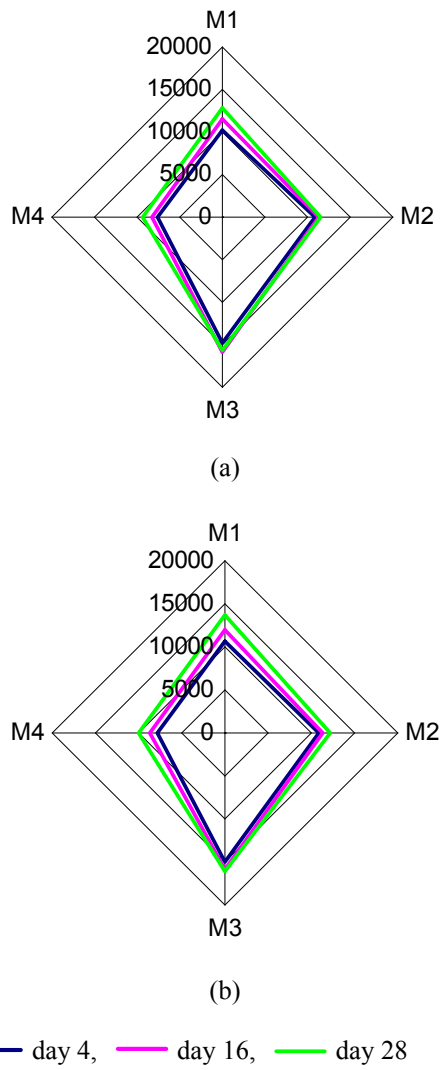


Fig. 2. 'Visual footprints' of odour in the dry-aged samples: (a) sample 1L; (b) sample 2L.

According to the organoleptic research of the vacuum-packed beef on day 28, the samples belonged to the category 'fresh meat' during the entire period of ageing. The organoleptic studies were confirmed by the results of a multisensory assessment of the odour at all stages of ageing.

According to the organoleptic properties of the dry-aged beef, the samples could be placed into the 'meat of dubious freshness' category after 28 days of ageing. The samples possessed a less elastic consistency and emitted an acidic or musty odour, untypical of fresh meat; the broth was opaque.

The multisensory analysis of volatile components during the gaseous phase showed that the odour intensity increased during the ageing in both packed and unpacked beef. According to the multisensory analysis, the packed samples remained fresh without signs of decomposition throughout the entire ageing period (28 days). The odour intensity increased by 1.2 and 1.4 times on day16 and day 28 respectively. During the gaseous phase, there was an increase in the content of volatile fatty acids and free amino acids. Low molecular nitrogen compounds responsible for the aroma of meat and precursor substances of cooked meat odour were detected (Figs.1a and 1b, Table 5).

The multisensory analysis of the gaseous phase on day 28 showed that the odour intensity in samples 1L and 2L increased by 1.9 and 2.2 times respectively. The increase in odour was associated with an increase in the content of volatile fatty acids, ketones, and aldehydes that resulted from the oxidation of muscle tissue fats during the gaseous phase (Fig. 2a and 2b, Table 6).

The multisensory analysis of the dry-aged samples on day 28 showed that the meat remained fresh in the refrigerator for 16 days, which agreed with the results of the organoleptic assessment.

According to the organoleptic assessment made after cooking on day 4, the sample received a high score (8 points) in terms of flavour, juiciness, and tenderness. Its appearance and odour received the maximum score (9 points). The total score was 8 points, which denoted a very good quality. The sample had a fine texture and a very pleasant strong odour. The broth also received a high overall score of 8 points. According to its organoleptic properties, it was evaluated as tasty and thick, with a pleasant strong odour.

After 16 days of ageing, the panellists detected some increase in the tenderness of the vacuum-packed beef. Its quality level remained the same. The overall score of the product was 8 points (very good). The broth also had high organoleptic properties; its overall score was 8 points (very good) (Table 8, 9).

After cooking, the dry-aged samples demonstrated less juiciness – 7 points (juicy enough). The overall score was 8 points (very good). No decrease in broth quality was detected. The overall organoleptic score of the broth was 8 points (very good) (Table 10, 11).

By day 28, the organoleptic properties of the cooked dry-aged samples had not deteriorated. The panellists gave them 9 points for tenderness (very tender) and 8 points for juiciness (juicy). The overall score of the quality level of the cooked meat and broth was 8 points (very good) (Tables 7, 8).

After 28 days of ageing, the organoleptic indices of cooked dry-aged meat (appearance, odour, taste juiciness) and broth started to go down because of foreign smell, off-taste, opaque broth, poor juiciness, etc. The overall score was 7 points for the cooked meat and 5 points for the broth (Table 9, 10).

Table 6. Areas of 'visual footprints' of odour in the dry-aged samples

Period of ageing, days	Areas of 'visual footprints', c.u. × 10^7	
	Samples	
	1L	2L
4	23.63	23.45
16	28.46	30.73
28	45.15	51.26

Table 7. Quality indices of the vacuum-packed beef after cooking, 9-point scale

Ageing period	Appearance	Odour	Taste	Texture	Juiciness	Overall score
4 days	9	9	8	8	8	8
	Very pleasant	Very pleasant, fragrant, strong	Tasty	Tender	Juicy	Very good
16 days	9	9	8	8	8	8
	Very pleasant	Very pleasant, fragrant, strong	Tasty	Tender	Juicy	Very good
28 days	8	9	8	9	8	8
	Very good	Very pleasant, fragrant, strong	Tasty	Very tender	Juicy	Very good

Table 8. Quality indices of broth, 9-point scale

Ageing period	Appearance	Odour	Taste	Thickness	Overall score
4 days	9	9	8	8	8
	Very pleasant	Very pleasant, fragrant, strong	Tasty	Thick	Very good
16 days	9	8	8	8	8
	Very pleasant	Pleasant, strong	Tasty	Thick	Very good
28 days	9	8	8	8	8
	Very pleasant	Pleasant, strong	Tasty	Thick	Very good

Table 9. Quality indices of the dry-aged beef after cooking, 9-point scale

Ageing period	Appearance	Odour	Taste	Texture	Juiciness	Overall score
4 days	9	9	8	8	8	8
	Very pleasant	Very pleasant, fragrant, strong	Tasty	Tender	Juicy	Very good
16 days	9	8	8	8	7	8
	Very pleasant	Pleasant, strong	Tasty	Tender	Juicy enough	Very good
28 days	6	3	6	7	6	7
	Not good enough	Pleasant, strong	Not tasty enough	Tender enough	Not juicy enough	Good

Table 10. Quality indices of broth, 9-point scale

Ageing period	Appearance	Odour	Flavour	Thickness	Overall score
4 days	9	9	8	8	8
	Very pleasant	Very pleasant, fragrant, strong	Tasty	Thick	Very good
16 days	9	8	8	8	8
	Very pleasant	Pleasant, strong	Tasty	Thick	Very good
28 days	6	3	3	6	5
	Not good enough, opaque	Slightly unpleasant, foreign	Slightly unpleasant, foreign	Not thick enough	Medium

CONCLUSION

The method of extended ageing had a significant impact on the quality of the beef.

During ageing, destructive changes developed in the structure of muscle tissue; volatile aroma-forming compounds accumulated in the beef, which improved its organoleptic properties.

The vacuum-packed beef retained the properties of fresh meat, colour and pH value for the entire 28-day period of ageing. However, the destructive changes in the muscle tissue detected on day 16 and 28 were obvious and widespread.

The dry-aged beef retained the properties of fresh meat for 16 days. After 16 and 28 days, its surface obtained a dark red to burgundy-red dry crust. The colour was significantly different from the colour the samples obtained after 4 days of ageing (ΔE from 49.4 to 49.8). The destructive changes in the muscle tissue on the corresponding day were less pronounced.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to this article.

ACKNOWLEDGEMENTS

The authors express their gratitude to limited liability company Ltd Gorodskoy Supermarket (TM Azbuka Vkusa) for providing the samples and assistance.

FUNDING

The study was conducted within the framework of the contract with OOO Gorodskoy Supermarket

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