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COMPARATIVE ASSESSMENT OF BEEF CHARACTERISTICS FROM YOUNG BULLS OF DIFFERENT BREEDS AND THE INFLUENCE OF STORAGE CONDITIONS ON MEAT QUALITY INDICATORS

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Keywords: *beef, quality indicators, storage conditions*

Abstract
Comparative assessment results for quality indicators of meat samples obtained from Black Pied, Simmental and Aberdeen Angus young bulls and the influence of different temperature conditions on the quality of vacuum-packed beef during refrigerated storage are presented. The general chemical composition, physicochemical properties, and biological value of the samples based on the content of nonessential and essential amino acids were determined, as well as the protein quality index (PQI) and amino acid score. Analysis of the general chemical composition revealed higher moisture and protein content and the lowest fat content in Black Pied beef compared to other breeds. The amino acid composition of the protein showed a higher content of essential amino acids and the highest PQI value in Simmental beef. According to the calculation results, higher amino acid scores for lysine (149.1% and 129.1%) and tryptophane (200.0% and 240.0%) were noted in meat from Simmental and Aberdeen Angus young bulls, respectively. For the process of storing vacuum-packed meat in a cooled (at a temperature of 2.0 ± 0.5 °C) and superchilled state (minus 2.0 ± 0.5 °C) at a relative air humidity of 85%, a comparative analysis of changes in free amino acids and dynamics of hydrolytic and oxidative spoilage of meat samples from various breeds was conducted. After 21 days of storage in a superchilled state, the content of free amino acids in Black Pied, Simmental and Aberdeen Angus beef was lower by 13.1% ($P > 0.05$), 24.1% ($P \leq 0.05$) and 17.0% ($P \leq 0.01$) compared to storage in a cooled state, respectively. For all studied samples stored in a cooled state, the acid number values were 40% to 41% ($P \leq 0.01$) higher than in a superchilled state and peroxide number values were 20% to 23% ($P \leq 0.05$) higher than in a superchilled state. It has been established that lowering the storage temperature of vacuum-packed beef helps to better preserve quality and ensure safety for meat from all breeds studied.

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Introduction

Currently, one of the most important strategic goals of state policy is to increase domestic production of meat raw materials and products under international restrictions. Achieving this goal will ensure food security, solve the problems of import substitution, increase the competitiveness of the Russian economy and meet the needs of the population for high-quality meat products [1–2].

The concept of sustainable development of meat livestock breeding in the Russian Federation for the period until 2030[1] provides for the necessary measures of socio-economic, legal and administrative nature in solving key problems in the development of meat livestock breeding including ensuring expanded reproduction of meat and crossbred livestock and increasing beef production.

Beef is in growing demand in the consumer market not only in our country, but also abroad. Due to its high protein content, low fat content, and good taste, this type of meat is able to effectively satisfy the body's need for all essential nutrients, vitamins and microelements [3].

According to the National Meat Association, the share of beef in the total volume of meat consumption in the Russian Federation has decreased to a reasonable level due to the affordability of poultry and pork [4]. However, it is impossible to reduce beef production because demand for it in the world is not decreasing. One of the new poten-

[1] Ministry of Agriculture of the Russian Federation. National Beef Producers Union. Federal State Budgetary Scientific Institution "Federal Research Center for Biological Systems and Agricultural Technologies of the Russian Academy of Sciences". (2017). Concept of sustainable development of meat livestock breeding in the Russian Federation for the period until 2030. Retrieved from http://fncbst.ru/wp-content/uploads/2018/10/Концепция-мясного-скотоводства-версия-27.02.18.pdf Accessed April 10, 2023. (In Russian)

tial markets is China, which opens up broad prospects for increasing exports. At the same time, there is greater interest in high-quality beef obtained from specialized meat breeds, which are currently in short supply.

Currently, the share of specialized beef and crossbred cattle in the Russian Federation is about 20%, and the main backup for increasing beef production is its production through the use of dairy and combined productivity cattle [5]. Breeding specialized meat breeds and their crosses should become one of the strategic directions for the formation of a large-scale industry of specialized beef cattle breeding capable of compensating for this deficiency in the future until 2030.

The biological value of meat mainly depends on the quantity and quality of protein and is determined by its structural features, composition and degree of absorption. Meat proteins are distinguished by a high content of essential amino acids, the ratio of which in meat is especially favorable [6].

As can be seen at Figure 1, the amino acid composition of meat proteins is close to the amino acid composition of proteins that are officially accepted as ideal ones, i. e. human milk and chicken egg proteins [7]. Beef is a valuable addition to a healthy diet. It satisfies human need for essential amino acids, and is a rich source of vitamins B6 and B12 and essential microelements, i. e. potassium, phosphorus, iron and zinc [8,9].

One of the effective ways to preserve meat and meat products in order to preserve their structure, biological and nutritional value is to cool them to a temperature not lower than cryoscopic one. However, during the period of refrigerated storage, autolytic processes in tissues only slow down, but do not stop [10].

The quality of chilled meat deteriorates over time, not only during storage, but also as it moves through the all stages of the cold supply chain. At the same time, the intensity of negative changes from the chemical reactions and microbiological activity largely depends on strict adherence to the required temperature conditions during the process of distribution, storage, transportation and sale [11].

The most common method for significantly increasing shelf life is freezing technology, since it inhibits microbiological spoilage and significantly slows down autolytic processes in products of animal origin. However, the use of low temperatures irreversibly affects meat quality and taste, especially when the freezing process is slow, which leads to a high concentration of dissolved substances in the unfrozen matrix and loss of nutrients after thawing [11].

Assuming the maintenance of meat consumer properties, the shelf life of chilled meat may be increased by storing it in a controlled temperature range below the water freezing point while maintaining storage conditions that prevent the product itself from freezing [12–14]. In recent years, NFTS technology (near-freezing temperature storage) has been widely used for various products of plant origin (blueberries, spinach, green beans, pears, peaches, and cherries) [15–19].

The shelf life of poultry and pork meat may also be significantly increased when using this technology [20,21]. Research results [22] showed that fresh meat was stored for approximately 14 days in a superchilled state, which exceeded the shelf life of chilled meat due to slower growth of pathogenic microorganisms. At the same time, such a quality parameter as drip loss has shown that superchilling has advantages over freezing [22]. Thus, superchilling method is not as effective for long-term storage as freezing, but it allows for longer quality maintenance compared to storage in a cooled state.

A number of studies have confirmed that when stored in a superchilled state at a temperature of minus 2 °C, the shelf life of rabbit and broiler meat may be increased by 3 to 5.5 times [20,23]. The shelf life of beef steaks stored at cooling medium temperatures down to minus 4 °C was 2.4 times longer (up to 12 weeks) than for steaks stored at 2 °C [24].

The superchilling process in combination with the use of film packaging under vacuum or in a modified atmosphere increases product shelf life by 1.5 to 4 times compared to traditional cooling. In [12], the authors studied the effect of various storage conditions on beef texture and concluded that storage at freezing point using vacuum

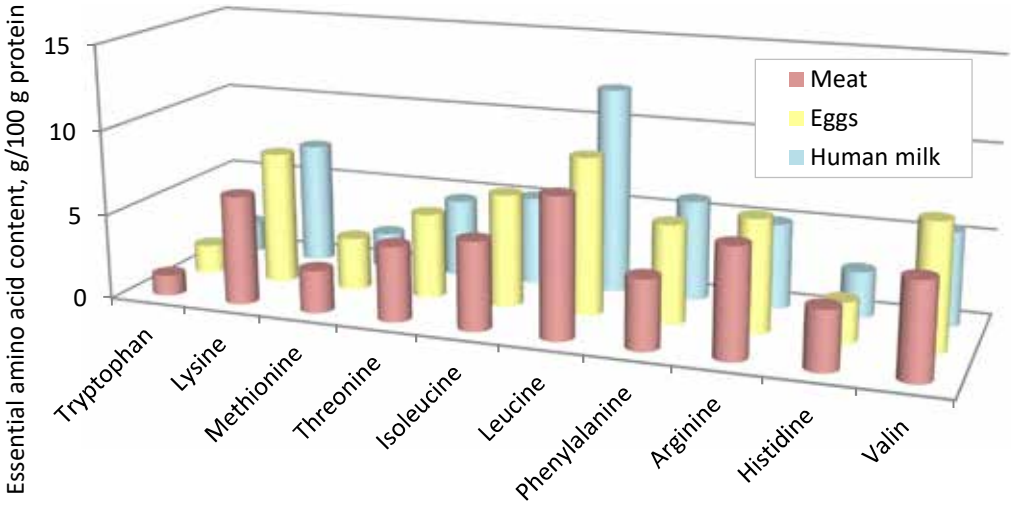


Figure 1. Content of essential amino acids in meat and the most valuable foods, g/100 g protein [7]

packaging may effectively delay the processes of microbiological spoilage, as well as maintain quality for a long time. Meat quality may be assessed by the following indicators: pH, water-binding capacity, amount of lactic acid and volatile fatty acids, protein solubility, color and tenderness. Nutritional value is the content of amino acids, fatty acids, vitamins, minerals and other components, which are important quality indicators of meat. Quality factors perceived by consumers are related to sensory properties (color, tenderness and taste), nutritional properties (caloric content, vitamin content and fatty acid profile) and appearance (exudation, marbling and visible amount of fat). Meat quality also depends on muscle fiber structure, including internal structure (sarcomere length, myofilament diameter, and fiber types) and chemical composition (mass content of moisture, protein, fat, and ash) [3].

An analysis of existing refrigerated storage technologies shows that the superchilling method is the most attractive in terms of increasing shelf life while preserving the structure of chilled meat as far as possible. The use of this method involves freezing a small part of the free moisture, but eliminates significant fluctuations in the temperature of the cooling medium and creates conditions for stabilizing the temperature of the food product during storage, transportation and retail trade [25–27]. The degree of superchilling is one of the most important parameters that determine the quality of stored products [25–27], which depends on the portion of frozen water. The lower the degree of superchilling, the better the taste of chilled products; the degree of superchilling over 30% may lead to a greater loss of moisture from the product [25,28–30].

The main reason for the introduction of superchilling technology may be its ability to combine the beneficial effect of low temperature along with the conversion of some free water into ice [31], thereby making it less accessible to the processes of product structure destruction by ice crystals. A number of studies have shown that the optimal proportion of frozen moisture is 5% to 30% when it is remains in the structure of the food product [28–30]. The advantage of superchilling technology is its ability to maintain the structural "freshness" of muscle tissue, as opposed to freezing. Therefore, its potential for industrial application has been noted by many authors [20,23,32–34].

The purpose of the study was a comparative assessment of the quality indicators for meat obtained from Black Pied, Simmental and Aberdeen Angus young bulls and the influence of different temperature conditions on the quality of vacuum-packed beef from these breeds during refrigerated storage.

Objects and methods

The object of the study was the samples of *Longissimus dorsi* muscle obtained from Black Pied, Simmental and Aberdeen Angus young bulls. Twenty-four hours after slaughter and cooling of half-carcasses at air temperature of 0 to 4 °C, *L. dorsi* from the lumbar part was isolated in the form of a rectangular layer, removed from the lumbar vertebrae 1 to 2 cm below the transverse processes without membranes and tendons for the preparation of test samples.

Before vacuum packaging and storage, for the initial samples of meat from various breeds, the chemical composition and physicochemical properties were studied, protein quality index (PQI) was determined, and the amino acid score was calculated.

The study of the chemical composition and physicochemical parameters of muscle tissue was carried out in order to determine the nutritional value of meat as a source of complete proteins of animal origin. The chemical composition of meat was determined for the following indicators:

— moisture content according to GOST 9793–2015[2];
— protein content according to GOST 25011–2017[3];
— fat content according to GOST 23042–2015[4];
— ash content according to GOST 31727–2012[5].

PQI (tryptophane to oxyproline ratio) according to GOST R70149–2022[6] and GOST 23041–2015[7];

The active acidity of meat (pH) was measured with Testo 205 portable pH meter (Germany). The water-holding capacity of meat was determined by the planimetric pressing according to Grau-Hamm method, modified by Volovinskaya-Kelman.

The amino acid composition of the protein was assessed by comparing the results obtained with a standard (reference) protein based on the amino acid score:

$$AC = \frac{C_{test} \cdot 100}{C_{std.}}$$

where AC is amino acid score, %; C_{test} is the content of essential amino acids in 1 g of tested protein, mg; $C_{std.}$ is the content of the same amino acid in 1 g of standard protein, mg; 100 is conversion factor.

Storage studies were carried out on an experimental bench with the ability to precisely control the temperature of the cooling medium in the refrigeration chamber. Two modes of vacuum-packed meat storage in a cooled and superchilled state were selected: at cooling medium temperatures of 2.0 ± 0.5 °C and minus 2.0 ± 0.5 °C, respectively. At

[2] GOST 9793–2015. "Meat and meat products. Method for determination of moisture content". Moscow: Standartinform, 2018. Retrieved from https://docs.cntd.ru/document/1200144231 Accessed February 8, 2023. (In Russian)

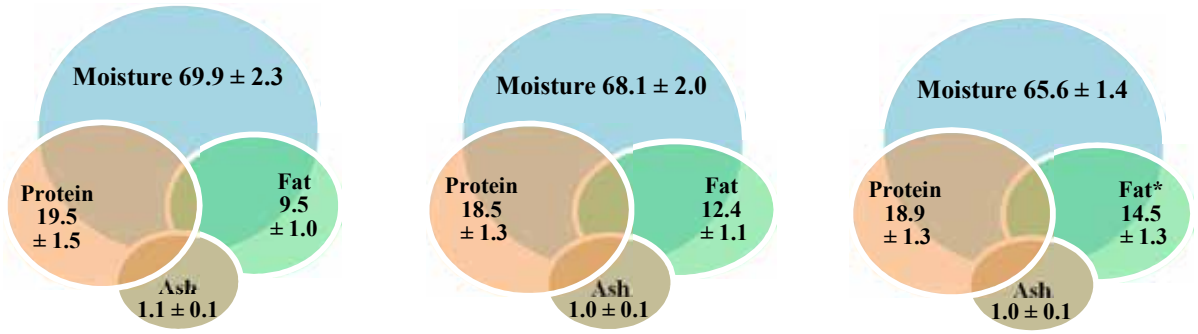
[3] GOST 25011–2017. "Meat and meat products. Protein determination methods". Moscow: Standartinform, 2018. Retrieved from https://docs.cntd.ru/document/1200146783 Accessed February 8, 2023. (In Russian)

[4] GOST 23042–2015. "Meat and meat products. Methods of fat determination". Moscow: Standartinform, 2017. Retrieved from https://docs.cntd.ru/document/1200133107 Accessed February 8, 2023. (In Russian)

[5] GOST 31727–2012. "Meat and meat products. Determination of total ash". Moscow: Standartinform, 2013. Retrieved from https://docs.cntd.ru/document/1200098742 Accessed February 8, 2023. (In Russian)

[6] GOST R70149–2022." Meat and meat products. Determination of the mass fraction of tryptophane by spectrophotometric method". Moscow: Standartinform, 2023. Retrieved from https://docs.cntd.ru/document/1200184801 Accessed February 8, 2023. (In Russian)

[7] GOST 23041–2015. "Meat and meat products. Method for determination of oxyproline". Moscow: Standartinform, 2016. Retrieved from https://docs.cntd.ru/document/1200123926 Accessed February 8, 2023. (In Russian)



a) b) c)

Figure 2. Chemical composition of meat, %: a) Black Pied; b) Simmental; c) Aberdeen Angus

* $P \leq 0.05$ — compared to Black Pied.

the selected temperature conditions, the meat was stored for 21 days at a relative humidity of 85%. Air temperature and humidity were measured with DV2TSM-R instruments (Research and production company "Microfor", Russia), temperature measurement range: minus 40 to 60 °C, permissible absolute measurement error limit: ± 0.5 °C, relative humidity measurement range: 0% to 98% (±1.0%).

During storage, control samples were taken on days 10 and 21. Quality indicators of the initial and control samples were determined during storage using the following methos:

— total amino acid analysis according to GOST 34132–2017[8];
— free amino acid content according to measurement procedure MVI-02–2002[9];
— acid and peroxide numbers according to GOST R55480–2013[10] and GOST 34118–2017[11], respectively.

Data obtained were statistically processed using the MS Office application package. The research was repeated in triplicate. The significance of the difference was accepted at a significance level of $P \leq 0.05$; $P \leq 0.01$.

Results

Study results for the chemical composition and physicochemical properties of beef

The chemical composition makes it possible to determine the nutritional and caloric value of meat as a source of complete animal proteins, as well as fats and minerals. Figure 2 shows that in terms of moisture and protein content, the highest values were obtained in beef from Black Pied young bulls. Before storage, these indicators were higher for moisture content by 1.8 abs.% and 4.3 abs.% ($P > 0.05$) and for protein content by 1.0 abs.% and 0.6 abs.% ($P > 0.05$) compared to Simmental and Aberdeen Angus, respectively.

The highest fat content was found in meat of Aberdeen Angus young bulls, 14.5%. Comparing this indicator in Aberdeen Angus with Black Pied and Simmental young animals, it was found that it was higher by 5.0 abs.% ($P \leq 0.05$) and 2.1 abs.% ($P > 0.05$), respectively. In the meat of the studied breeds, no differences were found in minerals content. Chemical analysis results for meat obtained from young bulls of different productivity types show that the beef of the studied breeds was characterized by high nutritional value.

After the slaughter of animals, the process of meat autolysis begins, and its physicochemical properties change significantly. During autolysis, intensive breakdown of glycogen occurs and lactic acid is formed, which softens meat and, after ageing, it acquires a specific taste and smell characteristic of aged meat.

In the context of meat processing and storage technology, active acidity (pH) is an important quality indicator. Measured 24 hours after slaughter, this indicator is a direct result of muscle glycogen (energy) levels. Its final value determines meat color, water-holding capacity, texture and, accordingly, the quality of the raw material. Analysis results of the data shown in Figure 3 indicate that the active acidity decreased after 24 hours ageing compared to 1 hour after slaughter by 1.6% to 3.3% due to the conversion of muscle glycogen into lactic acid. The highest values of pH_1 and pH_{24} were in Aberdeen Angus young bulls, and the lowest values were in Black Pied young bulls. According to this indicator, beef from young bulls of all breeds had no defects and was characterized as NOR beef.

Water-holding capacity depends on the composition and properties of proteins, pH level and structure, which is important during meat processing and affects the sensory properties of finished meat products made from it. The ability to retain water in relation to the total moisture in the meat of the studied breeds varies from 60.4% to 66.5%. Black Pied beef had the highest water-holding capacity: higher by 3.7 abs.%. and 6.1 abs.% ($P > 0.05$) compared to the meat of Simmental and Aberdeen Angus young bulls, respectively.

Figure 3 shows that Black Pied beef is characterized by the best values.

[8] GOST 34132–2017. "Meat and meat products. Determination of amino acids composition of animal protein". Moscow: Standartinform, 2019. Retrieved from https://docs.cntd.ru/document/1200146930 Accessed February 8, 2023. (In Russian)

[9] Measurement procedure No. 02–2002. "Mass concentration of basic amino acids in aqueous solution. Methodology for performing measurements using high-performance liquid chromatography". Irkutsk, 2002. Retrieved from new.econova.ru Accessed February 8, 2023. (In Russian)

[10] GOST R55480–2013. "Meat and meat products. Method for determination of acid value". Moscow: Standartinform, 2014. Retrieved from https://docs.cntd.ru/document/1200103311 Accessed February 8, 2023. (In Russian)

[11] GOST 34118–2017. "Meat and meat products. Method for determination of peroxide value". Moscow: Standartinform, Retrieved from https://docs.cntd.ru/document/1200146654 Accessed February 8, 2023. (In Russian)

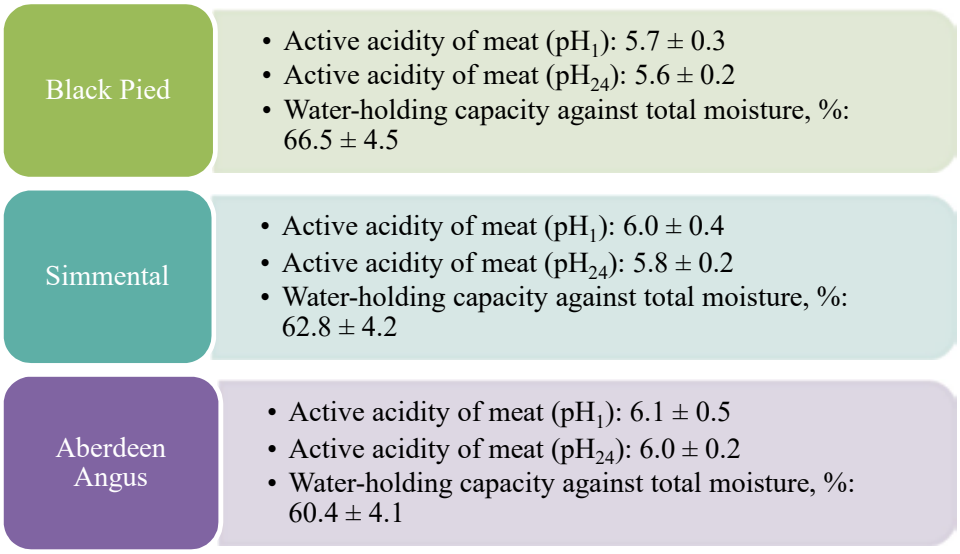


Figure 3. Physicochemical parameters of meat ($\overline{X} \pm S\overline{x}$)

Study results for meat biological value

The biological value of meat is determined by the presence of amino acids in its composition, as well as their quantitative ratio (Table 1).

Table 1. Amino acid composition of muscle tissue, g/100 g protein, ($\overline{X} \pm S\overline{x}$)

Parameter	Black Pied	Simmental	Aberdeen Angus
	Essential amino acids		
Isoleucine	4.05 ± 0.15	4.59 ± 0.11*	4.22 ± 0.16
Leucine	6.92 ± 0.31	7.41 ± 0.27	7.33 ± 0.26
Lysine	7.23 ± 0.31	8.22 ± 0.32	7.10 ± 0.26
Methionine + Cystine	3.33 ± 0.15	3.89 ± 0.10*	3.64 ± 0.16
Valine	5.38 ± 0.15	5.08 ± 0.22	5.03 ± 0.16
Tryptophane	1.54 ± 0.21	2.00 ± 0.05	2.39 ± 0.26
Phenylalanine + Tyrosine	8.82 ± 0.20	8.43 ± 0.22	8.24 ± 0.27
Threonine	5.77 ± 0.21	4.32 ± 0.22**	5.56 ± 0.16
Total	43.04 ± 5.44	43.94 ± 5.51	43.51 ± 5.34
	Nonessential amino acids		
Aspartic acid	8.97 ± 0.36	9.08 ± 0.32	9.63 ± 0.32
Serin	4.67 ± 0.21	4.65 ± 0.22	3.75 ± 0.16*
Glutamic acid	19.79 ± 0.62	19.78 ± 0.32	16.77 ± 0.53*
Glycine	5.08 ± 0.26	4.38 ± 0.16	5.89 ± 0.21**
Alanine	4.56 ± 0.26	4.11 ± 0.16	5.89 ± 0.21**
Histidine	3.79 ± 0.15	3.46 ± 0.05	3.39 ± 0.11
Arginine	6.46 ± 0.36	5.84 ± 0.38	6.95 ± 0.21
Proline	3.28 ± 0.15	4.43 ± 0.16**	3.82 ± 0.16
Oxyproline	0.36 ± 0.10	0.33 ± 0.22	0.40 ± 0.26
Total	56.96 ± 5.74	56.06 ± 6.05	56.49 ± 4.91
Amino acid index,%	75.6	78.4	77.0
PQI	4.28 ± 0.1	6.06 ± 0.2**	5.98 ± 0.2**

* P ≤ 0.05; ** P ≤ 0.01 — compared to Black Pied

The biological value of meat may be identified using the protein quality index (PQI) determined by the ratio of tryptophane (an essential amino acids) to oxyproline (a typical representative of nonessential amino acids). The biological value of meat is lower the more oxyproline it contains, the content of which determines the amount of connective tissue proteins.

In general, meat of Simmental and Aberdeen Angus young bulls had a high protein quality index; in Black Pied young bulls this indicator was lower by 1.78 and 1.70 units (P ≤ 0.01), respectively. Meat of Simmental young bulls was characterized by the highest biological value due to the high content of tryptophane, which is essential amino acid.

For each group, the amino acid score was calculated and the limiting amino acids were determined. The calculation results are presented in Table 2.

Table 2. Amino acid score, %

Amino acids	Breed		
	Black Pied	Simmental	Aberdeen Angus
Valine	108.0	102.0	100.0
Isoleucine	102.5	115.0	105.0
Leucine	98.6*	105.7	104.3
Lysine	130.9	149.1	129.1
Methionine + Cystine	94.3*	111.4	102.9
Tryptophane	160.0	200.0	240.0
Threonine	145.0	107.5	140.0
Phenylalanine + Tyrosine	146.7	140.0	108.3

* Limiting amino acids.

The data in Table 2 show that when calculating the amino acid score in the meat of Black Pied young bulls, the limiting amino acids are: leucine (98.6%) and methionine + cystine (94.3%). For other amino acids, this value was more than 100%.

In Simmental and Aberdeen Angus beef, the amino acid score exceeds 100% for all limiting (essential) amino acids as follows:

— for lysine content, 149.1% and 129.1%, respectively;

— for tryptophane content, 200.0% and 240.0%, respectively.

According to the results of the studies (Table 1 and Table 2), the meat of the studied breeds is characterized by high biological value.

Study results for meat quality indicators depending on storage conditions

During storage for 10 and 21 days at different temperatures, the dynamics of changes in free amino acids, hydrolytic and oxidative spoilage of fats in vacuum-packed young bull meat of various breeds were assessed.

In the initial samples (before storage), the lowest content of free amino acids was observed in Black Pied young bulls' meat (0.404 mg/100 g), which is lower compared to Simmental and Aberdeen Angus breeds by 27.7% and 25.9%, respectively (P > 0.05) (Table 3).

Table 3. Change in free amino acids during storage of vacuum-packed meat, mg/100 g muscle tissue ($\overline{X} \pm S\overline{x}$)

Breed	Storage period	Temperature, °C	Free amino acids, mg/100 g
Black Pied	Initial samples	—	0.404 ± 0.050
	10 days	2.0 ± 0.5	0.431 ± 0.046
		minus 2.0 ± 0.5	0.406 ± 0.018
	21 days	2.0 ± 0.5	0.615 ± 0.097
		minus 2.0 ± 0.5	0.544 ± 0.096
Simmental	Initial samples	—	0.516 ± 0.079
	10 days	2.0 ± 0.5	0.773 ± 0.066*
		minus 2.0 ± 0.5	0.698 ± 0.095*
	21 days	2.0 ± 0.5	0.887 ± 0.006*
		minus 2.0 ± 0.5	0.715 ± 0.014
Aberdeen Angus	Initial samples	—	0.511 ± 0.015
	10 days	2.0 ± 0.5	0.641 ± 0.016*
		minus 2.0 ± 0.5	0.524 ± 0.016**
	21 days	2.0 ± 0.5	0.745 ± 0.015
		minus 2.0 ± 0.5	0.637 ± 0.016

* P ≤ 0.05; ** P ≤ 0.01 — compared to Black Pied.

During the first 10 days of storage at cooling medium temperature of 2.0 ± 0.5 °C and minus 2.0 ± 0.5 °C, the content of free amino acids increases. At air temperature of 2.0 ± 0.5 °C, the content of free amino acids is higher compared to storage at air temperature of minus 2.0 ± 0.5 °C: for Black Pied by 0.025 mg/100 g or 5.8% (P > 0.05), for Simmental by 0.075 mg/100 g or 9.7% (P>0.05), and for Aberdeen Angus by 0.117 mg/100 g or 18.3% (P ≤ 0.01) (Table 3).

After 21 days of storage in a cooled and superchilled state, the lowest content of free amino acids was observed in Black Pied young bulls' meat (0.615 ± 0.097 and 0.544 ± 0.096 mg/100 g, respectively). For Simmental and Aberdeen Angus beef, this indicator (Table 3) was higher by:

— 0.272 mg/100 g or 44.23% (P ≤ 0.05) and 0.13 mg/100 g or 21.1% (P > 0.05) at a temperature of 2.0 ± 0.5 °C (Simmental breed);

— 0.171 mg/100 g or 31.4% (P > 0.05) and 0.093 mg/100 g or 17.1% (P > 0.05) at a temperature of minus 2.0 ± 0.5 °C (Aberdeen Angus breed).

Thus, when stored for 21 days in a superchilled state, the content of free amino acids in beef was lower compared to a cooled state: in Black Pied by 0.071 mg/100 g or 13.1% (P > 0.05), in Simmental by 0.172 mg/100 g or 24.1% (P ≤ 0.05) and in Aberdeen Angus by 0.108 mg/100 g or 17.0% (P ≤ 0.01).

It should be noted that the cooling process allows to preserve higher consumer properties of both meat itself and meat products, such as flavor, taste, texture, color of the product. The acid number of fats in meat and meat products is a measure characterizing the degree of fat hydrolysis, which allows to predetermine shelf life. Thus, after 10 days of storage in a refrigerator with a temperature of 2.0 ± 0.5 °C (Figure 4), the acid number in Black Pied, Simmental and Aberdeen Angus beef increased compared to initial values by 3.50, 2.63, and 2.56 (P ≤ 0.01) times, respectively, while at minus 2.0 ± 0.5 °C, the changes in this indicator were insignificant. After 21 days of storage in a cooled state, the acid number increased by 7.33, 5.63, and 5.44 (P ≤ 0.01) times, respectively, while in a superchilled state, there was an increase by 4.33, 3.38, and 3.32 (P ≤ 0.01) times, respectively.

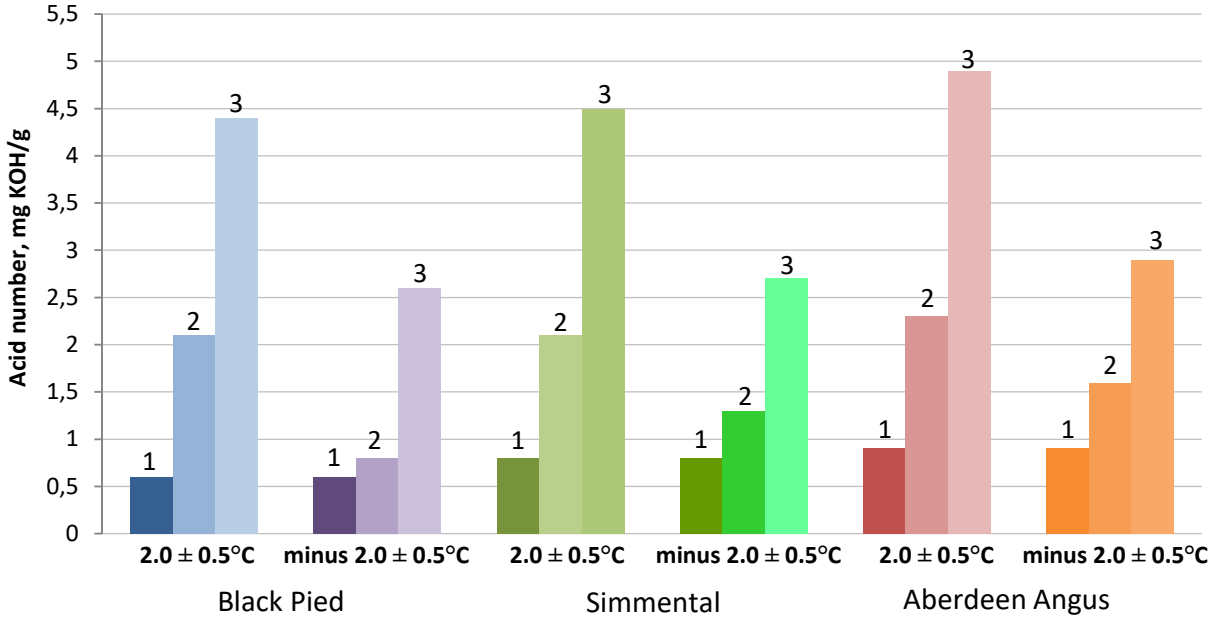


Figure 4. Dynamics of changes in acid number during storage of vacuum-packed meat, mg KOH/g:
1 — initial samples; 2–10 days storage; 3–21 days storage

For all studied samples stored in a cooled state for 21 days, the increase in acid number was 40% to 41% ($P \le 0.01$) higher than in a superchilled state.

The data in Figure 4 show that the greatest increase in acid number during storage for 21 days at a temperature of 2.0 ± 0.5 °C was observed in Aberdeen Angus beef (5.0 to 5.4 times, $P \le 0.01$). The smallest increase in acid number was found in the meat of Black Pied breed (3.0 to 3.3 times, $P \le 0.01$)).

During the same period of meat storage at a temperature of minus 2.0 ± 0.5 °C for 21 days, the lowest acid number of 2.6 mg KOH/g was observed in meat of Black Pied breed, which is lower compared to Simmental and Aberdeen Angus by 0.1 mg KOH/g and 0.3 mg KOH/g, respectively ($P > 0.05$). This may be explained by the fact that during storage, the acid number of fats in fattier meat samples increases faster, resulting from the hydrolysis of triglycerides and accompanied by the formation of free fatty acids.

After 10 days of storage, an increase in peroxide number in Black Pied, Simmental and Aberdeen Angus beef was also observed as a result of fat oxidation (Figure 5):

— for storage at 2.0 ± 0.5 °C, by 2.3, 2.7, and 3.0 times, respectively ($P \le 0.01$);
— for storage at minus 2.0 ± 0.5 °C, by 1.7, 2.1, and 2.0 times, respectively ($P \le 0.01$).

After 21 days of storage in a cooled state, this indicator exceeded the values obtained for 21 days of storage in a superchilled state: for Black Pied and Simmental by 0.3 mmol active oxygen/kg and for Aberdeen Angus by 0.4 mmol active oxygen/kg ($P \le 0.05$).

Discussion

During the research, data was obtained and a comparative analysis of the chemical composition and physicochemical parameters of meat from Black Pied, Simmental and Aberdeen Angus young bulls of different productivity type was carried out. The biological value of meat samples from various breeds was determined based on the content of nonessential and essential amino acids, as well as the protein quality index and amino acid score were calculated. Based on the results of experimental studies, it was concluded that beef obtained from young bulls of the studied breeds has high nutritional and biological value and contains all the essential amino acids for protein synthesis, which is consistent with the results of studies by other scientists [35–37].

As a result of the comparative assessment, it was concluded that in terms of physical and chemical indicators (active acidity and water-holding capacity of meat), Black Pied beef is characterized by the best indicators.

It was established that in muscle tissue (samples of the *Longissimus dorsi* muscle) of Simmental and Aberdeen Angus young bulls, the amino acid score for all limiting (essential) amino acids exceeds 100%.

For storage processes of vacuum-packed meat at a relative air humidity of 85% and a temperature of 2.0 ± 0.5 °C (cooled state) and minus 2.0 ± 0.5 °C (superchilled state), a comparative analysis of the changes in free amino acids and the dynamics of hydrolytic and oxidative spoilage of meat samples from the studied breeds was conducted. Thus, analysis of the data in Table 3 indicates a general tendency to increase the amount of free amino acids during meat storage compared to the original samples, both in a cooled and superchilled state. The results obtained may be explained by changes in amino acid content as a result of enzymatic processes. Decomposition of amino acid decreases their content in meat and is catalyzed by the activity of oxidases and decarboxylases, which is highest during the initial period of refrigeration and storage. An increase in the activity of cathepsins is promoted by proteolysis and, accordingly, an increase in the content of amino acids occurs later in the process of refrigerated storage, as they are released from degrading lysosomes. The initial decrease and subsequent increase in the content of free amino acids in meat at different storage times may be explained by differences in the rates of these enzymatic processes [7].

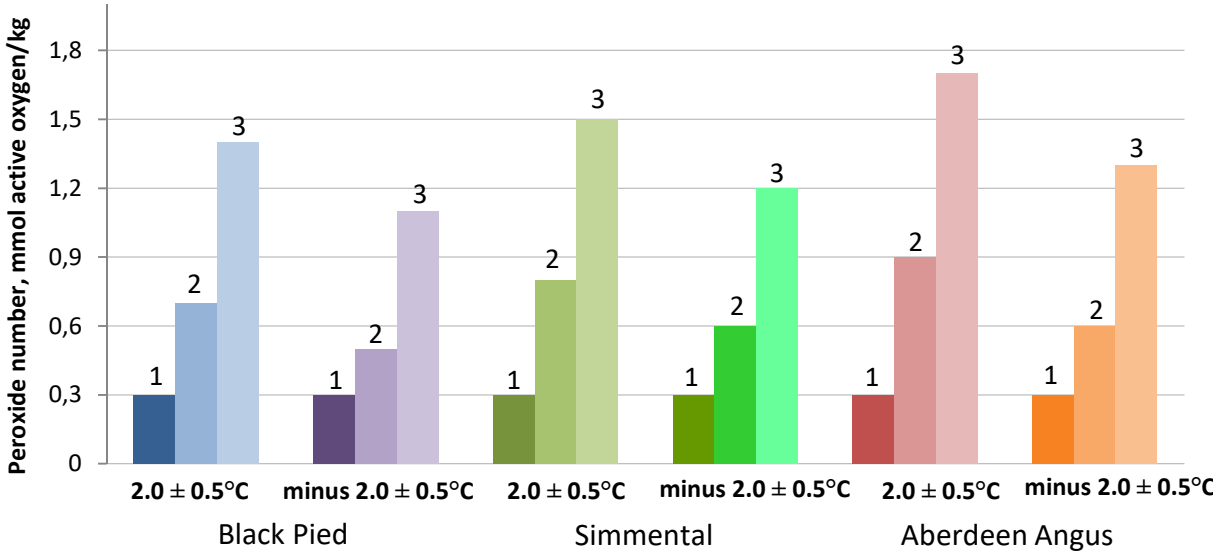


Figure 5. Dynamics of changes in peroxide number during storage of vacuum-packed meat, mmol active oxygen/kg: 1 — initial samples; 2–10 days storage; 3–21 days storage

It was found that lowering the storage temperature of vacuum-packed beef contributes to better preservation of meat quality for all breeds studied, which is consistent with research data from other authors [38, 39]. After 21 days of storage in a superchilled state, the content of free amino acids in the meat of Black Pied, Simmental and Aberdeen Angus breeds was lower compared to storage in a cooled state by 13.1% ($P > 0.05$), 24.1% ($P \leq 0.05$), and 17.0% ($P \leq 0.01$), respectively. For all samples stored in a cooled state, the acid number values were 40% to 41% higher ($P \leq 0.01$) and peroxide number values were 20% to 23% higher ($P \leq 0.05$) than in a superchilled state.

It has been confirmed that at a lower temperature of the cooling medium, hydrolytic and oxidative changes in lipids slow down, as well as the accumulation of free amino acids in vacuum-packed meat, which has a positive effect on maintaining quality and is consistent with research data from other authors [38, 39].

A comparative analysis of the data obtained and the results of similar studies shows that the predicted shelf life of vacuum-packed beef stored in a superchilled state may be increased by 20% to 40% [10, 14, 40].

Conclusions

Beef obtained from young bulls of the studied breeds was generally characterized by a balanced chemical composition. According to physical and chemical indicators, it belonged to NOR quality group, contained all essential amino acids and had high nutritional and biological value.

The results of experimental studies show that the superchilling better maintains the quality of vacuum-packed meat compared to cooling method.

To determine the maximum shelf life of vacuum-packed beef, further experimental studies are needed, taking into account not only changes in free amino acids, hydrolytic and oxidative dynamics, but also microbiological parameters during storage.

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Completely prepared the manuscript and is responsible for plagiarism.

The author declares no conflict of interest.