

Review

The Quality of Horsemeat and Selected Methods of Improving the Properties of This Raw Material

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Abstract: Horsemeat has a strictly defined group of consumers whose demand varies depending on the country or region. There is no tradition of consuming horsemeat in Poland. From a technological point of view, this raw material is as good as other types of meat. In the opinion of the consumer, compared to other species of animals, horsemeat is characterized by an intense red-brown colour and greater cohesiveness resulting from the type of muscle fibres. This meat has a sweetish taste due to the high carbohydrate content. The management of horsemeat often involves the use of modern freezing methods. Freezing horsemeat with the use of liquefied carbon dioxide is a method that increases its suitability for consumption as well as for export purposes in comparison with the traditional air-cooling method. To eliminate the unfavourable quality features of horsemeat, there are substances used to improve the functional and sensory properties of this meat. This paper discusses the research and development work carried out in the field of horsemeat quality and selected methods contributing to its improvement.

Keywords: horsemeat; marinating; freezing; quality; glycolysis



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1. Introduction

The consumption of horsemeat has been interrupted throughout history for religious, social or cultural reasons. As a consequence, it was not considered a popular type of meat and it was generally associated with poor social classes, starvation and periods of food shortage [1]. In Europe, the consumption of horsemeat and ritual horse sacrifice was banned in the 8th century after the introduction of Christianity. Horsemeat returned to European tables only at the beginning of the 19th century, which was caused by numerous wars on the European continent and the related shortage of meat [2].

There are regions in the world where horsemeat is commonly used as the main meat food product [3]. Horsemeat is a sought-after and valuable raw material, especially in Western markets [4]. In Europe, the leaders in terms of the amount of consumed horsemeat are Italians, who consume 0.88 kg per capita per year, followed by Belgians, with an annual consumption per capita of about 0.5 kg [5]. The popularity of horsemeat in Western European countries is due to the fact that it is treated equally with other types of meat or sometimes it is even more valued than beef or pork. In Poland, the consumption of horsemeat and the interest in this type of meat is low. For this reason, 80–95% of domestic production is exported. The main recipient is Italy, where the meat of cold-blooded horses is highly valued, followed by France, Belgium, Austria and Germany, who buy 70–72% of Polish horsemeat [4,6].

From a technological point of view, horsemeat is not inferior to other species appreciated by consumers. It is a valuable, delicate and safe material from the health point of view. The advantages of horsemeat include a slight amount of fat and low calorific value, as well

as a wealth of valuable nutrients. One of the less favourable quality properties of horsemeat is its colour, which is dark red with a slight shade of brown. This mainly concerns older animals, as the colour of the foal is similar to that of beef [4,6–8]. Compared to other types of meat, horsemeat is characterized by greater cohesiveness and firmness due to the type of muscle fibres. The muscle fibres are thin, interspersed with fatty tissue, which gives the desired marbling effect. The meat of foals and young horses, however, has a more delicate structure and is better digestible than beef or pork. It should be noted that the horsemeat obtained after slaughter is relatively hard and cohesive and has unfavourable tenderness. Insufficient tenderness of this type of meat, unlike other species, is due to the high level of connective tissue proteins, as well as the higher thermal resistance of horse muscle collagen [4,6,9]. In terms of sensory properties, horsemeat does not differ significantly from the meat of other slaughter animals. This meat has a sweetish smell and aftertaste, mainly due to the high glycogen content in muscle tissue but also due to the presence of amino acids such as glycine and alanine [4,6]. In Poland, this sweetish smell and the aftertaste of horsemeat are considered a disadvantage. Meanwhile, proper culinary preparation of meat for consumption completely eliminates this disadvantage. The use of a long maturation period makes glycogen decompose into lactic acid, the sweetish aftertaste disappears and the meat becomes soft, tasty and easily digestible [6,7].

The technological and culinary suitability of horsemeat is determined not only by the amount of meat obtained but also, above all, by its quality [6]. Nowadays, the meat industry uses many methods to eliminate the unfavourable quality features of horsemeat, especially the colour and tenderness of the meat immediately after slaughter, aiming at improving the sensory quality of this raw material. Taking into account the above information, the aim of the publication was to systematize the knowledge and to discuss the research and development work carried out in the field of horsemeat quality and selected methods contributing to the improvement of the properties of this raw material.

2. Chemical Composition and Nutritional Value of Horsemeat

The quality of horsemeat is influenced by individual factors such as diet, breed, age/life weight, gender or the type of muscle [10]. The analysis of the chemical composition of horsemeat showed that horsemeat is characterized by a high (19.9%) protein content [3,11,12], the amount of which may range from 17.6% to 22.4% [2] and even up to 24.5% [13]. Moreover, horsemeat is characterized by a low fat content (from 0.5% to 3.0%) [3,14], the amount of which may vary significantly, from 0.15% to 16.5%, depending on the breed, age, type, diet, season or meat quality class and the anatomical part of the carcass [2]. Table 1 presents data on the chemical composition of horsemeat.

Table 1. Chemical composition of horsemeat.

Muscle	Sex	Slaughtered Age	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Cholesterol (mg/100 g)	Reference
LD	M	24 months	72.32 ± 0.70	20.64 ± 0.73	2.08 ± 0.10	1.13 ± 0.05		[15]
LD	M	24 months	70.58 ± 0.90	21.81 ± 0.67	2.22 ± 0.14	1.23 ± 0.05		[15]
LD		6 months	68.11 *	23.63 *	2.57 *	1.97 *		[16]
LD		11 months	71.32 *	21.24 *	3.11 *	1.38 *		[16]
LD		18 months	72.43 *	20.13 *	3.19 *	1.25 *		[16]
LD		15 months	76.49 ± 0.66	22.31 ± 0.74	0.22 ± 0.08	1.25 ± 0.18		[17]
LD	F		74.08 ± 0.06	20.08 ± 0.24	3.9 ± 0.03			[18]
LD	M		73.3 ± 0.17	21.76 ± 0.17	4.02 ± 0.03			[18]
LD		9–11 years	73.3 * ± 1.7	22.5 * ± 1.1	2.9 * ± 0.30	1.1 * ± 0.1	40.5 * ± 2.6	[11]
LD	M	16 months	68.34 ± 4.20	19.91 ± 1.59		3.34 ± 1.09		[19]
LD	F	16 months	70.70 ± 2.43	19.90 ± 1.84		4.03 ± 2.58		[19]
LD	M	24 months	68.98 ± 10.03	20.59 ± 1.29		2.56 ± 0.82		[19]
LD	F	24 months	71.37 ± 1.72	20.50 ± 1.55		3.16 ± 0.83		[19]
LD	M, F	11 months	69.51	21.67		1.14		[20]
LD	M, F	15 months	76.49 ± 0.66	22.31 ± 0.74		1.25 ± 0.18	62 ± 6	[21]
LD	M	15 months	76.63 ± 0.54	22.30 ± 0.51		1.23 ± 0.18	64 ± 8	[22]
	F	15 months	76.28 ± 0.80	22.31 ± 1.06		1.27 ± 0.17	60 ± 3	[22]
LD	M, F	15 months	74.78	20.98				[23]
		15 months	74.79	20.65				[23]
LD	M, F	9 months	75.43	20.61				[10]
		12 months	75.93					[10]
	M	18 months	73.23					[24]
			72.80	20.44				[24]
BF	M	2 years	72.32 ± 0.71	20.64 ± 0.73		1.13 ± 0.06		[15]
		2 years	70.58 ± 0.91	21.81 ± 0.68		1.23 ± 0.05		[15]
LL		11 months	72.63 * ± 1.78	21.25 * ± 1.31	1.94 * ± 2.	1.03 * ± 0.05		[25]
BF	M, F	11 months	68.39	20.68		1.02		[20]
BF	M, F	15 months	76.83 ± 0.73	21.67 ± 1.04		1.22 ± 0.24	57 ± 16	[21]
BF		15 months	76.83 ± 0.73	21.67 ± 1.04	0.37 ± 0.10	1.22 ± 0.24		[17]
LL			70.79 * ± 1.63	21.70 * ± 1.73	2.88 * ± 2.83	0.97 * ± 0.08		[25]
LL	M, F	10 years	69.78 ± 0.32	19.67 ± 0.19		1.10 ± 0.03		[26]
TB			73.91 * ± 0.90	21.60 * ± 0.74	1.07 * ± 0.34	1.04 * ± 0.03		[25]
TB		15 months	77.40 ± 0.73	21.44 ± 0.72	0.28 ± 0.16	1.27 ± 0.17		[17]
TB	M, F	15 months	77.40 ± 0.73	21.44 ± 0.72		1.27 ± 0.17	62 ± 8	[21]
RF		11 months	69.15	21.08		1.15		[20]
SM		15 months	76.69 ± 0.77	21.98 ± 1.17	0.15 ± 0.07	1.28 ± 0.14		[17]
SM	M, F	11 months	73.59	19.57		1.09		[20]
SM	M, F	15 months	76.69 ± 0.77	21.98 ± 1.17		1.28 ± 0.14	59 ± 9	[21]
ST		15 months	77.40 ± 0.48	21.39 ± 1.05		1.28 ± 0.18	60 ± 11	[21]
ST	M, F	15 months	77.40 ± 0.48	21.39 ± 1.05	0.31 ± 0.18	1.28 ± 0.18		[17]
ST		10 years	72.54 ± 0.23	20.17 ± 0.11		1.12 ± 0.03		[26]
PM	M, F	15 months	77.24 ± 0.78	21.17 ± 1.17		1.27 ± 0.14	61 ± 15	[21]
PM	M, F		~74	20.1	8.5			[5]
PM		15 months	77.24 ± 0.78	21.17 ± 1.17	0.67 ± 0.13	1.27 ± 0.14		[17]
Thigh	M, F	6–10 years	70.9 ± 0.67	19.8 ± 0.50		0.98 ± 0.02	61 ± 4	[27]
Loin	F	32 months	69.07 ± 1.95	21.09 ± 1.20	5.27 ± 2.97		63.16 ± 6.56	[28]
Brisket	F	32 months	69.60 ± 1.82	20.38 ± 0.56	5.25 ± 1.47		61.02 ± 16.02	[28]
Top-round	F	32 months	71.69 ± 0.85	21.28 ± 0.46	2.56 ± 0.59		72.36 ± 9.57	[28]
Shoulder-clod	F	32 months	69.17 ± 2.05	20.10 ± 0.57	5.56 ± 3.00		65.14 ± 10.53	[28]

Notes: * g/100 g meat. Muscle: LD—longissimus dorsi; LT—longissimus thoracis; LL—longissimus lumborum; ST—semitendinosus; BF—biceps femoris; RF—rectus femoris; SM—semimembranosus; LTD—latissimus dorsi, RA—rectus abdominis, TB—triceps brachii; PM—psoas major and minor; M—male; F—female.

The ratio of protein to fat is important in assessing the nutritional value of raw meat. The ratio of these nutrients for horsemeat from the dorsal part of the carcass of 6.6:1 indicates the high nutritional value and biological value of the meat. Horsemeat protein is characterized by a sufficiently high balance of amino acids and is not inferior in this respect to other types of meat (beef, pork, poultry). Horsemeat muscle proteins contain the full set of amino acids, including the required ratio of essential amino acids, while the content of tryptophan, histidine, tyrosine, phenylalanine and methionine is higher than in beef [3]. Thanks to the tryptophan content, horsemeat proteins are similar to those of hen's egg and breast milk, in which its content is 1.65% and 1.9%, respectively. It is known that tryptophan is an exogenous amino acid necessary for the normalization of reproductive functions and for the synthesis of haemoglobin [29].

Horse muscle fat contains 12 fatty acids, 5 saturated and 7 unsaturated. Its high biological value is evidenced by the high content of essential unsaturated fatty acids (60.49–63.04%), most of which are monounsaturated fatty acids—for example, oleic (38–55%) and palmitoleic (3–10%), whose sum is as much as 45.16% of all acids. Among polyunsaturated acids (17.5%), the content of linoleic acid (9.14%) and linolenic acid (8.02%)—acids belonging to PUFA—should be distinguished. The total amount of these acids, amounting to 17.5%, undoubtedly contributed to the high value of the tested raw material. What is also important in this assessment is the lower content of undesirable saturated acid, i.e., stearic acid (2.82%), than in other types of animal fats, as well as the sum of all saturated acids not exceeding 38% [21,27,30,31].

There is a significant amount of vitamin A in horsemeat—up to 20 mg%. In beef, vitamin A is only present in trace form. The other vitamins contained in horsemeat are thiamine 0.16 mg%, riboflavin 0.26 mg%, niacin 3.5 mg% and vitamin E 0.82 mg%; in beef, these values are 0.06, 0.15, 4.7 and 0.57 mg% respectively. Vitamin C in horsemeat is 0.8 mg%, while in beef, it is only found in trace amounts. Consequently, horsemeat is far superior to beef in terms of the content of most vitamins. The biological value of horsemeat is also increased by the high concentration of essential minerals: potassium 370 mg%, sodium 50 mg%, calcium 13 mg%, magnesium 25 mg% and phosphorus 168 mg%. In beef, the level of these macronutrients is 355, 73, 10, 24.4 and 188 mg%, respectively. Among the trace elements, the concentration of iron in horsemeat is 4150 µg%, zinc 6200 µg%, copper 206 µg% and cobalt 30 µg%, and in beef, it is 2900, 3240, 182 and 7 µg%, respectively. In horsemeat compared to beef, there is more potassium, calcium, magnesium and copper and almost two times more iron, two times more zinc and four times more cobalt. The liver of horses contains such rare micronutrients as vanadium and molybdenum [29,32–34].

Horsemeat has a number of beneficial properties. It has a beneficial effect on the human body due to the content of a large amount of linoleic and linolenic fatty acids, which prevent the accumulation of cholesterol on the walls of blood vessels [13]. Currently, there are a lot of data on the physicochemical and biological properties of horsemeat, which prove its high nutritional value and confirm the possibility of using it as a therapeutic, dietary product [3,13,31,35]. As a dietary product, it is recommended to be used in the event of insufficient nutrition in order to restore protein reserves [13]. In addition, the use of horsemeat, which contains a significant amount of vitamins and minerals, helps improve metabolism in people with obesity, atherosclerosis, hypertension, heart, liver, pancreatic diseases, etc. [3]. Moreover, the composition of horsemeat, rich in minerals and vitamins, is a strong argument used by nutritionists to recommend the consumption of this type of meat by people suffering from anaemia [12].

2.1. Way of Feeding

Franco et al. [10] showed that finishing diet foals have 51.60% more intramuscular fat (IMF) content than foals not so finished. In other studies, Franco et al. [23] found that the content of IMF is four times higher in the meat of foals finished with a higher amount of commercial feeding (0.58% vs. 0.15%; $p < 0.001$). In turn, Tateo et al. [20] found the IMF content in horsemeat ranging from 3.91% to 4.47% for animals that were

kept in homesteads for 11 months and fed twice a day. The reported values are 30 times higher than those shown in their work by Lorenzo et al. [22]. Franco et al. [10] observed a higher protein content in foals reared in an extensive system compared to the protein content in foals reared in a semi-extensive system. The subject of the research conducted by Borowski et al. [36] was the determination of changes in fresh and stored horsemeat, depending on the way of feeding the animals. In the feeding of animals, which were divided into four groups, feed rations differing in terms of component composition were used. The share of such feed ingredients as broad bean middlings, triticale, rape "00", rye and oats, hay and rapeseed oil as an energy factor was different. The conducted research has shown that the different method of fattening horses does not affect the basic chemical composition of the muscle tissue but has some influence on the properties of meat as a raw material in food technology. The most favourable properties (muscle tissue reduction, malondialdehyde content) were characteristic of meat samples from animals fed on diets containing horse bean meal and triticale [36].

2.2. Age and Gender

The chemical composition of horsemeat depends on the age of the slaughtered animals. The raw material obtained from carcasses of foals and young horses, similarly to other animal species, is characterized by high water content and low protein and fat content [37]. Foal meat is characterized by a high level of protein (from 21.15% to 22.44%) and a low level of fat (from 0.86% to 2.0%) [38]. The research carried out by Znamirowska [37] showed the protein content in the meat of the youngest animals (up to 2 years of age) at the level of 20.04%, fat 2.37% and water 76.42%. In the meat obtained from carcasses of young horses (over 2 to 7 years of age), the basic chemical composition was as follows: protein 21.41%, fat 3.46% and water 74.04%; in the case of the oldest animals (over 17 years old), the content of these basic chemical components was 22.38%, 5.36% and 71.03%, respectively. Such a distribution of results proves that in the meat of older animals, the protein and fat contents clearly increase and the water content becomes lower [37].

With the age of horses, the degree of fatness of the carcasses also increases if they are intensively fattened, and at the same time the content of intramuscular and tissue fat increases. In turn, higher fat content helps to improve tenderness by changing the structure of the tissue. The presence of fat makes the meat more tender and therefore increases the feeling of juiciness. As the animals age, the fat becomes yellowish and even orange [37]. Franco et al. [10] found a significantly higher ($p < 0.05$) content of intramuscular fat (IMF) in foals slaughtered after 9 months compared to foals slaughtered after 12 months.

According to Sarriésand and Beriain [39], the slaughter age of horses had a significant ($p < 0.05$) influence on the ash content in horsemeat. Foals slaughtered after 16 months had higher ash levels than those slaughtered after 24 months, which may be related to the mineral content of grazed pastures.

Gender has a greater influence on the slaughter yield than on the quality of the meat. Males are better muscled than females and therefore have a higher body weight at the same age [38]. Taking into account the gender of animals, Martin-Rosset et al. [40] showed that female foals show higher proportions of fat depots in the carcass (12.3% vs. 9.4%) and a lower percentage of skeleton fat (14.9% vs. 15.8%) than male foals. The obtained results confirm the fact that the degree of fatness is higher in the case of carcasses of female foals than in the case of male carcasses. Taking into account the gender of horses, Tateo et al. [20] found significant ($p < 0.05$) differences between the genders, and a higher protein content was found for males (21.91 vs. 19.99%). In contrast, Lorenzo et al. [22] showed no significant differences ($p > 0.05$), indicating the protein content in horsemeat at the level of 22%.

2.3. The Type of the Basic Element and the Muscle

Studies by Korzeniowski et al. [41] showed that horsemeat obtained from the cutting of basic elements is characterized by a relatively even protein content. Its amount ranged from 20.88% in shoulder meat and 20.86% in leg meat to 19.86% in rump meat and 19.57%

in neck meat. The difference between the elements with the highest and the lowest share of protein amounted to 1.3%, and these differences were statistically insignificant. In turn, the lowest fat content was found in shoulder meat (4.78%), higher in leg meat (6.23%) and the neck contained almost twice as much fat as the shoulder (8.67%). The rump turned out to be the meat with the highest fat content (12.91%), and the difference from the other elements was defined as significant.

Considering the water content of horsemeat, Lorenzo et al. [17] observed significant ($p < 0.01$) differences among muscles, ranging from 76.49% in *longissimus dorsi* (LD) to 77.40% in *semitendinosus* (ST). The presented research results are consistent with the results of the work of Tateo et al. [20], who observed the same result, informing at the same time that the LD muscle contains a lower percentage of dry matter compared to the ST muscle (Table 1). A lower water content (less than 73%) was shown in foal meat in studies by Juárez et al. [15], Lanza et al. [24], Sarriés and Beriain [39] and Tateo et al. [20].

In turn, Lorenzo et al. [17] in the conducted studies showed that the muscle type has a significant ($p < 0.001$) impact on the content of IMF in horsemeat, and its amount ranged from 0.15% in *semimembranosus* (SM) to 0.67% in *psaos major and minor* (PM). These values were clearly lower compared to the values for IMF content in horsemeat reported by other authors [10,15,20,24,27,39], which may be related to the foal breed. In turn, Tateo et al. [20] found no significant influence of muscle type on the level of IMF in horsemeat.

Tateo et al. [20] showed that the muscle type has a significant ($p < 0.05$) influence on the protein content in horsemeat. A higher protein content was observed in the *semitendinosus* (ST) (21.80%) compared to the *semimembranosus* (SM) (19.57%). In contrast, Lorenzo et al. [17] showed no significant differences in the protein content between muscles, showing the average content of this component at the level of 21.66%. *longissimus dorsi* (LD) was characterized by the highest protein content (22.31%), while *psaos major and minor* (PM) by the lowest (21.17%).

Lorenzo and Pateiro [21] showed no significant differences between muscles in the level of cholesterol. Similar values were found by Badiani et al. [27], who showed an average cholesterol content in horsemeat at the level of 61 mg/100 g. According to Lorenzo and Pateiro [21], a daily intake of 150 g of foal meat trimmed of all visible fats provides 93–85 mg of cholesterol.

2.4. Breed

The water content in horsemeat ranges from 68.34% in the meat of Burguete foals slaughtered at the age of 16 months [39] to 77.40% in Galician Mountain foals slaughtered at the age of 15 months [17]. The meat of Burguete foals has a significantly ($p < 0.05$) higher water content compared to the meat of the Hispano-Bretón breed [15].

Considering the intramuscular fat content in horsemeat, Franco et al. [23] found its content at the level of 0.15% in Galician Mountain foals slaughtered after 15 months. A higher IMF content of 6.63% was observed by Badiani et al. [27] in horses slaughtered between 6 and 10 years of age.

Horsemeat has a high variability in ash content, ranging from 0.98% in slaughtered horses aged 6 to 10 years [27] to 4.03% in Burguetes slaughtered after 16 months [39].

3. Properties of Horsemeat Important in Terms of Technological Suitability

Horsemeat, especially from older heads, has undesirable stringiness and hardness that does not yield even after heat treatment. One of the reasons for the above-mentioned disadvantage of this type of meat is a greater share of connective tissue (collagen) in it compared to other types of this raw material. However, horsemeat from young animals is generally characterized by good tenderness, significantly exceeding beef in this respect. The mechanical stability of the connective tissue increases with the age of the animals due to the crosslinking of collagen. Collagen contained in the intermuscular connective tissue becomes stiffer, harder and more resistant to thermal denaturation and is responsible for the progressive hardening of the meat [2]. In studies by Zin et al. [42], a foal was found to

be tender at the level of 6.24 kg/cm². With the age of the animals, tenderness deteriorated and amounted to 7.28 kg/cm² in the meat of horses aged 3–7 years, while in the subsequent age groups (8–13 years and 14–20 years) it amounted to 7.69 kg/cm² and 7.70 kg/cm², respectively. This distribution of results is confirmed by the fact that the meat of older animals is tougher and has lower tenderness, which results in the use of more force to cut such a meat sample. It should be emphasized that the presence of connective tissue protein of inferior quality lowers the biological value of this raw material. Collagen represents 3.5% of the total amount of protein in horsemeat, and its content depends on the quality class of the meat and the anatomical part of the carcass. For comparison, pork, characterized by relatively good tenderness, contains little collagen compounds (less than 0.5% in the tissue). The amount of this compound for beef varies from 0.49% to 1.0% [42].

Belew et al. [43], grouping beef muscles according to the value of the cutting force, cut the muscle sample with the Warner–Bratzler device (Warner–Bratzler shear (WBS) force) and distinguished very tender (WBS < 3.2 kg), tender (3.2 < WBS < 3.9 kg), intermediate (3.9 < WBS < 4.6 kg) and tough (WBS > 4.6 kg) muscles.

A feature that distinguishes horsemeat, even from beef, is its relatively dark-red colour, with a slight shade of brown, which darkens quickly and becomes black-brown when exposed to air. This property of horsemeat results from the high content of muscle pigment—myoglobin. The amount of myoglobin in 1 g of muscle tissue is 7.4 mg. For comparison, in beef it is 3.8 mg and in pork 0.79–1.44 mg. The high concentration of pigments makes their transformation faster and more visible to the eye than in pork or veal. Hence, the colour fastness of horsemeat is not high [31,44].

Horsemeat is characterized by a relatively good water absorption, which is a measure of water-holding capacity, but the low content of intramuscular fat and its low melting point result in the fact that in terms of juiciness it does not stand out, especially in comparison with other types of meat (Table 2). According to Strashynskiy and Fursik [3], high indicators—water-binding capacity (WBC) 73.9 ± 0.8 and water-holding capacity (WHC) 67.3 ± 1.1 indices—allow the use of horsemeat in semi-product technology. This fact helps reduce the loss of moisture during thermal treatment and thus increase the yield of finished products.

In recent years, there has been a noticeable improvement in the meat content of livestock delivered to the slaughterhouse, which, however, is often accompanied by a reduction in the quality of the meat. Therefore, a number of actions are taken to improve the quality of the raw material by genetic means and to optimize the conditions of trade in animals before slaughter, as well as post-slaughter procedures (bleeding, cooling and the maturation process), aimed at eliminating stress factors. These factors contribute significantly to the occurrence of defective meat. The most common changes in meat are pale soft exudative (PSE) and dark firm dry (DFD) defects, the occurrence of which depends on genetic and environmental factors. The culinary quality of meat is perceived by consumers as a result of visual evaluation. Most consumers prefer a light-pink colour of meat with minimal fat and drip and no visible marbling, while a dark-red colour and large drip of meat juice are equated with loss of freshness [45]. The starting point for the description of muscle defects must be the presentation of the characteristics of the meat of normal quality, sometimes abbreviated as the letter N (normal) or RFN (red firm normal). For example, pork with correct quality parameters has a light-red colour (L^* —43–50), which is stable. Its consistency is firm, and it binds water well. When exposing a slice of meat, there is little or no drip of muscle juice (2–5%). The pH1 value is >6.3 (above 5.8 is allowed), while the pH24 value is within 5.5–5.7 (it can also be up to 6.0). Low values of pH1 (5.8) and pH24 <5.5 in the case of PSE (for pork) should correspond to greater amounts of thermal drip, free water (>5%), lighter colour of the meat (L^* > 50) and a low level of protein soluble in water; high values of pH1 (>6.3) and pH24 (>6.3), sometimes >6.0 in the case of DFD, correspond to smaller amounts of thermal drip, loose water (<2%), a darker colour (L^* < 43) and a high level of proteins soluble in water [38,45].

A feature that distinguishes horsemeat from other types of meat is its high glycogen content. The content of this compound in the muscle tissue is about 0.9%, while in beef the content of this polysaccharide ranges from 0.3 to 0.6% and in pork up to 0.2%. Glycogen gives horsemeat its typical sweetish smell and taste, which is unfortunately quite a significant disadvantage from the consumer's point of view. Compared to other types of meat, horsemeat is highly resistant to spoilage and rot. It is a raw material with high durability. This property results from the specificity of postmortem changes taking place in the muscles due to a high level of glycogen, which is associated with long-lasting acidification inside the muscles. This is a result of the ongoing anaerobic glycolysis, the end product of which is lactic acid, which lowers the pH of the muscle tissue [46,47]. Immonem et al. [48] reported that about 45 mmol of glycogen is needed to lower the pH level of 1 kg of muscle from 7.2 to 5.5. Kwiatkowska [49] showed that 15 min after slaughter, the glycogen content in horsemeat, depending on the type of muscles, ranges from 73.85 $\mu\text{M/g}$ to 84.30 $\mu\text{M/g}$. During 105 min of storage, the glycogen content in the dorsal muscle decreased by 18.66 $\mu\text{M/g}$ and after the next 6 h by 2.40 $\mu\text{M/g}$. A similar rate of change in the content of this compound was maintained during the next 10 h. As a result of glycolysis, on the first day after slaughter, the initial glycogen content decreased by 38.94 $\mu\text{M/g}$, i.e., by 46.19%. Between 24 and 48 h, horse muscles had a further 8.82 $\mu\text{M/g}$ reduction in glycogen content. A significant reduction in its content (by 5.42 $\mu\text{M/g}$) was also demonstrated 72 h after slaughter, while the content of this polysaccharide after 96 h at the level of 35.92 $\mu\text{M/g}$ was considered as residual glycogen. After 144 h of storage, the glycogen content was still 35.08 $\mu\text{M/g}$. In other studies [50], it was shown that the content of this compound in horsemeat immediately after slaughter may even reach 93.2 $\mu\text{M/g}$. After 48 h, the level of glycogen had decreased to 49.72 $\mu\text{M/g}$, and after 120 h, there was still 29.33 $\mu\text{M/g}$ of this component in the analyzed raw material.

Table 2. Sensory assessment chart.

Pts	Aroma	Juiciness	Tenderness	Tastiness
1	Very negative	Very dry	Very hard, very fibrous	Very negative
2	Negative	Dry	Hard, fibrous	Negative
3	Neutral	Slightly juicy	Slightly tender	Neutral
4	Desirable	Juicy	Tender	Desirable
5	Very desirable	Very juicy	Very tender	Very desirable

Source: [51,52].

Animal fats also need to meet the relevant quality requirements to be allowed for consumption and sale, but such parameters have not been specified for horse fat. Determining such requirements in beef tallow required studies, which showed that the peroxide number should be no more than 2.0 meq/kg before storage, 4.0 after storage and no more than 6.0 in sale [53]. However, the acid number of beef fat before storage should not exceed 1.2 mg KOH/g [54].

4. Ways to Improve the Quality of Horsemeat

4.1. The Use of Enzymes

There are many substances that are used to improve the quality of horsemeat in order to eliminate the unfavourable features of the meat. Kim and Joo [55] used the following enzymes to improve the texture parameters of horsemeat: papain, bromelin, pepsin and pancreatin. The cited authors prepared enzyme solutions by mixing 2.5 g of each enzyme with 1 L of sterile water (containing 0.075% enzyme) and leaving it in a water bath until the temperature of 30 °C was reached. In the next stage of the research, 30 g of the prepared enzyme solution and the meat sample were placed in a vacuum package and subjected to heat treatment for 1, 2, 3, 4, 5, 6, 7 and 8 h in a water bath at 55 °C. At the same time, a control test was also performed, which was not treated with any of the enzymes. The obtained test results proved that the use of all enzyme solutions contributed

to the improvement of the texture parameters of horsemeat, i.e., hardness and elasticity, compared to the control sample. Along with the extension of the duration of action from 1 to 8 h of papain, bromelin, pepsin and pancreatin, the specified parameters of the texture of horsemeat were characterized by successively lower values. The authors of the study showed that the use of enzymes in the case of horsemeat contributes to the improvement of tenderness, which is important in the case of consumption of the analyzed raw material by elderly people who have problems with dentition and related difficulties when chewing this type of meat. Consumption of horsemeat softened in this way by the elderly will contribute to reducing the protein deficit in this group of society. In addition, the action of enzyme solutions aimed at softening horsemeat, combined with promoting its palatability, may cause, according to the authors of the research, a change in the attitude of many meat consumers about starting not only to eat this type of meat but also to sell it. However, more research is needed to elucidate the detailed changes that occur in the proteins of muscle fibres when treated with enzyme solutions, which will allow the technology to be adapted in the food industry.

4.2. The Use of Calcium Salts

At the present time, many substances are used in the food industry to improve the quality of horsemeat. The use of calcium salts is practised because of the role calcium ions play in the pre- and post-slaughter process. Marinating, injection or infusion of calcium salt solutions into the structure of the muscle tissue accelerates postmortem changes by activating calpain and increasing the intracellular ionic strength [56,57]. Calcium chloride, as an activator of proteolysis in meat of slaughter animals, is introduced mostly during injection or marinating [58,59]. Research aimed at improving the quality of horsemeat using CaCl_2 was carried out by, among others, Pérez-Chabela et al. [60], Pérez-Chabela et al. [61], Pérez-Chabela et al. [62] and Pérez et al. [63]. The use of 150 mM calcium chloride solution for marinating horsemeat for 48 h caused the activation of calpains, thus affecting the degradation of myofibrillar proteins and improving the tenderness of the analyzed meat [60]. In other studies, marinating horsemeat with 150 mM calcium chloride solution for only 24 h resulted in maximum enzymatic activity, which resulted in a significantly lower ($p < 0.01$) hardness of the marinated meat (0.77 N) compared to the control. The reduction in hardness of horsemeat subjected to the marinating process resulted from the decrease in the collagen content in this meat and the increased enzymatic activity. It was also shown that the use of 250 mM CaCl_2 solution to marinate horsemeat for 48 h resulted in a reduction in enzymatic activity [62]. Research by Pérez-Chabela et al. [61] showed that after marinating horsemeat in 150 mM calcium chloride solution for 15 days at 4 °C, no significant differences are found in the pH values of the analyzed meat. This means that both the process of marinating horsemeat and its duration do not affect the acidity of the tested meat. Extending the duration of marinating horsemeat with calcium chloride to 15 days did not affect the water-holding capacity of this meat, but significantly higher WHC values were found for the marinated meat samples compared to the control sample. This phenomenon is due to the effect of increased protein solubility and higher pH values in the marinated meat. The conducted research also showed that the use of CaCl_2 for marinating horsemeat results in higher overall intensity. In samples marinated with CaCl_2 solution, an increase in bitter flavour and chicken liver odour was shown, which were considered to be undesirable organoleptic features. Moreover, no significant differences were found in the assessment of hardness, chewiness, cohesiveness and juiciness. The said authors concluded that marinating horsemeat does not improve its quality; although it promoted an increase in WHC by filament widening by CaCl_2 and possibly by protein degradation, no significant tenderization occurred. Pérez et al. [63] marinating horsemeat in 75 mM and 150 mM solutions of calcium chloride in phosphate buffer showed a higher pH in the control meat samples (5.72) compared to the samples treated with CaCl_2 (5.24). The treatment of horsemeat with calcium chloride solutions resulted in the reduction in WHC, while increasing the juiciness of the tested meat. Marinating horsemeat with CaCl_2

solutions allowed obtaining a higher lightness (32.5) compared to the samples of meat not subjected to the marinating process (23.80). To enable sensory evaluation, the horsemeat was cooked in a home microwave oven at high power for 7 min at an internal temperature of about 70 °C. In sensory evaluation, higher overall acceptability, tenderness, juiciness and flavour were found in meat samples marinated in a calcium chloride solution compared to samples not subjected to the marinating process. In addition, the sensory evaluation showed that CaCl_2 solutions used in marinating promote a bitter taste.

4.3. The Use of Solutions of Selected Substances in the Marinating Process

Vlahova-Vangelova et al. [64] conducted a study to demonstrate the effect of the type of marinating on the morphological and sensory properties of horsemeat. The authors of the study for marinating horsemeat used alkaline marinate (AL) consisting of 2% polyphosphates and 2% sodium chloride brine; acid marinate (AC) consisting of 2% sodium lactate and 2% sodium chloride brine; water–oil emulsion (50/50) containing 2% sodium chloride (WO); and marinate containing 2% sodium chloride (SC). The marinating process lasted for 24 and 48 h, while the control samples (C), not subjected to marinating, were stored for 19 days at a temperature of 0–4 °C. After the marinating process, the meat samples were subjected to thermal treatment by roasting at 180 °C until the temperature inside the samples was 80 °C. The authors of the study showed that marinating horsemeat in alkaline marinate improves the qualitative characteristics of the sensory evaluation, i.e., colour, odour, taste and tenderness, of the analyzed meat in comparison with acid and oil–water marinating. Taking into account the specified sensory properties, the evaluators made the following classification: $\text{AL48} > \text{AL24} > \text{AC24} > \text{AC48} > \text{SC48} > \text{SC24} > \text{WO24} > \text{WO48} > \text{C}$. Marinating in an alkaline solution for 24 h contributed to obtaining the most attractive bright-red colour of the raw horsemeat. In addition, this type of marinade allowed obtaining the highest sensory scores before roasting in the case of marinated samples for both 24 and 48 h. Taking into account the type of marinade used, studies have shown that the highest tenderness of horsemeat can be obtained by alkaline marinating for 48 and 24 h, followed by marinating for 48 and 24 h with the use of acid marinade. The authors of the study emphasized the fact that after 48 h of marinating with alkaline marinade, an unusually smooth and shiny surface was demonstrated in meat samples, which was caused by maceration resulting from the activation of proteolytic enzymes due to a shift in the pH value towards their optimal activity. The appearance of an unusually smooth and shiny surface could also be caused by the lower initial pH of the horsemeat, leading to a stronger effect of alkaline marinade solutions. Taking into account the autolytic changes occurring in horsemeat during marinating, it should be emphasized that they were greatest after 48 h of marinating with 2% phosphates and 2% sodium chloride solutions in comparison with other types of marinades used in the tests. Microscopic images also confirmed the fact that the greatest proteolytic and morphological changes in the muscle and connective tissue were observed during marinating of horsemeat with the use of alkaline marinade and then with the use of acid marinade. Taking into account the changes in connective and muscle tissue, they increased as follows: $\text{AL48} < \text{AL24} < \text{AC48} = \text{AC24}$. The authors of the study pointed out that alkaline marinating should be carried out for 24 h, justifying it with morphological observations of the samples, which after 48 h of marinating were characterized by a soft and extremely delicate consistency. The conducted studies have shown that horsemeat should not be marinated in a water–oil marinade because of the negative rancid odour and taste found by evaluators. In addition, horsemeat samples marinated with this type of marinade have been rated as the lowest odour before roasting and the lowest taste after roasting. It was also found during morphological observations that marinating horsemeat in a water–oil marinade causes the smallest changes in muscle and connective tissues. Overall, all types of marinades used in the study contributed to the opening of protein chains, the loosening of the myofibrillar structure and an increase in the amount of water retained in the muscles compared to controls samples.

4.4. The Use of Low Temperatures

A characteristic feature of horsemeat is insufficient tenderness that is caused by the high content of connective tissue. Due to the fact that horsemeat is characterized by a high content of collagen compounds, their softening and the course of proper physico-chemical transformations should take place for a long time in an acidified environment. The specificity of biochemical changes taking place in horsemeat during post-slaughter cooling is related to its chemical composition [65]. The high initial content of glycogen in horsemeat indicates a high probability of intensive and long-lasting post-slaughter glycolysis. Kwiatkowska [49], 25 min after slaughter, showed a pH value of 6.78 in the longest dorsal muscle and 6.77 in the medial gluteus muscle. The lowest pH value in the tested raw material were determined after 3 days, and this low pH (highest acidity) was maintained for the next 8–10 days. Weyermann and Dzapo [66] showed the initial pH of horsemeat at 6.85, and after 24 h of storage at 5.65. Ley [67] found a pH of 6.88 in the longest dorsal muscle. In the further hours of storage, the pH of the horsemeat decreased slowly, reaching the value of 5.80 after 72 h. In turn, Zin et al. [42] in the conducted research showed the highest acidity (pH 5.37) in the foal material only after 72 h, and then this value remained low for the next few days. In subsequent age groups of horses, i.e., 3–7 years, 8–13 years and 14–20 years, the process of glycolysis was faster, since after 48 h the lowest pH was found in all age groups, which was at the level of 5.39, 5.40 and 5.33, respectively. It is noteworthy that in all age ranges of the animals, the initial pH value was high. Published national studies conducted on similar experimental material also showed that in the case of meat from animals up to 2 years of age, as well as from 2 to 10 years of age and over 10 years of age, the lowest acidity was achieved by meat 45 min after slaughter, at the level of 6.69, 6.75 and 6.78, respectively. This feature then increased, reaching the lowest pH value of 5.25 in foals after 48 h, and the lowest pH value in other age groups (5.35 and 5.38) was obtained after 72 h of refrigerated storage. The acidity numerical distribution shows that a fast and rapid decrease in the pH of horsemeat takes place within 2 or 3 days and that this low pH level is then maintained throughout the further refrigerated storage period. This proves a low rate of biochemical changes and the completely unfinished maturation process of this raw material and thus indicates the possibility of its further refrigerated storage in the event of such necessity [68]. This fact is also confirmed by other research works [69], which emphasize the long duration of the process of muscle glycogenolysis of horsemeat for all age groups of animals. The research carried out by Stanisławczyk [68] showed that the refrigerated storage process for 120 h in refrigerated conditions (6 °C) of horsemeat from three age groups of animals (up to 2 years, 2–10, over 10 years) resulted in the improvement of the tenderness of the tested raw material, regardless of age group. Extending of refrigerated storage time contributed to lowering the pH of the analyzed meat and thus activating the proteolytic cellular enzymes that decomposed the protein structures of muscles. In turn, the decomposition and partial digestion of collagen and elastin fibres in the meat lead to the softening and improvement of tenderness of the meat. The obtained research results are consistent with the data presented by Kwiatkowska et al. [70], with the help of which the authors confirm that extending the refrigerated storage time of horsemeat has a positive effect on its tenderness. The value of the force needed to cut the meat sample after 96 h of storage decreased by about 30% from the initial value and after 168 h by over 50%. In the studies by Stanisławczyk [68], the persistently high acidity of horsemeat during the maturation process caused a darkening of the colour and deterioration of the hydration properties of horsemeat in all age groups. The low pH of horsemeat during refrigerated storage, close to the isoelectric point of proteins, led to the removal of calcium ions from myofibrils. The accompanying contraction of muscle fibres in turn tightened all muscles, which contributed to the squeezing of water particles located within the sarcomeres. It should be added that meat from the oldest animals was characterized by the lowest drip, both thermal and forced, after 48 h of refrigerated storage compared to meat from other age groups [71]. According to Kwiatkowska [49], the storage of horsemeat at a temperature of 4 °C up to 96 h after slaughter did not significantly change the value of thermal drip. A

slight increase, from 1.0% to 2.4% in the tested parameter, was demonstrated after 144 h. In other studies, Stanisławczyk [72] analyzed changes in sensory properties of horsemeat during refrigerated storage, depending on the age of horses (up to 2 years, 2–10, over 10 years). The author showed that extending the storage of horsemeat from 48 to 120 h in refrigeration improves all the quality parameters of the tested raw material but it does not neutralize the differences resulting from the age of the horses. Taking into account the sensory quality, the most unfavourable feature was shown by horsemeat after 48 h of refrigerated storage. Considering the age of horses, in both time periods, the meat of foals was characterized by higher scores compared to other age groups. Improvement in the quality of horsemeat during refrigerated storage for 120 h was confirmed by other studies [73], which showed an improvement in all qualitative parameters of the sensory evaluation of the analyzed raw material.

Kwiatkowska [49], conducting research on changes in the sensory properties of horsemeat during refrigerated storage at 4 °C, showed that during 24 to 96 h, the sensory evaluation of horsemeat is low, showing insufficient tenderness of horse muscles. After 144 h, in the sensory evaluation, tenderness was assessed as unsatisfactory, and after 216 h, there was still no improvement in the tenderness of the tested meat. Horse muscles stored at 12 °C after 96, 144 and 216 h were assessed as sufficiently tender. However, after 312 h of storage of horsemeat under said conditions, the tenderness of the meat was judged to be excessive and undesirable.

A commonly used method that allows obtaining high durability and quality of perishable meat is the freezing process [74]. The subject of many research studies was the assessment of the impact of the freezing process, as well as freezing storage, on changes in the quality of horsemeat. In the conducted research, Stanisławczyk [71] subjected horsemeat from three age groups of animals (up to 2 years, 2–10, over 10 years) to freezing in liquid nitrogen vapours. The average temperature in the freezing process dropped to −75 °C, and the process itself lasted about 1 h. After freezing, horsemeat samples were stored for 1 and 3 months at −22 °C. The process of freezing and freezer storage of horsemeat changed the hydration properties of the tested raw material. In all age groups, after freezing and freezer storage for 1 and 3 months, a reduction in the water-binding and retention capacity was demonstrated. However, the raw material from the oldest animals, in contrast to other age groups, was characterized by a more favourable level of hydration features. For this reason, the author of the study showed that meat obtained from carcasses of older animals is more suitable for freezer storage. This fact is also confirmed by the size of thawing drip, the amount of which after extending the freezer storage time from 1 to 3 months in the case of foal meat was about 2%, while in the other age groups it was about 1.5%. Freezing meat obtained from young animals generates greater losses of raw material, as opposed to meat obtained from carcasses of older animals. In other studies, Stanisławczyk and Rudy [9], subjecting horsemeat from three age groups of animals (up to 2 years, 2–10, over 10 years) to freezing in liquid nitrogen vapour and freezing for 1 and 3 months, also showed deterioration of the hydration properties of horsemeat in all age groups. However, the raw material from older animals showed less forced and thermal drips. Moreover, the freezing process and the extension of freezer storage from 1 to 3 months resulted in a reduction in the quality of horsemeat also due to the deterioration of colour in all age groups. The freezing and storage process contributed to the improvement of the tenderness of horsemeat in all age groups. This is important because the raw material from older heads is characterized by a higher collagen content compared to other types of this raw material. It should be mentioned that with the age of animals, collagen contained in intermuscular connective tissue becomes stiffer, harder and more resistant to thermal denaturation [49,75]. In the conducted research, Stanisławczyk and Znamiorska [76] and Stanisławczyk et al. [77], by subjecting horsemeat after freezing in liquid nitrogen vapours to freezer storage, showed that extending the storage time of horsemeat at low temperatures from 1 to 3 months contributes to darkening of the colour and deterioration of the hydration properties of the tested meat. The amount of thawing drip increased by

1.94% in the analyzed period. The deterioration in the ability to bind and retain water during freezer storage was also accompanied by an increase in the rate of hydrolytic and oxidative rancidity of horse fat, as an increase in both the acid value and the peroxide value of the analyzed adipose tissue was observed. It is important from the technological point of view that freezing and extending the freezing time of horsemeat contributed to the improvement of tenderness of the tested meat by $2 \text{ N} \cdot \text{cm}^{-2}$. Comparing the course of the process of muscle glycolysis between fresh and thawed meat, it was found [68] that the final pH of frozen meat (both for 1 and 3 months) in all age groups is higher than the final pH of fresh meat stored under refrigerated conditions after 120 h from slaughter. This proves that fresh meat can be stored in refrigeration for a longer period than frozen meat after it has been thawed.

Stanisławczyk [73], analyzing changes in sensory properties of horsemeat during refrigerated and freezer storage, showed that the process of freezing and freezing horsemeat for 1 to 3 months contributes to the improvement of the sensory quality of the tested raw material compared to meat stored for 48 h in refrigerated conditions. Extending the freezing storage time of the analyzed meat to 6 months resulted in further improvement of the sensory quality, mainly juiciness, tenderness and palatability, while reducing the intensity of the smell of horsemeat. Table 3 presents data on the sensory properties of horsemeat.

Table 3. Sensory properties of horsemeat.

Specification	Sensory Properties							Reference
	Aroma (Intensity)	Aroma (Desirability)	Aroma	Tenderness	Juiciness	Taste (Intensity)	Taste (Desirability)	
48 h postmortem—cold conditions	3.83 ± 0.19	4.07 ± 0.14		3.94 ± 0.41	3.92 ± 0.36	4.00 ± 0.27	3.97 ± 0.26	[73]
120 h postmortem—cold conditions	4.02 ± 0.13	4.17 ± 0.18		4.22 ± 0.34	4.22 ± 0.25	4.29 ± 0.25	4.48 ± 0.72	[73]
1 month—frozen conditions—LN ₂	3.93 ± 0.14	4.20 ± 0.18		4.27 ± 0.25	4.12 ± 0.21	4.28 ± 0.22	4.31 ± 0.23	[73]
3 months—frozen conditions—LN ₂	3.91 ± 0.18	4.15 ± 0.18		4.15 ± 0.23	4.09 ± 0.18	4.07 ± 0.23	4.11 ± 0.24	[73]
6 months—frozen conditions—LN ₂	3.63 ± 0.27	4.07 ± 0.43		4.20 ± 0.39	4.17 ± 0.33	4.22 ± 0.38	4.16 ± 0.39	[73]
48 h postmortem—cold conditions—I			2.94 ± 0.12	3.12 ± 0.18	3.15 ± 0.22		4.19 ± 0.15	[72]
48 h postmortem—cold conditions—II			2.96 ± 0.23	3.02 ± 0.18	3.20 ± 0.32		4.10 ± 0.12	[78]
48 h postmortem—cold conditions—III			2.90 ± 0.18	2.99 ± 0.13	3.09 ± 0.23		3.98 ± 0.20	[72]
48 h postmortem—cold conditions—I			2.91 ± 0.18	2.95 ± 0.18	3.05 ± 0.31		3.99 ± 0.22	[78]
48 h postmortem—cold conditions—II			2.84 ± 0.15	2.83 ± 0.12	2.95 ± 0.17		3.88 ± 0.25	[72]
48 h postmortem—cold conditions—III			2.88 ± 0.19	2.86 ± 0.19	2.99 ± 0.18		3.92 ± 0.25	[78]
120 h postmortem—cold conditions—I			4.12 ± 0.1	4.22 ± 0.30	4.31 ± 0.20		4.72 ± 0.27	[72]
120 h postmortem—cold conditions—II			3.92 ± 0.16	4.15 ± 0.19	4.15 ± 0.24		4.57 ± 0.20	[72]
120 h postmortem—cold conditions—III			3.88 ± 0.16	4.08 ± 0.24	4.04 ± 0.14		4.41 ± 0.31	[72]
1 month—frozen conditions—LN ₂ —I			4.09 ± 0.15	4.36 ± 0.30	4.20 ± 0.20		4.28 ± 0.27	[78]
1 month—frozen conditions—LN ₂ —II			3.97 ± 0.16	4.12 ± 0.19	4.18 ± 0.24		4.15 ± 0.20	[78]
1 month—frozen conditions—LN ₂ —III			3.86 ± 0.16	4.06 ± 0.24	4.09 ± 0.14		4.11 ± 0.31	[78]
3 months—frozen conditions—LN ₂ —I			4.15 ± 0.15	4.45 ± 0.28	4.39 ± 0.33		4.47 ± 0.12	[78]
3 months—frozen conditions—LN ₂ —II			3.98 ± 0.16	4.16 ± 0.25	4.25 ± 0.33		4.23 ± 0.19	[78]
3 months—frozen conditions—LN ₂ —III			3.91 ± 0.19	4.09 ± 0.26	4.15 ± 0.31		4.19 ± 0.17	[78]

Table 3. Cont.

Specification	Sensory Properties							Reference
	Aroma (Intensity)	Aroma (Desirability)	Aroma	Tenderness	Juiciness	Taste (Intensity)	Taste (Desirability)	
0.5 months—frozen conditions—O _w	4.61 ± 0.29	4.71 ± 0.38		3.96 ± 0.69	4.36 ± 0.36	4.18 ± 0.54	4.14 ± 0.53	[79–81]
3 months—frozen conditions—O _w	4.10 ± 0.20	4.10 ± 0.21		4.00 ± 0.50	4.00 ± 0.38	4.10 ± 0.39	3.97 ± 0.35	[79–81]
6 months—frozen conditions—O _w	4.83 ± 0.31	4.73 ± 0.37		4.10 ± 0.54	4.33 ± 0.4	4.17 ± 0.52	4.33 ± 0.49	[79–81]
0.5 months—frozen conditions—LCO ₂	4.90 ± 0.28	4.97 ± 0.13		4.17 ± 0.45	4.27 ± 0.37	4.33 ± 0.41	4.33 ± 0.45	[79–81]
3 months—frozen conditions—LCO ₂	4.33 ± 0.31	4.37 ± 0.30		4.10 ± 0.47	4.10 ± 0.54	4.23 ± 0.46	4.27 ± 0.53	[79–81]
6 months—frozen conditions—LCO ₂	4.87 ± 0.30	4.63 ± 0.44		3.80 ± 0.65	4.30 ± 0.37	3.97 ± 0.48	4.20 ± 0.62	[79–81]
0.5 months—frozen conditions—O _w —U	4.70 ± 0.37	4.67 ± 0.36		4.13 ± 0.40	4.43 ± 0.37	4.33 ± 0.45	4.23 ± 0.37	[82]
3 months—frozen conditions—O _w —U	4.30 ± 0.25	4.10 ± 0.21		3.50 ± 0.53	3.70 ± 0.53	3.50 ± 0.50	3.63 ± 0.48	[82]
6 months—frozen conditions—O _w —U	4.50 ± 0.50	4.10 ± 0.21		2.73 ± 0.78	2.90 ± 0.87	2.73 ± 0.70	2.87 ± 0.79	[82]
0.5 months—frozen conditions—O _w —N	4.60 ± 0.28	4.53 ± 0.40		3.77 ± 0.42	3.97 ± 0.30	4.00 ± 0.33	3.87 ± 0.35	[82]
3 months—frozen conditions—O _w —N	4.30 ± 0.41	4.00 ± 0.00		3.20 ± 0.41	3.37 ± 0.40	3.20 ± 0.32	3.23 ± 0.37	[82]
6 months—frozen conditions—O _w —N	4.83 ± 0.24	4.17 ± 0.24		2.77 ± 0.82	2.93 ± 0.70	2.77 ± 0.82	2.83 ± 0.72	[82]
0.5 months—frozen conditions—LCO ₂ —U	4.53 ± 0.35	4.53 ± 0.35		3.90 ± 0.57	4.13 ± 0.52	3.93 ± 0.62	4.10 ± 0.57	[82]
3 months—frozen conditions—LCO ₂ —U	4.30 ± 0.32	4.33 ± 0.31		3.53 ± 0.44	3.50 ± 0.42	3.53 ± 0.40	3.53 ± 0.40	[82]
6 months—frozen conditions—LCO ₂ —U	4.77 ± 0.37	4.63 ± 0.44		2.97 ± 0.81	3.10 ± 0.78	3.03 ± 0.74	3.03 ± 0.77	[82]
0.5 months—frozen conditions—LCO ₂ —N	4.17 ± 0.41	4.17 ± 0.41		3.53 ± 0.40	3.70 ± 0.46	3.60 ± 0.47	3.77 ± 0.42	[82]
3 months—frozen conditions—LCO ₂ —N	4.27 ± 0.26	4.37 ± 0.35		3.13 ± 0.55	3.13 ± 0.48	3.07 ± 0.50	3.17 ± 0.49	[82]
6 months—frozen conditions—LCO ₂ —N	4.75 ± 0.50	4.75 ± 0.50		3.63 ± 0.48	3.38 ± 0.25	3.25 ± 0.29	3.25 ± 0.29	[82]
0.5 months—frozen conditions—LCO ₂ × O _w —U	4.23 ± 0.32	4.23 ± 0.32		3.43 ± 0.56	3.80 ± 0.49	3.53 ± 0.48	3.80 ± 0.41	[82]
3 months—frozen conditions—LCO ₂ × O _w —U	4.23 ± 0.26	4.20 ± 0.25		3.27 ± 0.50	3.37 ± 0.40	3.20 ± 0.49	3.37 ± 0.40	[82]
6 months—frozen conditions—LCO ₂ × O _w —U	4.73 ± 0.32	4.53 ± 0.35		3.27 ± 0.59	3.37 ± 0.58	3.20 ± 0.62	3.40 ± 0.60	[82]
0.5 months—frozen conditions—LCO ₂ × O _w —N	4.13 ± 0.23	4.13 ± 0.30		3.17 ± 0.65	3.40 ± 0.60	3.27 ± 0.53	3.30 ± 0.49	[82]
3 months—frozen conditions—LCO ₂ × O _w —N	4.27 ± 0.26	4.30 ± 0.32		3.13 ± 0.55	3.13 ± 0.48	3.07 ± 0.50	3.17 ± 0.49	[82]
6 months—frozen conditions—LCO ₂ × O _w —N	4.65 ± 0.49	4.10 ± 0.75		3.21 ± 0.32	3.10 ± 0.20	3.15 ± 0.24	3.15 ± 0.24	[82]
96 h postmortem— cold conditions	3.20 ± 0.25	3.17 ± 0.11		2.82 ± 0.12	2.55 ± 0.31	2.85 ± 0.15	2.99 ± 0.17	[83]
96 h postmortem—NaCl *	3.75 ± 0.15	3.83 ± 0.10		3.18 ± 0.12	3.05 ± 0.18	4.15 ± 0.17	4.28 ± 0.21	[83]
96 h postmortem— citric acid *	2.50 ± 0.21	2.89 ± 0.16		1.12 ± 0.10	1.54 ± 0.09	1.05 ± 0.05	1.16 ± 0.08	[83]
96 h postmortem— 0.2 M CaCl ₂	4.20 ± 0.16	4.31 ± 0.12		4.01 ± 0.05	4.36 ± 0.09	4.45 ± 0.10	4.38 ± 0.12	[83]

Table 3. Cont.

Specification	Sensory Properties							Reference
	Aroma (Intensity)	Aroma (Desirability)	Aroma	Tenderness	Juiciness	Taste (Intensity)	Taste (Desirability)	
96 h postmortem—0.3 M CaCl ₂ *	4.05 ± 0.20	4.26 ± 0.14		4.10 ± 0.08	4.42 ± 0.12	4.50 ± 0.12	4.56 ± 0.09	[83]
24 h postmortem—cold conditions			5.160	2.000	3.708			[63]
24 h postmortem—150 mM CaCl ₂ *			7.980	5.960	5.380			[63]
120 h postmortem—cold conditions—II	3.16 ± 0.28	3.00 ± 0.01		3.00 ± 0.01	2.66 ± 0.57	3.16 ± 0.28	3.33 ± 0.57	[84]
120 h postmortem—cold conditions—III	3.16 ± 0.28	3.33 ± 0.28		2.66 ± 0.15	2.50 ± 0.86	2.50 ± 0.86	2.66 ± 0.15	[84]
120 h postmortem—II—lactic acid *	2.50 ± 0.50	2.83 ± 0.28		1.16 ± 0.28	1.83 ± 0.28	1.33 ± 0.57	1.66 ± 0.15	[84]
120 h postmortem—III—lactic acid *	2.50 ± 0.50	2.33 ± 0.58		1.00 ± 0.01	1.33 ± 0.28	1.83 ± 0.44	1.83 ± 0.44	[84]
120 h postmortem—II—malic acid *	3.00 ± 0.86	3.50 ± 0.50		1.50 ± 0.86	2.50 ± 0.86	2.50 ± 0.86	2.66 ± 0.15	[84]
120 h postmortem—III—malic acid *	2.50 ± 0.50	2.66 ± 0.57		1.16 ± 0.28	2.00 ± 0.01	2.66 ± 0.15	2.50 ± 0.86	[84]
120 h postmortem—II—phosphates with NaCl *	3.16 ± 0.76	3.33 ± 0.57		3.83 ± 0.28	3.66 ± 0.57	3.00 ± 1.00	3.16 ± 1.04	[84]
120 h postmortem—III—phosphates with NaCl *	3.50 ± 0.50	3.50 ± 0.50		4.00 ± 0.01	4.50 ± 0.50	4.00 ± 0.01	4.16 ± 0.28	[84]
120 h postmortem—II—phosphates with rosemary *	3.50 ± 0.50	3.83 ± 0.28		3.66 ± 0.57	3.00 ± 0.02	3.50 ± 0.50	3.50 ± 0.50	[84]
120 h postmortem—III—phosphates with rosemary *	3.66 ± 0.57	3.83 ± 0.28		4.66 ± 0.57	4.50 ± 0.86	4.00 ± 1.00	3.33 ± 1.52	[84]
144 h postmortem—II—lactic acid with phosphates *	4.00 ± 0.01	4.00 ± 0.01		4.16 ± 0.57	3.66 ± 0.76	4.00 ± 0.86	4.00 ± 0.86	[84]
144 h postmortem—III—lactic acid with phosphates *	3.50 ± 0.50	3.66 ± 0.57		4.16 ± 0.28	3.66 ± 0.76	3.66 ± 0.76	3.50 ± 1.32	[84]
144 h postmortem—II—malic acid with phosphates *	3.33 ± 0.57	3.33 ± 0.57		3.83 ± 0.28	3.50 ± 0.50	3.66 ± 0.28	3.83 ± 0.28	[84]
144 h postmortem—III—malic acid with phosphates *	3.00 ± 0.50	3.16 ± 0.28		2.50 ± 0.86	2.66 ± 0.76	2.50 ± 0.86	2.83 ± 0.44	[84]

Notes: LN₂—freezing by means of liquid nitrogen vapours; O_w—freezing in a ventilation chamber; LCO₂—freezing by means of liquid carbon dioxide; LCO₂ × O_w—two-stage freezing (pre-freezing by means of liquid carbon dioxide and further freezing in a ventilation chamber); I—foals; II—young horses; III—old horses; N—normal meat; U—meat enriched by an injection of fat in order to produce the effect of marbling. * Substances used for marinating horsemeat.

Kondratowicz [85] and Kondratowicz and Sobina [86] carried out research whose aim was to demonstrate the effect of the method of freezing horsemeat on its chemical composition and selected physicochemical properties. The studies used the traditional air-cooling method, in which the temperature in the chamber was −28 °C and the freezing time was 18 h; liquefied carbon dioxide was used for freezing, thanks to which the temperature dropped to −70 °C, and the freezing process itself lasted about 40 min. In both methods, after the freezing process, the temperature in the thermal medium was −28 °C. After freezing, the horsemeat samples were subjected to freezer storage for 0.5, 3 and 6 months. The conducted research showed that the samples of horsemeat frozen with liquefied carbon dioxide after 2 weeks of storage are characterized by a lighter colour compared to the samples frozen with the air-cooling method. In the case of horsemeat, this is a significant phenomenon, as it increases the suitability of this raw material for consumption and export purposes. However, extending the storage time in low tempera-

tures to 6 months contributed to the darkening of horsemeat. In the case of air-freezing, the opposite relationship was demonstrated, as the meat after 2 weeks was darker in colour than the samples stored for 3 and 6 months. Taking into account the hydration properties of horsemeat, it was shown that meat samples frozen with liquefied carbon dioxide show a tendency of slightly better water absorption (6.93 cm^2) than those frozen with the air-cooling method (7.32 cm^2). It is important that the water absorption of the meat improved when the refrigerated storage was extended to 6 months, especially in the case of the samples of horsemeat frozen with the use of liquefied carbon dioxide. Taking into account the changes in the chemical composition of horsemeat, it was shown that meat frozen with liquefied carbon dioxide is higher in dry matter and fat than meat frozen with the air-cooling method. According to the authors of the research, the use of liquefied carbon dioxide in the freezing technology is a good method that determines the use of meat for both consumption and export purposes. In other studies, Kondratowicz [81] and Kondratowicz and Kowalko [79] showed that freezing of horsemeat with liquefied carbon dioxide contributes to the lowest weight loss in the processes of freezing, storage and thawing (0.16% on average) compared to freezing with the air-cooling method (2.64% on average). Taking into account the sensory quality of horsemeat, a significantly higher organoleptic evaluation was observed, considering such features as smell—intensity and desirability in the case of horsemeat frozen with liquefied carbon dioxide compared to air-freezing. Moreover, there was a trend (not statistically confirmed) of slightly higher scores for palatability (intensity and desirability) for horsemeat frozen using liquefied carbon dioxide. The authors of the study noted that regardless of the method of freezing, the refrigerated storage time of horsemeat affects its sensory quality. Extending the storage time of horsemeat at low temperatures from 2 weeks to 6 months contributed to a greater reduction in the sensory quality characteristics (palatability—intensity and desirability, tenderness and juiciness) of meat frozen using liquefied carbon dioxide compared to the air-cooling method. The results of the studies obtained by the authors are consistent with other studies [80], which also showed that lower organoleptic evaluation is achieved by horsemeat frozen using the air-cooling method compared to meat frozen using liquefied carbon dioxide. In addition, extending the storage time of horsemeat at low temperatures to 3 months reduced the sensory quality, regardless of the freezing method used, and resulted in an increase in the total weight loss of horsemeat, which turned out to be lower with the use of liquefied carbon dioxide in the freezing technology.

The research conducted on the influence of low temperatures on the change in the quality of horsemeat was an impulse to continue further research, which used, apart from cooling technologies, an additional process, i.e., marinating. A popular method in recent years that has been used to improve the tenderness of meat is the use of multi-substance marinating processes that also aim at improvement of functional and sensory properties. Stanisławczyk et al. [56], Stanisławczyk et al. [87] and Stanisławczyk et al. [88] analyzed the effect of 0.2 M and 0.3 M calcium chloride solution and 3% citric acid solution on the quality of horsemeat. The compounds were applied to the muscle tissue structures 24 h postmortem, and the injected meat samples were stored in refrigerated conditions up to 96 h after slaughter. It was shown that marinating horsemeat with solutions of CaCl_2 and citric acid results in significantly higher L^* brightness and significantly lower values of the a^* and b^* components compared to the control sample. On the other hand, treatment of horsemeat with 0.3 M calcium chloride solution and citric acid solution resulted in a significant improvement in most of the texture parameters of the analyzed material. It is important that the use of a citric acid solution for marinating horsemeat contributed to a significant decrease in the pH value by about 1 unit and to deterioration of the hydration properties of horsemeat as an increase in the value of thermal and forced drips were observed. In the case of meat subjected to application with CaCl_2 solutions, no significant effect on the value of thermal drip was demonstrated, while the mentioned calcium salts caused a significant increase in the value of forced drip compared to the control sample, which proves it easier giving up water after mechanical pressure on this meat. The obtained

research results are consistent with the results of other research work [83], which showed that the lightest colour is obtained when a 0.3 M calcium chloride solution is used for marinating, while the darkest colour was obtained with NaCl. Moreover, marinating horsemeat with the mentioned substances significantly contributed to the improvement of texture parameters, such as hardness, stiffness and springiness. Marinating horsemeat with a citric acid solution contributed to a reduction in the sensory quality of the tested raw material. Horsemeat marinated with calcium chloride solutions were characterized by the largest numerical value characterizing the individual sensory features. There was a significant improvement in the qualitative characteristics of the sensory assessment, i.e., juiciness and tenderness, compared to the control sample and other samples of marinated horsemeat. The authors of the study also showed that treating horsemeat with sodium chloride contributes to the improvement of the sensory quality of horsemeat compared to the control sample.

The studies carried out with the use of citric acid and 0.2 M and 0.3 M calcium chloride solutions were extended, and in another work, devoted to improving the quality of horsemeat, an additional element was included, namely the process of freezing and freezer storage. In addition, sodium chloride was used for marinating horsemeat at a concentration of 2% in relation to meat weight. It has been shown that in the case of samples of horsemeat frozen at $-28\text{ }^{\circ}\text{C}$ and stored in a freezer for 1 and 3 months, the use of citric acid and calcium salts contributes to the deterioration of the hydration properties of the tested raw material. However, the use of sodium chloride for marinating horsemeat resulted in a reduction in the amount of forced and thawing drips. Regardless of the length of the freezer storage time, the substances used for marinating horsemeat significantly contributed to the improvement of the texture parameters of the tested raw material, i.e., hardness and stiffness. Taking into account other texture parameters (cohesion, elasticity, gumminess and chewiness), no significant impact of the freezer storage time or the type of substances used on their improvement was demonstrated. In the conducted research, it was found that freezer storage for up to 1 month of horsemeat marinated with citric acid and calcium chloride contributes significantly to the increase in brightness of this raw material compared to the control sample. However, extending the freezer storage time to 3 months contributes to the lightening of horsemeat only when calcium chloride solutions are used [88].

The conducted studies with the use of calcium chloride and citric acid solutions were a stimulus to continue the research that included not only other substances used in marinating horsemeat but also the different ages of animals. In the research of Stanisławczyk et al. [84] for marinating horsemeat from two age groups (4 to 7 years and 8 to 12 years), solutions of lactic acid and malic acid, phosphate solution and phosphate solution with rosemary were used. The above-mentioned solutions were applied to the structures of the muscle tissue 48 h postmortem and along with the control sample were stored for 72 h. at $6\text{ }^{\circ}\text{C}$. Marinating the horsemeat samples consisted of pouring on them 1% water solutions of the above-mentioned compounds in vessels. Additionally, samples of horsemeat were injected with 1% solutions of the above-mentioned compounds in the amount of 10% in relation to the sample weight. Pieces of meat marinated with lactic acid and malic acid were injected with a 1% phosphate solution in the amount of 10% by weight. The injected horsemeat samples were stored in 1% aqueous phosphate solutions in glass vessels for a further 24 h at $6\text{ }^{\circ}\text{C}$. The conducted research showed that the substances used for marinating the horsemeat samples resulted in higher L^* brightness and significantly lower values of the a^* and b^* components compared to the control sample. Moreover, the substances used in the research contributed to the reduction in the cutting force and hardness in the meat of both younger and older horses. Taking into account the sensory properties, marinating horsemeat from both age groups resulted in obtaining the lowest sensory scores ($p < 0.05$) of this raw material compared to the control samples and those in which other substances were used to marinate the tested raw material.

4.5. Thermal Treatment Methods Used

The subject of the research conducted by Borowski et al. [36] was the determination of changes in fresh and stored horsemeat, depending on the applied method of thermal treatment. After slaughter, the collected meat samples were heat-treated by frying in soybean oil and cooking in a microwave oven until the temperature inside the lump of meat was 85 °C. Some of the samples obtained were frozen and stored for 6 months at −18 °C. Subjecting the samples of horsemeat to heat treatment, which consisted in immersion frying, resulted in a significant increase in their fat content. This phenomenon is unfavourable both from the nutritional point of view and from the oxidative changes taking place during storage. This means that for horsemeat, it is beneficial to use other methods, including microwave cooking. According to the authors, from a nutritional point of view, horsemeat dishes should be boiled or stewed. The deep-fat frying process caused an increase in weight loss of horsemeat by approx. 8% in comparison with the losses resulting from heating in a microwave oven. The conducted research has shown that horsemeat is a good raw material for the preparation of dishes intended for longer storage at low temperatures, and the use of heat treatment before freezing has a positive effect on some physicochemical properties of muscle tissue. Raw meat samples lost 12.42–14.35% of weight during freezer storage, while the average weight loss of fried meat was 6.22% and of meat cooked in a microwave oven was 6.77%. In addition, meat samples after storage at low temperatures were characterized by a higher level of malondialdehyde as a product of fatty acid oxidation and greater ferrocyanide reduction, while fried meat was characterized by the smallest increase in the reduction in muscle tissue, accompanied by the highest increase in malondialdehyde content.

4.6. Horsemeat-Refining Treatment

A method that allows improving the tenderness and juiciness of horsemeat from, for example, horses in a worse fattening condition and of lower livestock classes, is the introduction of fat into the muscle tissue. For this purpose, the injection method is most often used, and the addition of fat by injection in relation to the amount of meat can be up to 100%. The subject of many research studies was the analysis of the impact of the treatment of horsemeat refinement by injecting a mixture of rendered horse tallow, gelatin and cyclodextrin in the amount of 10% by weight, as well as the impact of freezer storage on weight changes and sensory quality [82,89], chemical composition and physicochemical properties [90–92], the degree of microbiological contamination [93], stability of meat proteins [94] and stability of intramuscular lipids of horse tissue [95]. In the tests, the meat was frozen using the air-cooling method (O_w), the liquefied carbon dioxide method (LCO_2) and the two-stage method ($LCO_2 \times O_w$). The control consisted of meat samples that had not been refined. Horsemeat subjected to the injection technology was characterized by a higher dry matter content (5%), including a lower content of total protein and crude ash. Moreover, the content of analytical fat was almost twice as high as in the non-injected meat. The applied methods of freezing did not affect the quantitative changes in the tested meat. Taking into account the methods of freezing, a slightly lighter colour (greater percentage of light reflection) of the horsemeat frozen with liquefied carbon dioxide (11.60%) was observed compared to the meat frozen by the air-cooling method (10.53%) and the two-stage method (10.80%). However, taking into account the type of meat, it was shown that the enriched meat had the brightest colour compared to the meat that was not subjected to this treatment. Moreover, the enriched meat was characterized by better water absorption than the non-injected meat, which determines its better quality compared to the control group [90,91]. Moreover, injected horsemeat was characterized by lower thawing drip compared to untreated meat, regardless of the method of freezing and storage time. Taking into account the methods of freezing and the type of meat used, both these factors did not significantly affect the acidity after a 2-week storage period, while after 6 months of freezer storage, the used types of horsemeat frozen with the air-cooling method were characterized by a significantly reduced level of acidity compared to meat frozen with the use of liquefied

carbon dioxide and the two-stage method [90]. Kondratowicz [89], analyzing the effect of the addition of natural fat on the sensory quality and weight changes of horsemeat frozen with the air-cooling method (O_w), the method with the use of liquefied carbon dioxide (LCO_2) and the two-stage method ($LCO_2 \times O_w$), showed that the lowest meat losses during freezing and thawing occur during LCO_2 (1.55%) and $LCO_2 \times O_w$ (1.57%) freezing and the highest during O_w freezing (2.50%). Horsemeat injected with fat showed lower losses compared to raw meat. Taking into account the sensory quality, the best organoleptic evaluation was obtained by meat frozen with the air-cooling method; the meat frozen with the use of liquefied carbon dioxide was good, and the lowest evaluation was obtained for horsemeat frozen with the two-stage system. Processed horsemeat showed the best sensory evaluation [82]. Sobina and Kondratowicz [95], analyzing the influence of injection of a mixture of rendered horse tallow, gelatin and cyclodextrin in the amount of 10% by weight, as well as freezer storage, on the stability of intramuscular lipids in horse tissue, showed that refined horsemeat is characterized by approx. three times higher total fat content. It turned out that injection of horsemeat and its freezing with the use of liquefied carbon dioxide and the two-stage system decreased the rate of hydrolytic and oxidative fat rancidity, increased suitability for freezer storage and contributed to a positive management of horse fat. However, along with the extension of freezer storage time, a tendency was shown to deteriorate the freshness of the fat on the basis of an increase in the parameters characterizing the hydrolytic (acid number) and oxidative changes (peroxide number). In other studies, Sobina and Kondratowicz [94], analyzing the effect of injection of horsemeat on the rate of proteolytic changes during freezer storage, showed that freezing horsemeat with LCO_2 results in faster proteolysis of muscle proteins. Horsemeat subjected to the injection process contained a lower content of total protein, as well as total protein and non-protein nitrogen in water extract from meat. Along with the extension of freezer storage time, there was shown a tendency to increase the amount of total nitrogen and the increase in the content of tested nitrogen forms in water extract from meat, with the highest increase in ingredients after 3 months of storage and in the case of LCO_2 -frozen meat. Taking into account the degree of microbial contamination, Kondratowicz et al. [93] showed that the method of freezing with liquefied carbon dioxide and the two-stage method compared to air-cooling had a significantly higher effect on the reduction in bacterial populations in horsemeat. Extending the time of freezer storage of horsemeat resulted in a reduction in bacterial populations. It was most visible in the case of storing refined meat frozen with the use of liquefied carbon dioxide.

5. Conclusions

A characteristic feature of horsemeat stored in refrigerated conditions in the post-slaughter period is the deterioration of its hydration properties and a clear darkening of colour at a relatively low pH and a favourable change in tenderness (regardless of the age of the tested horses). Hence, the so-called refinement of horsemeat by, e.g., intramuscular injection of the mixture of rendered horse tallow is also recommended since it causes a higher dry matter content, brighter colour, less drip after thawing and a significantly higher sensory quality compared to untreated meat. The employed freezing and freezer storage methods can also significantly improve selected quality characteristics of horsemeat. For example, the use of liquefied carbon dioxide in freezing technology is a method that increases its suitability for consumption as well as for export purposes compared to the traditional air-cooling method of horsemeat. The lowest weight losses in the freezing, storage and thawing processes of this raw material occurred after freezing with liquefied carbon dioxide and the two-stage system and the highest when using the air-cooling method. For comparison, the process of freezing in liquid nitrogen vapours and freezer storage do improve the tenderness of horsemeat; however, they also cause darkening of colour, a decrease in the water-holding capacity and a relatively low pH in all age groups of horses. Therefore, the first method of freezing and freezer storage of horse raw material is more favourable. The use of enzyme solutions contributed to the improvement of the

texture parameters of horsemeat, i.e., hardness and elasticity, compared to the control sample. From a nutritional point of view, horsemeat dishes should be boiled or stewed, but immersion frying is not recommended. Marinating horsemeat in alkaline marinade also contributes to the improvement of the qualitative characteristics of the sensory evaluation and tenderness of horsemeat compared to acid and water–oil marinating. In addition, due to the appearance of a negative rancid odour and taste, horsemeat should not be marinated in a water–oil marinade. On the one hand, the use of solutions of organic acids and calcium salts in the marinating of horsemeat most frequently contributes to the deterioration of the hydration properties of the tested raw material, which proves the reduction in the water-holding capacity of such meat. On the other hand, the use of the abovementioned solutions contributes to increasing the brightness of colour and improving the hardness of horsemeat. In addition, the use of phosphates for marinating horsemeat resulted in higher L^* brightness and significantly lower values of the a^* and b^* components, a reduction in the value of cutting force and a reduction in hardness of the tested meat compared to the control sample.

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